World Soils Book Series

Edoardo A. C. Costantini
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Editors

The Soils of Italy

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Aims and Scope

The *World Soils Book Series* brings together soil information and soil knowledge of a particular country in a concise and reader-friendly way. The books include sections on soil research history, geomorphology, major soil types, soil maps, soil properties, soil classification, soil fertility, land use and vegetation, soil management, and soils and humans.

International Union of Soil Sciences

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The Soils of Italy

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Preface

Soil fulfills basic functions for the human society, not only concretely, by providing goods and materials, but also abstractly, by stimulating intellective activity and spiritual wellbeing.

In ancient societies the soil has always had a privileged position, by virtue of its fundamental role of providing foodstuffs. It helped in modeling the lifestyle and way of thinking of these societies. Even today, in various parts of the world, social systems reflect the conditions of soil and environment. The management of soil fertility is still at the heart of this relationship.

Recognition of these functions emerges from the etymological ties between soil and man. In old Hebrew "*adamat*", soil, comes from the same root as "*Adam*", the first man. The same metaphor echoes in the Latin name of the man, "*homo*" which derives from humus, one of the most important soil constituent. Therefore, no wonder that since ancient times, and in all civilizations, man has often attributed a supernatural dimension to the soil, in an attempt to develop a form of knowledge of the life and to explain the world that surrounds him. In the long history of man, when first religions were dominant, soil was conceptualized as part of a world controlled by powerful and invisible entities, being stewards of intangible quality, and became a subject of religious deference and ritual practices, in particular to ensure and continue the fertility.

Passing to the age of "Anthropocene", man has completely forgotten the ancient bond that tie him to the soil, and turning from "*Homo sapiens*" to "*Homo technologicus*" never stops to reflect on how much his wellbeing and the quality of his life are fundamentally linked to the quality of the soil. And today, as never before, maintaining the quality of the soil is a critical objective for sustainable development. Unfortunately, as soil is a crypto resource, only few laypeople recognize its importance in the biosphere equilibrium and, wretchedly, seldom consider it among the environmental resources!

This volume belongs to an international series of books aiming at spreading the knowledge on soils of different European and extra-European Countries. Its ambitious goals are to establish a broad base for the knowledge of the soils of Italy, and to give useful information on (i) their characteristics, diffusion, and fertility, (ii) the main threats whose they are subjected, and (iii) the future scenarios of the relationships between soil science and other disciplines, not traditionally linked to the world of agriculture, such as urban development, medicine, economics, sociology, and archeology. The writing of this book was attended by numerous experts from several Italian universities and research centers, which have taken on the responsibility of editing the various chapters.

A specific characteristic of this book is that it collects scripts of both mature and young soil scientists, who contributed in a decisive way to render the text up-to-date and, hopefully, attractive. A special mention must be given to the information provided by Prof. Fiorenzo Mancini, father of the modern Italian pedology, which was picked up by Costanza Calzolari in Chap. 1 "Research in Pedology: A Historical Perspective". The chapter is a comprehensive history of the pedological research in Italy, spanning more than a century, from the first steps out of agrochemistry and geology to the first complete soil map of Italy, dated on 1928. At that time, the map was based on the geological map published in the late nineteenth century. Further, milestones were the soil map of Italy made by Paolo Principi in 1953 and the soil map published in 1966 by a national committee led by Fiorenzo Mancini. This time the mapping unit limits were based on geomorphology. The chapter also surveys the promising diffusion of pedology in the second half of the last century, fostered by applications in different agricultural and environmental fields, as well as by the setting of some regional soil bureaux. The birth and life of the current three soil societies and associations present in Italy are finally depicted, with the conclusion that a stronger and official coordination could be beneficial for Italian pedology and soil science in general.

In Chap. 2 , the role played by the factors of soil formation in Italy is examined by different authors. Edoardo Costantini, Maria Fantappié, and Giovanni L'Abate explore the potential strong influence of climate on soil nature and distribution. In spite of being placed in the middle of the temperate zone of the boreal hemisphere, the elongated shape of the Italian peninsula, stretching along 11 parallels in the middle of the Mediterranean sea, and the presence of two morphological barriers, the Alps and the Apennines, cause great local climatic variations, to an extent that they are much more important than means. In fact, long-term mean annual air temperature for the whole country is 12.6 °C and total annual precipitation 932.5 mm, but the differences between minima and maxima span 30 °C and 1,800 mm, respectively. Actually, in Italy there are 14 of the 35 climatic regions occurring in Europe. A general climatic change occurred in Italy in the period 1961–2000, with a general reduction of the mean annual precipitations, the number of rainy days, and a general increase of the mean air temperatures. The climate change had some influence on soil organic carbon variations, especially in the meadows and arable lands located in areas where a moderate or high decrease of the mean total annual precipitation value (<-100 mm) and a moderate to high increase of mean air temperature (>0.62 °C) occurred.

In Chap. 3, Claudio Bini concentrates on the main geological and morphological features of Italy, with the aim to examine the role of parent rocks and landforms in soil genesis and evolution. Italy is a geologically young land, with contrasting relief energy and a great variety of lithological types and landscapes. In the western and central part of the Alpine region, crystalline rocks prevail over sedimentary ones (mainly limestone and dolostone), which are widespread in the eastern part. Sedimentary detrital rocks are widespread in the preAlpine fringe, on gently undulating slopes; scarcely developed soils form at these sites. Alluvial soils form in the Po plain and in main river valleys, in strict correlation to corresponding landforms: Luvisols on terraces and high plains, Cambisols and Fluvisols in the low plains, with Gleysols in depressed areas. Three main domains may be recognized in the peninsular Italy: Northern Apennine with large sandstone outcrops, Central Apennine dominated by calcareous formations, and Southern Apennine with prevailing clayey flysch formations. Widespread water and mass erosion rejuvenate soils of these landscapes. Luvisols (*Terra rossa*) from limestone and Umbrisols or Cambisols from granite rocks are the typical soils of Apulia and Calabria, respectively. Peculiar soilscapes are related to particular lithotypes such as ophiolite and volcanic rocks, which outcrop disseminated in various parts of the peninsula, the former with general steep slopes and thin soils and the latter with andic properties. Besides actual Andosols, volcanic materials spread off over the land may contribute to form soils with some andic properties, not sufficient to meet criteria for Andosols, but able to affect significantly soil chemistry and hydrology and, in turn, soil fertility and landslide risk.

Andrea Giordano discusses in Chap. 4, “Vegetation and Land Use”, the importance of Italian vegetation in soil formation. Without the human intervention Italy would have been almost everywhere covered by forests, but the course of the very old Italian civilization has greatly changed the original natural vegetation. Currently, one-third of Italy is covered by forest, but the original forest is reduced to some thousands of protected hectares, while the rest is made of secondary, semi-natural, or artificial forests. Since soils have been often influenced by ecological conditions different from the actual ones, they are frequently not in accordance with the vegetation. Nevertheless, in certain cases the vegetation influence on soil is so determinant that soils formed under the same vegetation canopy, but on different lithology, show similar humus forms and superficial horizons, while the deep horizons are different. Forest surfaces are increasing everywhere in Italy, and this is mainly due to the abandonment of marginal agricultural lands, but also to afforestation and reforestation projects. In the present time, reforestation is mainly carried out using mixing conifers and broadleaves, to minimize the risk of fire and avoid soil acidification induced by the use of conifers alone. Coppices largely spread on the Italian mountains are in many places converted to high stands. The recent institution of new natural parks (national and regional) has created the premises for a pedogenesis more in equilibrium with the environment. In agricultural lands, the traditional land uses were for centuries connected with the original soil fertility or with the reconstitution of fertility by means of biomass returns to soil, but nowadays agricultural husbandry does not compensate the losses of organic matter suffered by soils, rather the large use of industrial fertilizers contributes to soil organic matter depletion.

In Chap. 5, Stefano Carnicelli and Edoardo A. C. Costantini examine time as a soil-forming factor in Italy. In most of the country, soil formation never stopped in the last millions of years, while at the same time undergoing constant, and often major, changes in soil-forming factors. This makes Italian soils a huge, and mostly as yet untapped, paleo- and archeo-environmental record. Investigation on soil age suggests that, after the Last Glacial Maximum (LGM), about 18,000 years ago, the soil that most likely forms on the most common, fine-textured, and calcareous parent materials of Italy is a partially decarbonated, fully base-saturated Cambisol. Horizons with clear clay illuviation appear to have formed only in favorable conditions. On the other hand, it is clear that Italian soils developed Nitric, Fragic, Ferric, and Plinthic horizons well within Pleistocene times. The formation of fully developed, carbonate-free but base-saturated Luvisols appears to have generally been possible starting much later than Marine Isotope Stage 5, the last fully fledged interglacial.

In Chap. 6, dealing with pedodiversity of Italy, Edoardo A. C. Costantini, Roberto Barbetti, Maria Fantappiè, Giovanni L'Abate, Romina Lorenzetti, and Simona Magini illustrate the distribution of soil classes, mainly by means of maps. Soil regions on hills are the most lithologically and climatically variable environments, and host the greatest soil variability and endemisms. A vast majority of the WRB reference soil groups (25 out of 32), as well as soil orders of Soil Taxonomy (10 out of 12) are represented in the main Italian soil typological units (STUs), but the clear skewness and lognormal distribution of STUs demonstrate the utmost endemic nature of many Italian soils. In particular, more than a fourth of STUs belong to Cambisols, more than a half to only four reference soil groups (Cambisols, Luvisols, Regosols, Phaeozems), and 88 % to nine RSGs (the former plus Calcisols, Vertisols, Fluvisols, Leptosols, and Andosols), while the remaining 16 RSGs are represented in 12 % of STUs. A similar trend is depicted by considering single soil profile classification, although a larger number of main soil types are represented as soil profiles than as STUs. In particular, there are profiles classified as Albeluvisol, Anthrosol, Cryosol, Plinthosol, and Technosol of WRB, and Gelisols of Soil Taxonomy, which are not correlated to a STU. Consequently, Ferralsols (Oxisols for Soil Taxonomy) and Durisols are the only main kind of soils that have not yet been found in Italy. Likewise RSGs, the distribution of WRB qualifiers shows an evident concentration in relatively few cases, followed by a long tail. In particular, 138 out of the 180 types foreseen by WRB are represented in Italy. Thus, it is possible to say that in Italy there is about three-quarters of the global pedodiversity. Although the most common qualifiers (that is Calcaric, Haplic, Skeletic, Eutric) are all related to the nature of parent material and to incipient pedogenesis, a second group (namely Chromic, Calcic, Stagnic, and Luvic) indicates the main soil forming mechanisms that typify current Italian pedogenesis.

In Chap. 7, Anna Benedetti, Maria Teresa Dell'Abate, and Rosario Napoli focus the attention on all those aspects concerning the soil function and the related ecological services. Stressing that soil organic matter content is widely adopted as soil quality indicator—since it is correlated with various aspects of productivity and sustainability of agricultural ecosystems and environmental conservation—with the aid of several case studies related to the Italian soilscapes, they highlight the way in which the soil microorganisms can provide essential services. In doing this, the AA identify two main causes of erosion of soil microbial genetic resources and consequently depletion in biological soil functions: (i) the impact of anthropic activities on soil (mainly inappropriate agricultural and forestry practices, industrial activity, urban development, soil sealing), and (ii) the natural pressures on soil due to climatic changes and natural disasters.

Carmelo Dazzi and Giuseppe Lo Papa examine in Chap. 8 the several threats that influence Italian soils. Soil threats in Italy started during the Roman period but only after the Second World War, with the transformation of the agriculture and the industrial development, soil degradation and its effects became more and more evident. Nowadays, several degradation processes threaten Italian soils: together with soil erosion, soil consumption, soil salinity/alkalinity, landslides, forest fires, new issues arose, all referable to incorrect relationships between human and soil and all driven by strong economic reasons. Such new threats are: (i) soil consumption by huge diffusion of photovoltaic ground-mounted installations which, as it happens for roads and rails, are preferentially established in flat areas regardless to any aspect on soil quality; (ii) loss of soil diversity by anthropic activity, which has driven pedologists to define new specific soil degradation processes defined as "entisolization" and "anthrosolization".

In Chap. 9, Giuseppe Corti, Stefania Cocco, Giorgia Brecciaroli, Alberto Agnelli, and Giovanna Seddaiu have drawn the attention on soil management. In Italy, soil management has a long story since the story of land use is as old as the occupation of the country by different peoples. The innovations that were concocted during the time depended on the difficulties the peoples encountered in the various places they settled, and on the human history. As a result, the anthropic impact on soil formation in Italy is particularly marked in all the agricultural areas. Besides deforestation, ploughing, liming, manuring, and fertilizing, some practices that particularly characterize Italian soil management have a strong effect on pedogenesis: (i) change of the relief by levelling, terracing, and burying of the previous surface, (ii) modification of the soil moisture regime through irrigation and/or drainage, and (iii) frequent and intensive cultivations, which enhance soil erosion.

Soil management has been frequently driven by policies such as laws and regulations and economic instruments like subsidies and taxes. The European Union (EU) policy instruments have always played a crucial role in shaping agricultural systems and, among them, the Common Agricultural Policy (CAP) contributed particularly to the increase of cropping systems productivity through agricultural intensification and farm specialization. The CAP's original goal was to expand production in order to reduce dependence from imported food as well as to cut down the EU import requirements in terms of energy, raw materials, etc., but the greater specialization toward arable farming systems had frequently meant the end of traditional cropping systems and the intensification of land degradation. The CAP reform in 1992 was designed to reduce production (e.g., setting aside farmland), to encourage greater attention to the environment and to the use of land, and to decrease prices. The subsidies favored the cultivation of some crops (wheat, oil seeds, etc.) even under unsuitable ecological conditions, leading to contrasting impacts on land use compared to the intended goals. The last CAP reforms have put a greater emphasis on environmental concerns by introducing accompanying measures such as agro-environmental schemes and by making direct payments to farmers conditioned to meet the cross compliance requirements, which are supposed to contribute to an improvement of soil quality.

Soils in urban areas are taken into consideration by Franco Ajmone Marsan and Ermanno Zanini in Chap. 10. In Italy, the interest has been directed mainly on the contamination of urban soils. The studies have started in the 1970s and data are now available for a number of cities. The soils of large cities like Rome, Naples, and Turin have been studied in view of their size and the intensity of the polluting sources therein, but also mid-sized cities such as Ancona or Palermo have been investigated. A common trait of all cities is the high spatial variability of their soils together with a high level of contamination. Numerical classification appears then to be preferable to the classic systems for application in urban areas.

Future soil issues are treated by Fabio Terribile, Angelo Basile, Antonello Bonfante, Antonio Carbone, Claudio Colombo, Giuliano Langella, Michela Iamarino, Piero Manna, Luciana Minieri, and Simona Vingiani in Chap. 11. The chapter focuses on country limitations and potentialities, and identifies the most important country-specific contributions by soil science aiming toward the wellbeing of Italy. The authors claim that future soil scientists must give major contributions in the followings aspects: (i) spatial planning of the landscape (oriented to urban planning), (ii) archaeology, cultural, and natural heritage, (iii) agriculture and forestry, combining productivity and environmental protection, (iv) hydrogeological risks, (v) integrated landscape management. In order to get these results, the authors anticipate that soil science requires a novel vision, novel approaches, and most important a novel education combining in-depth specialized knowledge with a very good but broad and basic soil knowledge.

The themes developed in this volume lead to conclude that a reassessment of the relationship between man and soil in Italy is needed. Managing our limited land in an inappropriate way, we are loosing the best, most fertile soil. Even more alarming is that the bill of the way we manage the soil will be paid by our grandchildren and our great-grandchildren. The reassessment of the relationship between man and soil should be based on the full awareness of what soil truly is. And this new awareness should involve the whole Italian society, from the common citizen to the Academy, to the public administrators, and paradoxically also to the scientific community. In most cases, soil is understood as a mere surface, or something in relation to vegetation, or to the geomorphology or geology. Among the consequences more devastating: the most fertile soils are forever subtracted to the agricultural management.

In Italy, during millennia of soil management, the attention toward its qualities has radically changed, passing by phases of intense and devastating exploitation to periods of reclamation and care. The budget is generally negative, as the more self-organized soils were often replaced by less self-organized and less resilient ones, showing sensible limitations to intensive uses. In the recent past, to provide a subsistence agricultural economy even on degraded soil, much confidence was given on the favorable climate and on inconsistent or pseudo-consistent lithologies. However, with the new challenges of the global market, many agricultural soils (but also forestry soils) are no longer competitive and are abandoned, or extensively used. It can be observed in recent years a significant increase of land covered by fodder crops, at the expense of arable land, especially in the central and southern regions of Italy. On the other hand, the high quality soils are more and more exploited, with an increasing widening of areas with horticulture and fruit tree groves. An economic consequence is the fact that land values are decreasing in the marginal areas of central and southern Italy, but are greatly increasing in the most competitive areas, especially in northern Italy. From an environmental point of view, it follows an enlargement of agricultural areas vulnerable to nitrates, which have now reached 16 % of cultivated areas (ISTAT 2010).

It is a common aspiration of the authors that this book could provide interesting information to soil experts and students, so that they can enhance the attention of the general public on this very limited but very economically and environmentally important resource of Italy.

E. A. C. Costantini
C. Dazzi

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Research in Pedology: A Historical Perspective

1

An Interview to Prof. Fiorenzo Mancini

Costanza Calzolari

La storia siamo noi, attenzione, nessuno si senta escluso (F. De Gregori).

Biography of Fiorenzo Mancini Prof. Fiorenzo Mancini has been Director of the Institute of Geology and Mineralogy of the University of Firenze, of the Centro Studio Genesi Classificazione Cartografia del Suolo of the National Research Council (CNR), has been President of Italian Society of Soil Science, of which he was one of the founder members, President of the Italian Geological Society, President of the Accademia di Scienze Forestali, President of the Experimental Institute for Soil Study and Soil Conservation, Vice-President of the Accademia dei Georgofili. He is honorary president of the Italian Society of Soil Science and of the Italian Society of Pedology. He published more than 100 papers, and with his master, Paolo Principi, founded the pedological school of Florence. Since 2002, he is honorary member of IUSS.

1.1 Introduction

Since the very beginning of agriculture, commonly dated 11,000 BP (Brevik and Hartemink 2010), man had to cope with the soil qualities and limitations. Therefore, the development of a scientific approach to soil knowledge is part of the more general human soil awareness and approach to scientific thinking. Strictly rooted in basic and applied sciences, mainly geology and agronomy, soil science developed as a specific discipline in eleventh century, in Italy as elsewhere.

Pedology is here defined as the study of the soils conceived as both natural bodies strongly interacting with their environment and as common goods; the term "pedology" was used as a synonym of soil science at the very beginning of the discipline. Fallou, who in 1862 introduced the word (Boulaine 1997), distinguished the naturalistic soil science, pedology, from the agricultural soil science, agrology, which studies soils in relation to the agricultural applications (Fallou 1862). In the scientific literature of the second half of twentieth century, pedology is considered as a branch of soil science, mainly coincident with soil genesis, classification and cartography (Churchman 2010; Ibanez and Boixadera 2002; Bockheim et al. 2005). However, the soil concept evolves, as does the concept of pedology, through the world and along the time (Cline 1961; Bockheim et al. 2005), so that the terms used reflect the status of knowledge and of the theoretical evolution of the discipline, together with the general scientific culture.

In Italy, the word pedology (*pedologia*) is introduced in a text book in 1904 (Vinassa de Regny 1904) as synonym of soil science,[1] and it cohabitates with the words agrology (*agrologia*), agro-geology (*agro-geologia*), agricultural geognostic (*geognostica agraria*), geopedology (*geo-pedologia*) used in different historical moments by differently rooted soil scientists. Moreover, in Italian, different words are used with reference to soil: *suolo, terreno, terra.* Their meaning is sometimes coincident; sometimes, and along the time, the different words have different nuances.

Similarly to other countries (Arnold 1987), in early 1980s, Italian soil scientists have lengthily disputed if soil survey could be defined as a research activity.

According to OECD (Frascati manual), "Research and Experimental Development (R&D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications" (OECD 2002). Therefore, "R&D must be distinguished from a wide range of related activities with a scientific and technological basis. These other activities are very closely linked to R&D both through flows of information and in terms of operations, institutions and personnel, but as far as possible, they should be excluded when measuring R&D" (OECD 2002).

Data collection and processing with pre-established models are excluded from the definition of research. However, since the early stages of pedology, and as far as Italy is

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[1] The first document reporting the word pedology as *pediologia* (sic) is dated 1884 (Bollettino del Regio Comitato Geologico 1884).

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concerned up until the second half of twentieth century, soil survey involved the study of the genesis of the soils and the analysis of the models that describe their distribution in space. Soil survey was an integral part of the research aimed at increasing the knowledge about the soil, the site-specific relations between soils and landscapes and the processes acting in them. In other words, quoting Richard W. Arnold, "soil survey is an example of applied research based on uncontrolled experiments with the results being the variability of soils themselves" (Arnold 1987).

Still following OECD (2002) "the basic criterion for distinguishing R&D from related activities is the presence in R&D of an appreciable element of novelty and the resolution of scientific and/or technological uncertainty".

From a historical point of view, research in pedology is therefore strictly linked with soil survey, which set the bases for any advancement in pedological concepts.

The present chapter deals with the history of research in pedology, since the early stages and up until the end of the past century, with a special emphasis on soil survey. It is based upon a series of conversations between a pedologist and researcher and the doyen of the Italian pedologists.

1.2 The Birth of Pedology in Italy (1880–1940)

Question: When is pedology born as a specific subject in Italy? What does distinguish pedology and pedologists from the other soil subjects and scientists?

Answer: Historically, and epistemologically, pedology means the study of the whole soil profile. In coherence with its definition as a natural body, soil is characterised by a succession of layers which is the result of a specific combination of the various pedogenesis factors and agents. This has been a central point in debate, e.g. with soil chemists, who were not used to study soils in the field, but instead to handle samples in laboratory. In early 1950s, this approach was quite new in Italian soil science, between geologists, who had a "lithological" approach, from one side, and soil chemists and agronomists, from the other one. The publication of the textbook "Geopedologia" by Principi, in 1953, giving a full theoretical frame to the discipline and receiving appreciation also at international level, allowed Italian pedological school to fully develop.

When early pedologists started with systematic studies of soils, their characteristics and geography, they were strongly influenced by their cultural heritage, given that in Italy, as elsewhere, a solid tradition in agronomy and agrochemistry and geology was present.

While in the second half of nineteenth century Dokuchaev in Russia and Hilgard in the United States gave their definitions of soil and pedology, early Italian soil scientists used to define soil as […] the blend of various materials, some of which very fine and not easily recognisable, some others made up by more or less coarse particles, which mostly derive […] from the rocks which are the most external part of the earth where we live […]. This very heterogeneous mixture is powdery or compact, when dry, and loose or plastic when moist […] but plants find in it both the support […] and most of nutrients they need […]

(Il terreno […] è un insieme di materie svariate, alcune minutissime e non facili a riconoscersi, altre in particelle più o meno grossolane che per la massima parte derivano, come a chiunque è agevole persuadersi, dalle rocce che costituiscono la parte più esterna del globo terracqueo su cui viviamo […] Tale congerie, assai eterogenea se asciutta è ora polverosa ora compatta; se umida è talora sciolta, talaltra pastosa. […] ma le piante trovano in essa non solo l'appoggio per stare diritte […] ma vi rinvengono soprattutto una buona parte delle sostanze nutritive […], Sestini 1899).

Soil is then characterised by its physical aspect, "mixture of more or less fragmented materials" (*congerie di materie più o meno frantumate*, Funaro 1904), and by a set of its main functions, as soil is "the ordinary site of most of the crops (and) contains in and around it all the conditions and materials that are necessary for plant life"

(Il terreno è la stazione abituale della maggior parte delle piante che forniscono i prodotti agrari [e] contiene in sé ed intorno a sé tutte le condizioni e tutti i materiali che sono necessari allo svolgimento della vita delle piante, Funaro 1904).

As far as soil formation is concerned, Vinassa de Regny in 1904 writes: "soil is a more or less weathered rock only rarely made up by solely mineral parts. In most of the cases, also life, and past natural vegetation mainly, influences soil, so that also organic compounds are present together with minerals".

It is worth to be noted that the two first definitions are given by soil chemists, Fausto Sestini (1839–1904) and by his collaborator, Angiolo Funaro. Paolo Vinassa de Regny (1871–1957), instead, was a geologist and palaeontologist. In 1904, he wrote the textbook "Elements of agricultural geology" (*Nozioni di Geologia Agraria*). He introduces the word "pedology" (*pedologia*) as synonym of "agrology" (*agrologia*), defining it as the science that "studies the composition and chemico-mechanical constitution of soil" (*studia la composizione e costituzione meccanica e chimica di un terreno*). It is part of geology, but it needs other fundamental disciplines, such as chemistry and physics and differs from geology, as it considers "soil as an active quasi-living medium, due to the continuous transformations induced by external physical and biological agents"

(il terreno attivo e quasi […] vivente, causa le continue trasformazioni che in esso inducono gli agenti esterni fisici e biologici., Vinassa de Regny 1904).

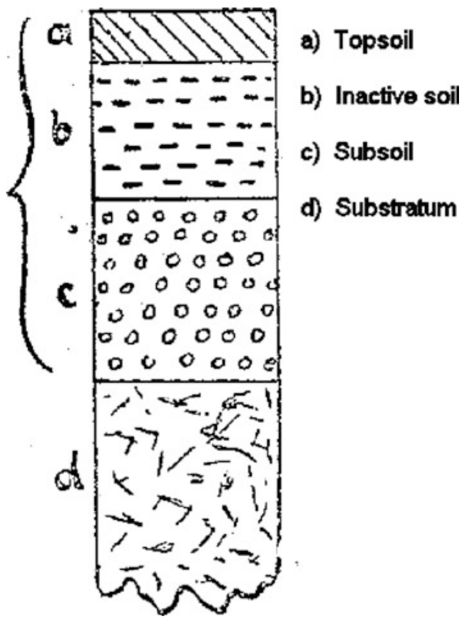

Fig. 1.1 Soil profile (Vinassa de Regny 1904)

In his text, Vinassa de Regny recognises the vertical morphology of cultivated soils. Quoting the Austrian palaeontologist Lorenz von Liburnau (1825–1911), he identifies two major soil sections: soil, further subdivided in topsoil, *suolo superficiale*, where most of humus is, and "inactive" soil, *suolo inerte*, where micro-organisms "seem to be lacking"; and subsoil (Fig. 1.1). Even if the vital part of soil is limited to topsoil, the inactive soil plays a role as reserve of water and nutrients (*magazzino di riserva*). In his opinion, and differently from contemporary agronomists, it is important to recognise the difference between inactive soil, subsoil and underlying rock, or substratum. Therefore, when considering the soil depth, all the soil sections should be taken into account. Actually, it is the recognition of the profile as the best descriptor of soil bodies. It is important to note that in none of his writings Vinassa de Regny does quote Dokuchaev and his concepts, and it is not clear whether he was aware of them.

In 1923, Giorgio Röster (1843–1927) published the text book "Agricultural soil and its relationships with air and water: complex influences on vegetation" (*Il terreno agrario nei suoi rapporti con l'aria e con l'acqua*: *influenze complesse su la vegetazione*). His definition of soil reads "agricultural soil […] is a mixture of highly fragmented mineral substances […] and, to a lesser extent, of vegetation residues at different stage of decomposition that make possible the necessary soil fertility"

> (Col nome di terra agraria […] deve intendersi una miscela di sostanze minerali in stato di grande divisione che ne formano il substrato o la base principale, alla quale si sono aggiunti in proporzione molto minore, gli avanzi che la pianta abbandona sul terreno in vario grado di decomposizione e che devono concorrere a dare al suolo la necessaria fertilità, Röster 1923).

Fig. 1.2 The foundation of ISSS, Roma 1924

In early twentieth century, the international links of Italian soil scientists were still sporadic. Some Italian scientists, among whom Vinassa de Regny (Mori 1929), attended the Second International Agrogeology Conference held in Stockholm in 1910, and took some contacts with the aim of holding an International Conference in Rome (Bollettino del Regio Comitato Geologico 1913–1914). After a series of preparatory meetings (van Baren et al. 2000), in May 1924, Rome hosted the IV International Conference of Pedology, under the patronage of the King of Italy (Fig. 1.2). The conference was held under the auspices of the International Institute of Agriculture, an international institution whose mandates would have been taken over by Food and Agriculture Organization (FAO), after World War II and the creation of United Nations.

The conference was attended by many international soil scientists, among whom Marbut and Glinka.

The geologist Gioacchino de Angelis d'Ossat (1865–1957) was the president of the Italian Organising Committee de and the microbiologist Renato Perotti was the Secretary General. Benito Mussolini, Italian Prime Minister, since few weeks and for the next 20 years, was the president of the honorary committee. On the last day of the conference, the International Soil Science Society was founded (van Baren 1974), following a decision taken in one of the conference preparatory meetings, in Zurich, in June 1923 (Actes de la IV^{eme} Conférence Internationale de Pédologie 1926). de Angelis d'Ossat, who claims the paternity of the initiative ("I had the opportunity to propose and to see flourishing the International Society of Soil Science", de Angelis d'Ossat 1928), was appointed as vice-president.

About a hundred Italian scientists attended the conference of Rome, and about 35 papers were presented. In one of his presentations, de Angelis d'Ossat exposed his theory about the necessity that soil classification should be based on the "lithological phase", as the "less unstable" component of soil: "Although the changes (of the lithological phase) can be so varied and profound so that the agricultural soil may differ […] from the parent rock, yet the course of evolution is limited […] by the point of departure (the parent rock) and by the point of arrival (derived rock). Agricultural soil represents the distance between the two rocks" (de Angelis d'Ossat 1924a). The dynamicity of soils and the complexity of the relations with the factors of its variability are for de Angelis d'Ossat a limitation for the feasibility and utility of geo-agronomic mapping of large areas (de Angelis d'Ossat 1924b). Instead, detailed and locally calibrated agro-geological maps could be very useful for agriculture, provided that the information is "not superfluous" and focussed on local environmental conditions (de Angelis d'Ossat 1924b). Given that the farmer would not benefit of a geo-agronomic map, as "he practices agriculture since ancient ages" (de Angelis d'Ossat 1924b), only reclamation activities and major land-use changes would need a geo-agronomic map. Also, such a map would be beneficial for combining "the maximum income […] without diminishing the land capital, which is incorrectly considered immutable" (de Angelis d'Ossat 1924b). Not very coherently, few years later, de Angelis d'Ossat would have published the first 1:1,000,000 Soil Map of Italy (de Angelis d'Ossat 1928).

In the same period, an agronomist, Alvise Comel, and a geologist, Paolo Principi, who would have greatly influenced Italian pedology, were active.

Alvise Comel (1902–1981) had worked since 1925 at the agricultural chemistry experimental station of Udine (in the relatively peripheral region of Friuli-Venezia Giulia), one of the several agronomic experimental stations set-up in Italy after the birth of the Italian kingdom in 1861. He was pupil of Michele Gortani (1883–1966), geologist (who attended the Rome conference presenting a paper on the agro-geological mapping in Italy). Comel was tasked with surveying the soils of Friuli-Venezia Giulia for producing acidimetric maps, and he published the results in several papers since 1925 and until 1940. His scientific interests were concentrated on "terre rosse" about which he published several works. In 1941, and until 1944, he was sent in Albania serving the Italian army during the World War II, but the interval did not impede his efforts: during the war, he published two works on Albania's soils (Comel 1942a, b). He continued the surveying for most of his life, leaving a fundamental contribution to the knowledge of the soils of Friuli-Venezia Giulia (Del Zan and Menegon 2003).

Between 1937 and 1940, he published three textbooks on pedology: "Notions of climatic pedology" (*Elementi di pedologia climatica*) and "Handbook for the practical study of soil and for the geo-agronomic survey" (*Guida per lo studio pratico del terreno e per il suo rilevamento geo-agronomico*) in 1937; and "Agricultural soil" (*Il terreno agrario*) in 1940. After quoting several international soil scientists, such as Fallou, Dokuchaev and Glinka, Comel gives his own definition of soil: "soil is the solid surface of the earth that is in contact with atmosphere and that is consequently subject to physical, chemical or biological modifications"

> (terreno [è] tutta la superficie solida della crosta terrestre che si trova in contatto con l'atmosfera e che subisce di conseguenza apprezzabili modificazioni di ordine fisico, chimico o biologico, Comel 1937).

He distinguishes between "natural soil" and "agricultural soil", that is, "the result of the conscious activity of the man, who modifies the natural course of pedogenesis with the aim of satisfying his own needs".

In his books, Comel recognises the soil as a body *per se* with its individuality and dynamics: "soil lives, this is a concept that must be well understood by any soil scientist" (*Il terreno vive, ecco un concetto che deve essere ben impresso in chi del terreno vuol far mèta dei suoi stud*i, Comel 1937). This is actually the first time that this concept appears in Italian pedological literature.

The degree and quality of the modifications to which soils are subject determine the differences among them, and therefore, the soils can be classified. Comel distinguished between classifications aimed at practical use of soils and pedological classifications, considering the latter as the "more scientific" ones. Without entering into the discussion about the soil classification systems, that was already a hot point of debate among soil scientists, Comel stated that a soil can be considered properly identified once some characteristics are known: the pedoclimatic environment, the parent rock, the mechanical and chemical characteristics and other site characteristics, such as morphology (Comel 1940). In this approach "the starting point" of soil, that is, the parent rock and the "final climatic soil" are well included, together with the main factors influencing the life of the plants. It is then recognised the dynamics of the soil, which, if autochthonous "must show in its profile the footprint of pedogenesis" (Comel 1937). Compared with the contemporary Italian geo-pedological literature, Comel is a step forward when stating that

> geo-lithology […] must still be considered a fundamental element for the knowledge of agricultural soils but it must be seen in the frame of the complex of the other elements that influence pedogenesis […] (Comel 1940).

Principi (1884–1963) worked in central Italy. After the first part of his academic career in Genoa, where his scientific interests were mainly about palaeobotany, in 1928 Principi moved to Perugia where he was professor of Agricultural Geology. Since then, his interests turned towards pedology. In 1940, he moved to Florence, and in 1942, he published "Geology and Pedology of the province of Florence" (*Geologia e pedologia della provincia di Firenze*) with two 1:100,000 maps (Principi 1942). In 1943, he published a monograph, "Soils of Italy, natural and agricultural soils" (*I terreni d'Italia, terreni naturali e terreni agrari*) with a soil map of the country in scale 1:3,125,000 (Principi, 1943). After the one by de Angelis d'Ossat, this is the first complete Soil Map of Italy. Soils are distinguished between "climatic types" and "azonal soils", according to the Russian pedological school. The monograph contains a complete list of the studies about Italian soils published so far. Between 1946 and 1952, Principi published a series of soil maps of the various Italian regions, later on re-edited and published as a new version of the monograph of 1943 (Principi 1961). In 1953, Principi published "Geopedology" (*Geopedologia*) the first complete textbook on pedology, since the one of Comel. In his text, Principi presents his vision of soil and pedology, giving an updated picture of the national state of the art and of the international literature (Principi 1953a).

Pedology in mid-twentieth century was still in its early stages, in Italy, and seeking for a clear identity between geology and soil chemistry. In particular, Principi was active in his efforts for defending the scientific status of pedology, in polite but open polemic with both soil chemists and geologists. In a series of publications (Principi 1953a, b, 1954, 1955a, b), Principi formalises his theories about geo-pedology ("the study of soil in situ, with the support of geological data") and about the relations with the other sister disciplines, namely agronomy and soil chemistry. "[Geo-pedology] considers soil […] as a dynamic entity, studying its origins and the various steps characterising its evolution; while [soil chemistry] studies mainly the present composition of soil". Geo-pedology is considered a more appropriate denomination as compared to agro-geology, which could have been interpreted as devoted merely to agricultural soils, while "useful applications for agriculture can be inferred more easily from the study of natural soils". The study of soil cannot be disjointed from the study of the whole soil profile (Principi 1955a).

In 1954, he writes: "Geo-pedology does not decrease the importance of soil chemistry, but […] only geo-pedology using information coming from petrography, tectonic, morphology, hydrology and climatology is capable to reach a complete knowledge of soil, of its origin, and of the transformations to which soil will be subject in time". Discussing a geo-pedological map recently published in southern Italy, he questions about the utility of a map based only on geological criteria without "taking into account the relationships between soil and vegetation" and the pedogenetic processes and dynamics (Principi 1954). Similarly, in the same paper, Principi criticises the Soil Map of Maremma compiled in 1954 by Valentino Morani and Orfeo T. Rotini (Morani and Rotini 1954), famous soil chemists (Morani was among the founders of the Italian Society of Soil Science, in 1952), where soil units were distinguished at higher level between soils over incoherent or rocky subsoil, and at lower level with a mixture of geological notations (Quaternary or Pliocene soils) and textural information (e.g. "heavy alluvial calcareous" or "loamy Quaternary"). The heavy criticism produced the reaction of Morani, who claimed the autonomous role of agronomy and soil chemistry in soil mapping. Actually, the dichotomy between pedologists and soil chemists characterises the early stages of soil science in Italy, still in twentieth century, as elsewhere in Europe since the birth of soil science (Yaalon 1997).

Principi is considered one of the fathers of pedology in Italy (Boulaine 1989), not only for the amount of papers published, more than 200 half of which pedological, but also for having been the initiator of the pedological schools of Florence and Perugia.

Even if not directly involved in soil survey and mapping, another soil scientist should be quoted here for his cultural weight in Italian agronomy, Giovanni Haussmann. Director of one of the experimental stations of the Ministry of Agriculture (the Experimental Institute for Fodder Crops of Lodi), Giovanni Haussmann (1906–1980), agronomist, was a singular figure in Italian soil science panorama. Born in Russia, he knew the Russian pedological school and followed the ideas of the Russian soil scientist Willliams. His scientific interests were about the conservation of soil fertility: "Soil is a natural body characterised by a certain degree of fertility". For Haussmann, fertility, defined as "the capability of fulfilling the plants' requirements", is the "peculiar quality of soil and only of soil" (Haussmann 1950) and is strictly linked to the soil's structural properties. Beside the strictly scientific publications, Haussmann wrote about the history of agriculture. In particular, he was interested in the relationships between soils, their characteristics and human history (Haussmann 1971).

1.3 Mapping Italian Soils: The Early Period (1940–1966)

Question: In 1966 the 1:1 M soil map of Italy was published, which is still the basis of the 1:1 M European soil map. What was the genesis of this map? How was it surveyed? How was the panel of participating pedologists selected?

Answer: About 20 soil scientists, pedologists, agronomists, foresters were involved in the so-called "Committee for Soil Map of Italy". They worked between 1961 and 1965, carrying on the survey in the different geographic areas of Italy: Northern, Central, Southern and Insular Italy. The mapping units were defined on a geomorphological basis by the various sub committees and discussed in plenary meetings of the National Committee. Moreover, several field surveys were organised attended by all the Committee members. Soils were classified according to the French system with modifications.

The first mention of the need of mapping Italian soils at national scale is due to Antonio Stoppani (1824–1891), geologist, palaeontologist, patriot and writer. Stoppani, with Torquato Taramelli (1845–1922) proposed in 1882 to the Royal Geological Committee, set up in 1867 as a branch of the Council of Mines at the Ministry of Agriculture Industry and Trade, a law for the setting of an autonomous National Geological Survey aimed at the compilation of the geological map of Italy (in open polemic with the Council of Mines). The map should have been complemented by an agricultural-geognostic map with "the indications about the lithological and chemical composition of the vegetal soil for the benefit of agricultural industry". The proposal established the responsibility of the map under the Geological Committee, with the participation of the agricultural experimental stations for soil analyses, and with the financial support of the Superior Council of Agriculture (*Consiglio superiore dell'agricoltura*) instituted in Rome in 1868 (Bollettino del Regio Comitato Geologico 1882).

Indeed, despite the efforts mainly of Taramelli, the Geological Committee was not particularly interested in mapping soils. The project did not succeed, due to the financial difficulties of the Italian kingdom and to the disputes among the Italian geologists (Corsi 2003). The geological survey would have obtained the financial and scientific autonomy in 1988 (D.P.C.M. 28 October 1988).

By initiative of Taramelli, in 1887, a project for a geognostic map of Po Valley was launched. Taramelli presents his project as "a very detailed study of the usually neglected portion of Earth that is the plain. It is connected with other studies of soil chemistry and hydraulic, as these links cannot be overlooked if we want this work to be at the same time scientifically sound and a collection of useful suggestions for agriculture, the actual main industry in that region" (Bollettino del Regio Comitato Geologico 1887). The surveys continued until 1899, but the results were not published.

These projects remained isolated initiatives. In 1901, in his annual report, the Chairman of the Geological Committee, Pellati, answering to Taramelli, declares that due to financial restrictions it was not possible for the Committee to take the responsibility for the production of agronomic maps, which instead should be under the responsibility of agricultural institutes, such as the experimental stations and agricultural extension services or *comizi agrari* (Bollettino del Regio Comitato Geologico 1901). In the same year, Augusto Stella (1863–1944), geologist and engineer, publishes a note on the bulletin of the Italian Geological Society, where he explains his ideas about the complexity, and eventual uselessness, of drafting proper agronomic maps (Stella 1901). According to Stella, whose ideas would have been endorsed by de Angelis d'Ossat (1924b), the complexity of the processes involved in the genesis of agricultural soils is too high to be represented in a sufficiently detailed map. He concludes stating that the geological map's accompanying notes, with an appendix including agricultural-geognostic information about "representative" agricultural soils, would have provided more scientifically based information as compared to unclear "agronomic" maps. Coherently with his approach, in 1902, Stella published a study on the geognostic characteristics of the soils of Montello, in northern Italy (Stella 1902).

Gioacchino de Angelis d'Ossat did not attend the first World Congress of the International Society of Soil Science, held in Washington in 1927, where Italy was represented by five official delegates: Bignami, Delfino, Orsenigo, Peroni and Rossati (Waksman and Deemer 1928). At the congress, the agro-geological map of Europe, edited by the Rumanian Gheorghe Murgoci, in scale 1:10,000,000 was presented, where only four mapping units were described for Italy. de Angelis d'Ossat was unsatisfied about the over simplification of Italian pedodiversity ("far from criticising the work of my eminent colleagues who participated in the difficult compilation of the [Europe soil] map, I would have liked a less crude comment about the Italian absence [in compiling the map]"), and on January 21, 1928, organised a meeting with soil scientists of Italian Geological Society (Bollettino della Società Geologica Italiana, 1928). He was eventually tasked of preparing the first (agricultural) Soil Map of Italy in scale 1:1,000,000, then published at scale 1:2,000,000 (de Angelis d'Ossat 1928). In drafting his map, de Angelis d'Ossat formally followed what established during the Rome conference about the central role of soil profile in soil classification (agricultural soils without [a differentiated] profile; soils with a partly developed profile; and soils with fully developed profile). However, de Angelis d'Ossat complained about the relatively low influence of geologists in the ISSS V Commission deputed to soil classification and mapping (Bollettino della Società Geologica Italiana, 1928), being still convinced that "[geology] should be taken as foundation for any classification of agricultural soils" (de Angelis d'Ossat 1928). Coherently, his map was based on the 1:1,000,000 geological map of Italy and did not contain the other information indicated by the soil cartography commission in the Rome congress: morphology, hydrography, climatology, vegetation and land use (Fig. 1.3). These

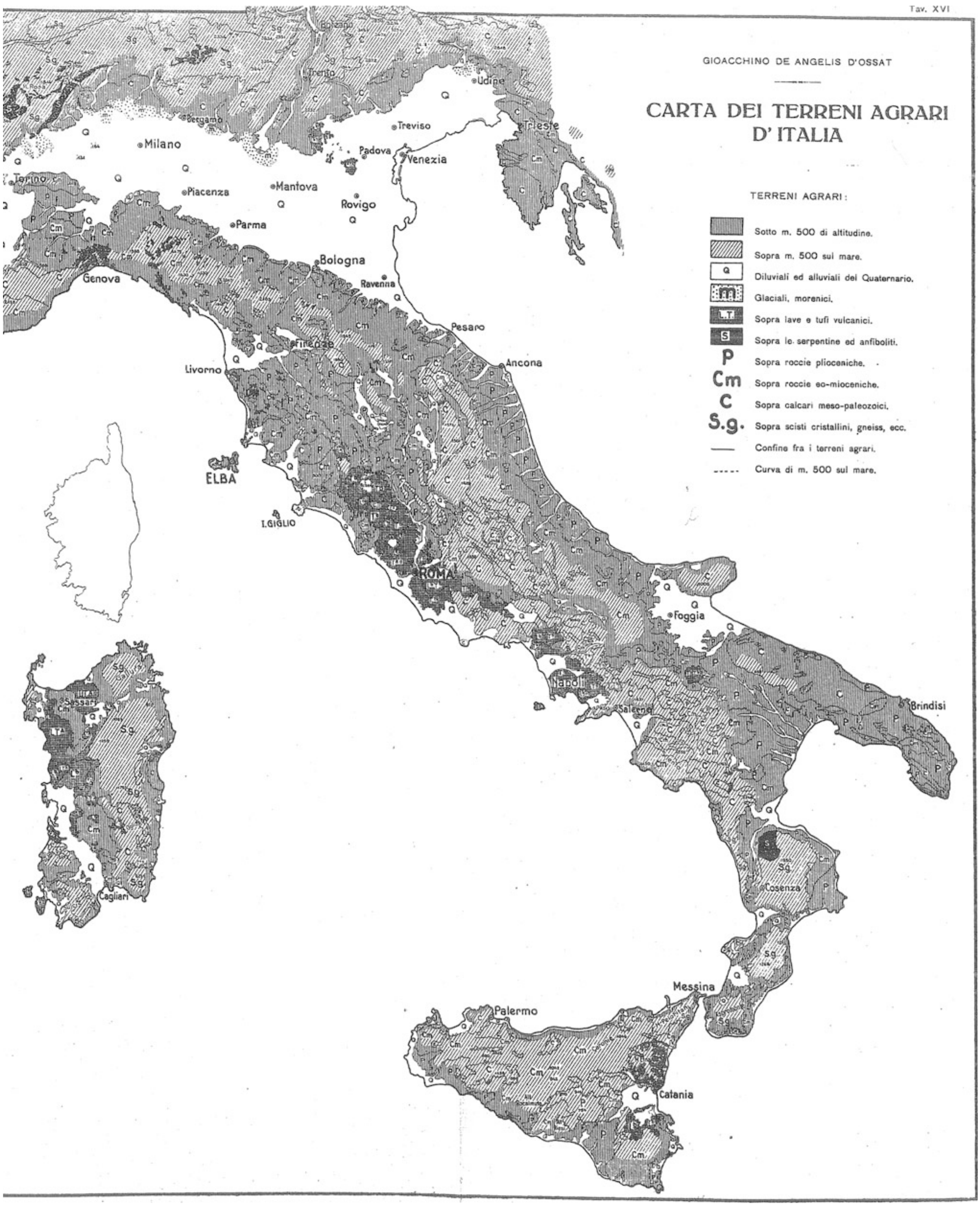

Fig. 1.3 The first soil map of Italy (de Angelis d'Ossat 1928)

would have resulted in an “excess of details”, difficult to manage in a small-scale cartography (Mori 1929).

In his map, de Angelis d’Ossat classifies soils distinguishing between autochthonous and allochthonous (colluvial and alluvial soils, and glacial soils) soils. Autochthonous soils are further subdivided according to elevation (>500 and <500 m asl.) and lithology. The published soil map results in six major categories, further subdivided in mapping units differentiated by lithology (Fig. 1.3). Even if de Angelis d’Ossat is listed among the collaborators, the final version of the Soil Map of Europe, published in 1937 in scale 1:2,500,000 (Stremme 1997), was very different from the Italian one (Mancini et al. 1966).

We had then to wait until 1942 for Principi’s map to be published.

When Principi moved to Florence in 1940, at the Institute of Geology and Mineralogy of the Agricultural Faculty, he had as assistant Ludovico Edlmann (1887–1974), who worked on soils of Tuscan Apennines and of Sardinia (Pietracaprina 1967–1974). In 1948, Fiorenzo Mancini became fellow assistant, after having been graduated in 1946 with a dissertation on the soil suitability for nursery industry in Tuscany. In Perugia, the chair left by Principi was taken up by Cesare Lippi-Boncambi (1911–1984), who in 1945, in a communication at the Geological Society, presented his ideas, about the constitution of a bureau for the Soil Map of Italy, under the coordination of the Royal Geological Committee (Lippi-Boncambi 1945). After the publication of the map of Principi, he proposed the realisation of a 1:100,000 (or even larger scale) soil map. The idea remained disregarded once more.

In 1950, Mancini and Lippi-Boncambi participated as Italian delegates at the IV Congress of the International Soil Science Society held in Amsterdam. Lippi-Boncambi presented a study on soils of Perugia province (Lippi-Boncambi 1950), where 30 soil typological units were mapped, following the methodology of Principi. Still in 1952, in the frame of the Marshall plan for European recovery after World War II, a group of European delegates from France, Germany, Austria and Italy attended a course on soil conservation held in the United States at the University of Georgia. Mancini was in the Italian delegation, composed mainly by agronomists, while Comel, who was supposed to participate, declined. When coming back, Mancini and his colleagues took a copy of the Soil Survey Manual just published in 1951 by USDA (USDA-SCS 1951). Few years later, Mancini published a “Short guide for studying soil in the field” (*Piccola guida per chi studia il suolo in campagna*, Mancini 1957), openly translating parts of the USDA manual, and with references to the 1937 handbook by Comel and to the British “The study of the soil in the field” (Clarke 1941). Explicitly addressed to students and field surveyors, this is the first Italian example of a field handbook, with a field form and codes for recording the main profile characteristics.

In 1953, a new soil map for Europe was planned by an European work group at FAO, in scale 1:1 M. A committee was set for correlation and for unifying the mapping and classification criteria. The group was led by René Tavernier from Belgium. Mancini was member of the committee and responsible for the correlation of the Soil Maps of Mediterranean Europe. In 1960, Mancini published the part concerning Italy in scale 1:1,500,000 (Mancini, 1960), using the legend discussed and agreed upon by the FAO work group and based on literature data available until 1959 in Italy (listed in the 1961 book of Principi).

The map was explicitly defined an “approximation” and one year later, in 1961, with the support of the Italian Society of Soil Science the Committee of the Soil Map of Italy was set up in Florence, with the aim of producing further approximations of the soil map of the Country, updated and more detailed. The project of the committee was threefold: beside a 1:1,000,000 new map of the country, some examples of 1:250,000 regional maps, and more detailed studies for pilot areas, were planned. The committee published the 1:1,000,000 map in 1966 (Mancini et al. 1966); 1:250,000 maps of the main Italian islands, Sicilia (Ballatore and Fierotti 1968) and Sardegna (Aru et al. 1967), and of the province of Trento (Ronchetti 1965); and 1:100,000 maps of the province of Belluno (Sief 1967) and of the north-west Sardinia (Pietracaprina 1964). Finally, two 1:25,000 maps were also published, one of the area of Arezzo, Tuscany (Pancaro 1966), and one of Fersina Forest, Trentino (Wolf 1967). For the preparation of the map and supporting the field activities, a new field guide was prepared by Giovanni Ferrari and Guido Sanesi in 1965 (Ferrari and Sanesi 1965). This should have been followed by a handbook for standardising the laboratory soil analyses. The handbook would have been published by Italian Society of Soil Science in 1976 and adopted as a standard reference for Italy in 1999 (Decreto Ministeriale 13/09/1999). The definition of soil given in this guide is influenced by the USDA soil survey manual: “soil is a natural body, made up by mineral material particles, containing organic matter and capable to support vegetation. […] The presence of well developed horizons is not necessary for defining soil” (Ferrari and Sanesi 1965).

Some 38 scientists participated in the drafting of the 1:1,000,000 map (Fig. 1.4), among them pedologists, geologists, agronomists and foresters, soil chemists and cartographers. The committee was organised in subcommittees according to the different geographical areas of Italy: northern, central, southern and insular Italy. Each subcommittee was responsible for drafting the soil mapping units on geomorphological basis. The units were then discussed in plenary meetings and during the field surveys

Fig. 1.4 The 1966 soil map of Italy (Mancini et al. 1966)

organised by each subcommittee in the various Italian regions. Soils were classified according to a modified version of the classification system used in France (Duchaufour 1956), few years later organised in the French CPCS system (C.P.C.S 1967). Some of the meetings and the field excursions were attended by Tavernier (Ronchetti 1963), one of the participants at the working group of the 7th approximation of the USDA—Soil Taxonomy (USDA-SCS 1960) and referent for Europe. The 7th approximation had been presented at the VII Congress of the International Society of Soil Science held in the United States in 1960, one year before the set-up of the committee. This allowed for an early discussion of the new American system (Ronchetti 1963) which would have been commonly used by Italian pedologists in the following years.

The final map was published with the contribution of the National Research Council (CNR) and received a financial support of Shell Italiana for excursions, thanks to a company manager, Francesco Favati, who graduated at the University of Florence in 1947. The map has been then updated in 1985 for the Soil Map of the European Communities 1:1,000,000 (CEC 1985), by Mancini himself with the contribution of Roberto Salandin, and in 1986, for the European Soil Database by European Commission, with the contribution of Donatello Magaldi, Ugo Galligani and Ugo Wolf (Platou et al. 1989). The mapping units' limits are still the basis of the most updated European 1:1,000,000 soil map. Finally, it must be quoted that an Italian group of scientists, formed by Angelo Aru, Giovanni Fierotti, Fiorenzo Mancini, Antonio Pietracaprina and Giulio Ronchetti, contributed to the World Soil Map, edited by FAO between 1971 and 1981 (FAO 1971–1981).

1.4 The Diffusion of Pedology (1966–1999 and Outlooks)

Question: In the second part of the last century consciousness about the importance of soil increased, and soil science and pedology spread from universities and research institutions towards soil survey agencies. What were the main subjects involved? What is the present role of research in pedology?

Answer: At National level, the Ministry of Agriculture, played, and still plays, a major role in supporting soil surveys, that are basic for a modern and sustainable agriculture. Since late 1970s, the regional administrations took up the responsibility on environmental and agricultural issues and much effort was undertaken in order to guarantee coherence at national level and among the various Italian regions. When dealing with practical applications, research is fundamental in ensuring scientifically based and updated competencies in processing soil information gathered with surveys. On the other side, the regional agencies have a major role both in stimulating the research demand and in providing the necessary feedbacks for researchers. Still some open questions remain, both in agricultural issues and environmental ones. Pedologists, both researchers and soil survey officers, should make all the efforts for exploiting at their best potentials and synergies.

Since the early mapping efforts, culminated in the constitution of the Committee of the Soil Map of Italy and in the so-called *Progetto finalizzato conservazione del suolo* (literally, focused project on soil conservation), funded by the CNR, soil survey had been mainly worked out by universities and research centres. Important exceptions were the cases of IPLA (Istituto Nazionale Piante da Legno), in Turin, and Sardinia, where two regional agencies, Ente Autonomo Flumendosa and Ente Regionale Sardo per la Sperimentazione Agraria, were active in soil surveying in early 1960s, mainly for applied pedology. Even if the early soil maps were explicitly aimed at providing information for agriculture, their applicability was limited. The first surveys were mainly intended to improve the knowledge of the Italian soils, their genetic relationships with the environmental factors and their distribution. However, information commonly included in the map legends and in accompanying notes was usually not sufficient to support applications. In 1967, a land capability map (Soil potentiality map) of Sardinia was published in scale 1:250,000 (Arangino et al. 1967), followed in 1968 by the first land capability map of Italy (Mancini and Ronchetti 1968), based on the 1:1,000,000 soil map. The Authors used an index for rating the limitations of each mapping unit (Ronchetti 1966), using an approach similar to the Storie Index Rating (SIR), proposed in 1933 by R.E. Storie (in FAO 1967). The map was questioned by the academic world, which criticised the applicative approach. After the publication in 1976 of the FAO framework for land evaluation, several examples of thematic maps were produced at general and detailed scale (for a review, see Costantini 2009). These examples, mainly published by research institutes, paved the way for the exploitation of soil maps in land planning. An early example of application of the FAO framework at national scale is given by a series of maps (scale 1:2,000,000) representing the suitability of Italian soils for maize production (Ministero dell'Agricoltura e delle Foreste 1984). The study, commissioned by the Ministry of Agriculture, involved different background researchers from various institutions.

Since late 1970s, early 1980s, when regions were entrusted with responsibility for agricultural and environmental issues, several Regional Administrations, Lombardy, Piedmont, Tuscany and Emilia Romagna started systematic soil survey programmes, mainly at semi-detailed scale, having as priority the mapping coverage of more productive agricultural soils (Filippi 2005). In those years, Emilia Romagna published a reconnaissance scale map of its territory (Casalicchio et al. 1979), so that at the beginning of the 1980s three regions (Emilia Romagna, Sardinia and Sicily) and an autonomous province (Trentino) had a 1:250,000 (or 1:200,000) soil map, and, in the case of Piedmont (Regione Piemonte—IPLA 1982) and Emilia Romagna (Angelelli et al. 1981), a Land Capability map.

The regional administrations needed professional pedologists for their survey plans. Some Regional administrations, for example, Regione Emilia Romagna and Lombardy, organised training courses with this aim in the late 1980s. In 1990, an "Observatory for Pedology and Soil Quality" was set up by the Ministry of Agriculture, with the aim of supporting the Ministry and the regional authorities in soil-related matters and for soil analysis methods standardisation (DM 7/7/1990, n. 15517, 20/9/1990, n. 20611).

The Observatory for Pedology and Soil Quality, formally still operative, was composed by representatives of the Ministries of Agriculture and of Environment, by scientists of the Agriculture Research Council (CRA), CNR and Academy and by regional officers. For that reason, it acted as a coordination body among the various actors in the complex Italian panorama. It promoted and published, and presently updates, a series of soil analysis methods handbooks: physical, chemical, microbiological, biochemical, mineralogical and water analysis, eventually adopted as official standard references.

In 1991–1992, the Observatory organised two courses for pedologists, for northern and central-southern regions, funded with European structural funds (European Agricultural Guidance and Guarantee Fund, REG. CE 270/79) aimed at training personnel to be eventually recruited by the regional services or agencies responsible for soil survey. Most of the people trained in those courses are presently active in the local soil surveys.

Main aims of regional soil surveys were providing information for the correct and sustainable use of soil, and supporting other regional services, such as agricultural or land-use planning services. Several examples of soil information applications can be recalled, at the beginning mainly focussed on agricultural issues, such as the already mentioned land capability maps of Emilia Romagna and Piedmont (Angelelli et al. 1981; Regione Piemonte—IPLA 1982) and land suitability for various agricultural systems (e.g. Regione Emilia Romagna 1987).

In 1998–1999, two joint soil programmes started at national scale: "Soil map of Italy" and "Pedological methodologies" (Costantini and D'Antonio 2001). The regional soil survey teams, under the coordination of Ministry of Agriculture, by means of the Observatory for Pedology and with the scientific coordination of the Experimental Institute for Soil Study and Soil Conservation and in cooperation with several universities, carried out the project "Soil Map of Italy". Contemporarily, the project "Pedological Methodologies" was aimed at providing reference standards for land units' definition and field surveying procedures, coherent with EU standard methodologies (ESB 1999), defined in the same period by a network of European soil scientists under the umbrella of the newborn European Soil Bureau Network set at the Joint Research Centre of the European Commission in Ispra (Italy, Montanarella et al. 2005). In both the projects, the participation of most of the institutions involved in soil survey, both at national and local level, allowed for a substantial coherence of approaches, despite the lack of a clear structure in management (Filippi 2005).

The main results of the two projects were the 1:250,000 soil map and database for most Italian Regions (16 regions out of 20), pursuing both exploitation of local knowledge and consistency of information at National and European level (Filippi 2005); the editing of a field guide for soil description (Carnicelli et al. 2001) consistent with the ones adopted at local level; the publication of a 1:5,000,000 soil region map harmonised at European level (Costantini et al. 2004; see Chap. 6); the set-up of a national soil database, the so-called Italian National Centre for Soil Mapping (Centro Nazionale di Cartografia Pedologica, CNCP, http://abp.entecra.it/soilmaps/en/home.html).

The linkage between regional soil survey teams and research institutions was very strict in those years, when a productive cooperation developed. From one side, the regional soil surveys were interested in gathering soil data and exploiting them for applicative aims. From the other one, the research institutions were involved in providing a scientific support based on the societal research demand. Moreover, the cooperation with regional soil surveys assured an invaluable feedback for a direct validation of scientific issues. As an example, in the frame of a trans-regional project (SINA-National Environmental Information System—Soil Mapping in Areas at High Environmental Risk 1996–2000), a set of locally validated pedotransfer functions for estimating hydrological soil properties was developed for soils of northern Italy alluvial plains (Ungaro and Calzolari 2001; Ungaro et al. 2005). This was possible thanks to the cooperation of research institutions and regional soil surveys of Piedmont, Lombardy, Veneto, Friuli-Venezia Giulia and Emilia Romagna.

Between 2006 and 2009, the SIAS (Sviluppo di Indicatori Ambientali sul Suolo in Italia—Development of Soil Indicators in Italy) project was launched (http://eusoils.jrc.ec.europa.eu/projects/Meusis/italy.html), led by the Italian Agency for Environment Protection (APAT), at present part of the Institute for Environmental Protection and Research (ISPRA), with the technical support of the Regional Agency for Environment Protection of Veneto (ARPAV) and the participation of most of the Italian regions (16 out of 20). The project was aimed at developing soil indicators, adopting a harmonised methodology among the various regions, with special reference to soil erosion and organic carbon content.

The project was conceived as part of the MEUSIS project (Multi-Scale Soil Information System) which had as objective the development of an approach for up-scaling soil data from local to regional and European scale in the frame of the INSPIRE directive (2007/2/EC) (Panagos et al. 2011). In recent years, the societal demand of soil information is increasing (Hartemink and McBratney 2008) for answering to new challenges such as climate change impact and mitigation needs, food security, sustainable use of resources, pollution minimising, management of contaminated sites, land take and consumption. Italian soil science community, as the international one, “should act promptly and deliver, whilst at the same time […] should continue to be innovative and develop new thinking about soils and how they are studied and properly managed” (Hartemink and McBratney 2008). This is the subject of a specific chapter of the present book (Terribile et al., Chap. 11).

1.5 The Research Institutions

Question: Around the mid of the past century, Florence appeared to be the centre of research in pedology. Is it correct? Which are the specific roles of University, Ministry of Agriculture and National Research Council? Which are the links with the other Italian universities?

Answer: From an historical point of view, Florence and Perugia were pioneers in “modern” pedology. The presence of Paolo Principi, who worked in both the cities, created a strict link between the two universities. Many future pedologists studied in the agriculture faculty of Florence, and then moved to other seats, spreading the discipline across Italy. The constitution in Florence of an experimental institute of the Ministry of Agriculture devoted to soil science, and the setting up of a CNR study centre, again in Florence, strengthened the pedological school of Florence. Later on other pedological schools formed, in other cities. But, the Florentine heritage is still a reality. The National Research Council that funded a huge project on soil conservation, directed by myself and centred in Florence, also played a major role.

From a historical point of view, two university departments had an important role at the very beginning of Pedology in Italy, the institute of Mineralogy and Geology of the University of Florence (formerly the National Forestry Institute), and the institute of Mineralogy and Geology of the University of Perugia (formerly Regio Istituto Agrario Sperimentale di Perugia). The first director of the Florentine Institute was Alessandro Martelli (1876–1934), famous geologist, senator and Ministry of National Economics (1928–1929). He was followed by Riccardo Ugolini, geologist, who published a 1:500,000 map of Tuscany, “Tuscan rocks as a basis for a rational evaluation of agricultural soils gross production” (Ugolini 1933). With the arrival of Paolo Principi, Ludovico Edlmann and Fiorenzo Mancini, the scientific interests of the Institute turned decidedly towards soil science. Strictly connected with the Florentine one, the Institute of Mineralogy and Geology of the University of Perugia was firstly directed by Guido Bonarelli (1896–1899), geologist and palaeontologist, followed by Paolo Vinassa de Regny, Gioacchino de Angelis d’Ossat, Paolo Principi, Cesare Lippi-Boncambi and Celso Giovagnotti, who in 1980 translated the USDA Soil Taxonomy (USDA 1980).

The first chairs of pedology (geopedologia) were the ones of Mancini in Florence and of Sandri in Bologna, in 1954. Chairs of Pedology were later on set in the Universities of Sassari (1965), Cagliari (1970), Palermo (1970), both in Geology and Agriculture faculties.

In Sassari, Antonio Pietracaprina (1931–2011), geologist and pupil of Ardito Desio (1897–2001), geologist himself and famous explorer, called as assistant Paolo Baldaccini, agronomist who studied with Mancini in Florence. At the beginning of his career, Baldaccini worked in Florence at the Experimental Institute for Soil Study and Soil Conservation. Also Angelo Aru, agronomist, who started his career at the Ente Regionale Sardo per la Sperimentazione Agraria, an experimental station of Sardinia Region, worked in Florence at the Experimental Institute for Soil Study and Soil Conservation. From there, he moved back in Sardinia, becoming professor of Pedology at the University of Cagliari. In Sicily, at the Agriculture faculty of the University of Palermo, Gian Pietro Ballatore (1921–1975), agronomist and soil scientist, had as assistant Giovanni Fierotti (1925–2011), chemist and pharmacist, who became full professor of pedology. These three University seats, with their researchers, remained strictly linked to the Florentine school, being active partners in the panel for the Committee for the Soil Map of Italy.

More recently, chairs of pedology have been set up in Torino, Venezia, Milano, Siena, Napoli, Ancona, Campobasso (Mancini 1994; Nannipieri 2001).

In 1952, Gino Passerini (1889–1961) with the political support of Michele Gortani, elected Senator at Italian Parliament in 1948, founded in Florence the Experimental Institute for Soil Study and Soil Conservation (ISSDS) under the control of the Ministry of Agriculture. Passerini, agronomist and specialist in hydraulics and soil conservation, had worked to the idea of having an institute dealing with soil conservation for many years. In 1939, he presented at the Georgofili Academia of Florence the proposal of setting up an institute with a twofold function: (1) a scientific research and experimental laboratory on soil, considered as “a subject of coordinated researches in the different elemental factors (physical, chemical and biological) which influence soil dynamics and fundamental nature”; and (2) a national-level soil conservation service. In the original project, the institute should have been organised in four sections: physics, chemistry, biology and statistical economics (Pure et al. 1939). The proposal was "unconditionally" accepted by the members of the Georgofili Academia. In 1947, the sum of 150 millions of Italian liras (correspondent to more or less 2.8 billion of euros) was allocated for the project, on a particular funding programme, "fondo—lire United Nations Relief and Rehabilitation Administration" (UNRRA), funded mainly by the United States for an extensive social-welfare programme after World War II (Passerini 1952). It took more than ten years for the project to be finally realised.

ISSDS was eventually organised in four sections: physics, chemistry, biology and genesis classification and cartography. Main research topics were on the impact of agriculture on soil quality: soil erosion, with the contribution of the group of Giancarlo Chisci who participated to the building of the erosion model EUROSEM (Morgan et al. 1998); land evaluation, with the early works of Giulio Ronchetti and Donatello Magaldi; and soil genesis and mapping, with Luciano Lulli and his collaborators. Until mid-1990s of the past century, it used to publish a yearly bulletin, with the main scientific results of the researches. With the reform of the Ministry of Agriculture and of its experimental institutes, ISSDS has been merged with the Experimental Institute for Agricultural Zoology, as Research Centre for Agrobiology and Pedology (ABP), within the network of the Agriculture Research Council (CRA).

The CNR, the largest Italian research public body, which funded the early studies of Italian soil scientists, as the Principi's maps of the province of Florence (Principi 1942) and the Soil Map of Italy, played an important role. Two so-called study centres, supported by CNR with personnel and funds, were constituted in 1969, in Florence, on Soil Colloids (CSCS), and on Soil Genesis, Classification and Cartography (CSGCCS), the latter being led by Mancini. CSGCCS played a major role in large-scale surveying of several pilot areas, in central and southern Italy and with Luciano Romagnoli (1926–1973), Guido Sanesi (1939–2006) and later on with Ermanno Busoni, specialised in research in soil physics and hydrology, soil and landscape evolution. Between 1988 and 1995, CSGCCS has published a peer review journal, "Quaderni di scienza del suolo". Following the CNR reforms, CSGCCS merged in 1998 with the Florentine section of CSCS, forming the Institute for Soil Genesis and Ecology, IGES, and, later on, with the Research Institute for Hydrogeological Protection (IRPI).

CNR played a further important role for soil science, and in particular for pedology, funding in 1978–1983 the *Progetto finalizzato conservazione del suolo* directed by Mancini. Some hundreds of scientific publication arose from that project, which was subdivided in different subprojects, dealing with slope dynamics, coastal dynamics, river dynamics and soil conservation. The central role of Florence in the development and consolidation of the Italian pedological school was somehow facilitated by the presence and character of Fiorenzo Mancini. Since the early stages of his career, Mancini, agronomist lent to earth sciences, worked at building a formal and informal network of scientists and professionals, rooted in various disciplines and from different areas, both at national and international level. This paved the road for a shared vision and a common understanding among Italian pedologists.

Finally, in recent years, the Institute for Environmental Protection and Research, ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale), has been established in Rome (L. 133/2008), merging the competencies of a number of existing research institutes and national environmental agencies, among which the geological survey. ISPRA is the National Focal Point of the European Environment Information and Observation Network (EIONET) and the primary contact point for of the European Soil Data Centre (ESDAC), the thematic centre for soil-related data in Europe (Panagos et al. 2012) hosted at the Institute for Environment and Sustainability (IES) of the Joint Research Centre of the EU Commission (http://esdac.jrc.ec.europa.eu/; http://eusoils.jrc.ec.europa.eu/library/data/eionet/PrimaryPoints.cfm). ISPRA publishes a yearly report on the state of the environment, including a thematic chapter on soil.

1.6 The Soil Societies and Associations

Question: what role did the Italian Soil Science Society have in the development of pedology in Italy? Which the one of the Italian Association of pedologists, AIP and of the Italian Society of Pedology, SIPe? What the future?

Answer[2]: In early 1960s, the V commission, Genesis Classification and Cartography, of the Italian Society of Soil Science was entirely involved within the Committee for Soil Map of Italy. The commission has always been very active in soil survey issues, representing a cultural reference for Italian pedologists. When AIP was founded, this was seen with some cautiousness by the academic pedologists, who would have rather preferred a scientific society. This was eventually created some years later, the Italian Society of Pedology, SIPe, whose main aim was representing pedology within the academic world. As in other countries, also in Italy, the university courses on soil science, and pedology in particular, decreased in the last years. Having a recognised scientific society could facilitate the dialectic with other stronger academic disciplines. In this situation, it is unlikely a merging of the three societies, even if a stronger and official coordination could be beneficial for Italian pedology and soil science in general.

Despite the exiguous number of pedologists, and in general of soil scientists, three soil societies are active in Italy, with slight differences in aims and composition. The Italian Society

[2] The question was jointly posed to Fiorenzo Mancini and Giulio Ronchetti. Prof. Ronchetti, agronomist and soil scientist, has been director of ISSDS between 1974 and 1995.

of Soil Science, SISS, is a multidisciplinary association, gathering all the sub-disciplines of soil science. Primarily focussed on pedology, the Association of Italian Pedologists, AIP, has a more professional and applicative character as compared to the Italian Society of Pedology, SIPe, which has an academic character mainly. The three societies cooperate in their activities, organising common events, workshops, conferences and scientific field excursions.

1.6.1 SISS

Two years after the IV Congress of the International Soil Science Society held in Amsterdam, the Italian Society of Soil Science (SISS) was founded on February 18, 1952, by Gino Passerini who was then elected as its first president. Since then, 12 presidents have been elected. 14 people were founder members, among whom agronomists as Gino Passerini, soil chemists as Alberto Malquori, pedologists as Fiorenzo Mancini and Paolo Principi. In analogy with the International Society, the Italian Society was organised in disciplinary commissions (presently eight: Physics, Chemistry, Biology, Fertility, Genesis Classification and Cartography, Soil use and conservation, Mineralogy, Soil and environment). The Italian Society counts about 190 members, mostly scientists from universities and research institutions. SISS is seated in Florence, at the Institute for Soil Study and Soil Conservation. Since 1969, SISS publishes a Bulletin, and since 1982, it organises annual meetings (biannual in the last years). With the V commission on soil genesis and classification, it participated in editing the Soil Map of Italy of 1966. Between 1997 and 2006, it edited seven agricultural technical handbooks for soil and water analysis, as reference scientific society of the Observatory for Pedology and Soil Quality. The aim of SISS is mainly cultural thanks to its multidisciplinary character (www.scienzadelsuolo.org).

1.6.2 AIP

The Associazione Italiana Pedologi (Italian Association of Pedologists, AIP) has been founded in Ferrara in 1992, by the initiative of a group of professionals, researchers and technicians in pedology (100 founder members). In order to maintain a strong link with SISS, the seat of AIP was set in Florence, at the Institute for Soil Study and Soil Conservation. First president of the Association was Enrico Favi, an officer of Tuscany regional administration. The main purpose of the Association is promoting the knowledge of pedology and the role of pedologists. To this aim, AIP organises professional training courses and scientific events, often in cooperation with other scientific associations and research institutions. It holds an annual assembly, with scientific excursions. AIP maintains an updated website (www.aip-suoli.it) and publishes a periodic electronic newsletter.

The main characteristic of AIP is the coexistence of different professional figures operating in pedology, as researchers, professionals and soil survey officers. This should facilitate the following: (1) the exchange and integration of experiences; (2) the development of a common cultural approach to the discipline; (3) the perception of the societal research needs; and (4) the dissemination of the results of the research.

In 1994, AIP published a *manifesto*, reported in the box. It is worth to be noted that many of the concepts then adopted in EC Soil Thematic Strategy are present in AIP manifesto 10 years earlier.

Manifesto of pedology (version of 18/01/94, excerpt).

- What man calls soil is a natural body at the interface between atmosphere and lithosphere. It is the result of the interactions of present and past chemical, physical and biological processes.
- Soil is a continuum on the earth surface, not homogeneous and in permanent exchange of energy and matter with the surrounding environment.
- Soil is a fundamental factor in maintaining the global equilibrium needed for biomass production, in regulating the other environmental components (e.g. water), in providing a substratum for most of the biological activities, included human activities, and as information archive (palaeo-environmental aspects, archaeological remnants, etc.).
- Soil is a natural resource, very slowly recovering and expensive to recuperate; the processes acting in it are mostly irreversible or very slowly reversible. Every soil degradation process (such erosion or sealing), its destruction or the incorrect transformation of its physical, chemical or biological characteristics (salinisation, alcalinisation, pollution) lead to an irreversible loss.
- Life and welfare are strictly linked to the soil capability to produce goods, and man can benefit of it through its activities, but he can benefit of it even more if, by means of his capacity of partitioning and cataloguing the surrounding world, he delimits the different soils and defines their properties assessing the alternative possibilities of managing and using soils.
- As a natural resource, soil must be preserved for future generations. It is in our responsibility to preserve it in such a way that it will be possible to benefit of it even in future. Therefore, people having responsibilities towards soil should take into

consideration not only its chemical, physical and biological characteristics, but also the technical, socio-economic and legal aspects which directly affect soil use and conservation […].

- When planning soil surveys, both in research and professional activities, it is necessary to consider two interconnected aspects: priorities and urgency. Priorities should be defined according to the different pedological topics (if soil mapping and classification, soil–plant relationships, soil degradation, etc.) and in its planning aspect: where, why and for whom studying soil.
- Urgency is given by the fact that research, experimentation and in general, the agronomic, forestry and environmental activities are long-term activities. On the contrary, soil degradation is a quick process which can lead in some circumstances to a permanent loss of the soil resource […].
- For the sake of urgency, when fast responses are needed for planning activities, it is important that adequate financial and human resources are allocated, in order to avoid obtaining low-quality results, and eventually a weak knowledge base for any planning decision.
- The motivations for studying soils are extremely important in planning activities, that is, the range of reasons for a customer in requiring the services of a pedologist […]. It is necessary that these motivations are clear, given the pre-existing knowledge about soil, its use limitations and degradation risks, so that fragile pedoecosystems can be identified and quantified. Any planning in soil study should be coherent with the concepts of priority and urgency.
- Stakeholders and end-users must be appropriately involved, so that they can correctly exploit the results of the soil surveys activities. On the other side, the pedologists should guarantee the correctness and usability of their work results, explicitly showing potentialities and limitations in their use.
- Research and applications must be interdisciplinary in order to address environmental questions in an integrated way. Interdisciplinary should involve also disciplines other than natural sciences […].
- Finally, pedologists should always consider the sustainability of any actions involving soils in agricultural and natural environments. This can be achieved by acting with the aim of preserving or recovering environmental integrity and productivity so that humankind can continue to benefit of it.

1.6.3 SIPe

The Italian Society of Pedology, SIPe, has been founded on 9 December 1997, in Palermo, on initiative of Giovanni Fierotti. Aim of the Society is to promote, sustain and coordinate studies and research in pedology and its applications, and to facilitate relationships and collaboration among scientists, acting as an interface with other academic societies. Also, it aims at promoting the academic education in pedology, representing the discipline in national committees, such as the national research evaluation agency. It acts for funding young scientists with grants (*Certamen Peologico*). As compared to AIP, SIPe has an academic character, even if the membership is not limited to academics. It counts about 110 members, with around 10 % of young pedologists, and organises workshops, scientific excursions, etc. (www.societapedologia.it).

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2 Climate and Pedoclimate of Italy

Edoardo A. C. Costantini, Maria Fantappié, and Giovanni L'Abate

2.1 Introduction

Climate is a major driving force of pedogenesis, especially during the first stages of soil formation. Italian soils, often rejuvenated by water erosion, have a potential strong geographic correlation with climate. Climate also determines vegetation cover and crop diffusion and management, which in turn influence the soil development. On the other hand, accelerated erosion and mass movements, triggered by relief and tectonic, as well as the deep and long-lasting impact of man in Italy, tend to homogenize soil profile and decrease pedodiversity.

Italy is placed in the middle of the Mediterranean basin and at the same time of the temperate zone of the boreal hemisphere, but its climatic regimes are much variegated and contrasted (Fig. 2.1[1]).

Italy stretches with its elongated shape from the 36° (35° considering the island of Lampedusa) and the 47° parallels; therefore, Italian climates are first of all influenced by different amounts of radiation energy. Another important geographic factor of the country is its peninsular nature. The Mediterranean seas, which almost surround the country, are a reservoir of heat and humidity for the inland. However, not all seas have the same mitigating action: the Adriatic Sea, in particular, rather thin and shallow, shows a less pronounced effect than the Tyrrhenian Sea (Fig. 2.2[2]), which is much larger and deeper.

Orography plays another major role on Italian climates. Italy hosts the highest elevation of geographic Europe (Monte Bianco 4,810 m, Aosta Valley) and the tallest active volcano (Etna 3,343 m, Sicily). The Alps as a barrier not only exert an action with respect to the cold currents from the Arctic regions of Northern Europe, but also against the temperate, wet air masses which come from the North Atlantic, often originating a warm strong wind (foehn), which during winter may cause severe episodes of snow melting and blowing. In addition, the Alps, along with the Northern Apennines, surround a river basin, the Po Plain, subject to atmospheric subsidence, with air stagnation in the lower layers, pronounced summer warming and strong cooling in winter, enhancing continentality.

The Apennines and related relieves deeply influence also the Italian climates, intercepting the perturbations coming from the Atlantic Ocean at west, but also those coming from the northeast. Their rough morphology, in particular, causes sharp temperature variations along short distances, frequent rainfalls for adiabatic cooling and stau[3] wind currents, winter fog stagnation inside the several internal closed basins and narrow valleys.

2.2 Temperatures

The long-term mean annual air temperature (MAT) of the whole of Italy, 12.6 °C, reflects its position in the temperate zone (Table 2.1). Nevertheless, it spans about 30 °C, from several degrees below zero on the Alps to around 20 °C in some parts of Sicily, pointing to an exceptional climatic variability, if compared with the size of the country (Fig. 2.3[4]).

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[1] Google Earth view.

[2] ArcGlobe data.

[3] Ascent of moist air is responsible for the enhancement or formation of stau cloudiness along the mountain slope.

[4] The map was obtained using the regression kriging method (MLRA) to spatialize long-term mean annual temperature data (MAT) of 1,086 meteorological station. A linear model was defined in which mean annual temperature was related to elevation and latitude (adjusted R-squared: 0.6613, *p* value: <2.2e-16). The model was applied by means of a raster calculation (MLRA grid). MLRA prediction errors (difference between predicted and measured values) were then interpolated by ordinary kriging and subtracted from MLRA grid. Differences between legend classes are larger than standard errors.

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Fig. 2.1 Italy is placed in the heart of the Mediterranean basin and temperate zone of the boreal hemisphere

MAT higher than 14 °C is widespread all along the central–southern part of the country and is rather well related with the cultivation of the olive tree, one of the most typical and widespread Mediterranean crop.

The degree of continentality is another important characteristic of Italian climates. On a country average, summer temperature is warmer than winter more than 15 °C (Table 2.1). In particular, Fig. 2.4 shows the relatively high continentality of the Po Plain and related valleys, exceeding a difference of 17 °C between summer and winter. Figure 2.4[5] also indicates a decrease in continentality from north to south and from east to west, as a main consequence of the distance from the seas and of the different mitigating action of them. The city of Ancona, for instance, has a thermal excursion similar to that of Florence, although it lies close to the Adriatic Sea, while Florence is about 100 km far from the Tyrrhenian Sea. On the other hand, long-term meteorological data of cities placed along the coast of the Tyrrhenian Sea, like Naples, Cagliari and Palermo, demonstrate seasonal excursions of around 13 °C, or less.

2.3 Precipitations

The variability of mean total annual precipitations (MAP) is even more pronounced than temperatures. Table 2.1 reports a mean value that is typical of temperate regions, but the difference between maximum and minimum long-term values, more than 1,800 mm, and the large standard deviation highlight the presence of very dissimilar rainy conditions, which are depicted in Fig. 2.5[6]. The highest long-term values are recorded in the northeast of the country, in the Friuli region. Values exceeding 1,900 mm are also reported in an area between the Lombardy and Piedmont Alps, as well as in northern Tuscany (Apuane range), where the Apennines intercept the Atlantic perturbations, as well as the cyclones that form in the Gulf of Genoa. On the other hand, the absolute lowest long-term average annual precipitation is reported for an area south-east of Cagliari (around 400 mm), but territories with relatively low rainfall are widespread in the two main islands as well as in the Apulia and Basilicata regions. Also some

[5] The map was obtained with an ordinary kriging interpolation of the difference between summer and winter air temperature of 1,086 stations. Differences between legend classes are larger than standard errors.

[6] The simple kriging prediction map was obtained by interpolating the mean annual precipitation of 2,200 stations. Differences between legend classes are larger than the standard errors.

Fig. 2.2 Italy stretches from the 36° and the 47° parallels

areas of northern Italy have averages ranging from 400 and 700 mm, in particular, the easternmost part of the Po Plain, the Bolzano, and the inner part of Valle d'Aosta.

The snow cover is widespread during wintertime in the Alps, the Apennines and the highest relieves of the islands, but it can also reach the plains of northern and central Italy, especially along the Adriatic part of the country, in occasion of the irruptions of arctic cold winds. Significant amount of snow in plain, between 20 and 50 cm, is particularly frequent in northwestern Italy (Valle d'Aosta, Piedmont and Lombardy) and on the hills of Emilia-Romagna and Marche regions, where the snow pack lasts between 10 and 25 days per year. On the Western and Central Alps, the average snow depth at 1,500 m a.s.l. ranges from 100 to 230 cm, but it reaches 250–400 cm on the Eastern Alps. Therefore, the amount of water stored in the snow pack (SWE) is absolutely relevant and at 1,800 m a.s.l. in the Western Alps ranges between 250 and 500 mm. The average snow cover duration is 200 days or more, according to the elevation. On the Apennines instead snow pack is between 100 and 350 cm, on average, and the mantle generally persists no more than 100 days, apart from the highest peaks.

Table 2.1 Long-term values of characteristic climatic and pedoclimatic parameters for the whole Italian territory

Parameter	Mean	Min.	Max.	St. Dev.
Mean annual air temperature (°C)	12.6	−11.0	19.0	3.9
Potential evapotranspiration (mm)	1002.0	643.9	1,308.1	149.2
Mean total annual precipitation (mm)	932.5	434.4	2,254.1	286.7
Aridity index (P/ETo)	0.98	0.36	2.80	0.40
Fournier index (mm)	90.2	42.9	210.9	24.9
Continentality index (summer minus winter air temperature, °C)	15.1	13.2	17.1	0.9
Seasonality index (rainiest minus lowest rainy month, divided by total annual rainfall, %)	10.7	3.6	20.6	3.0
Soil aridity index (dry days per year)	70	0	148	31
Soil temperature at 50 cm depth (°C)	14.4	4.6	22.7	2.6

Values obtained from the raster spatialization reported

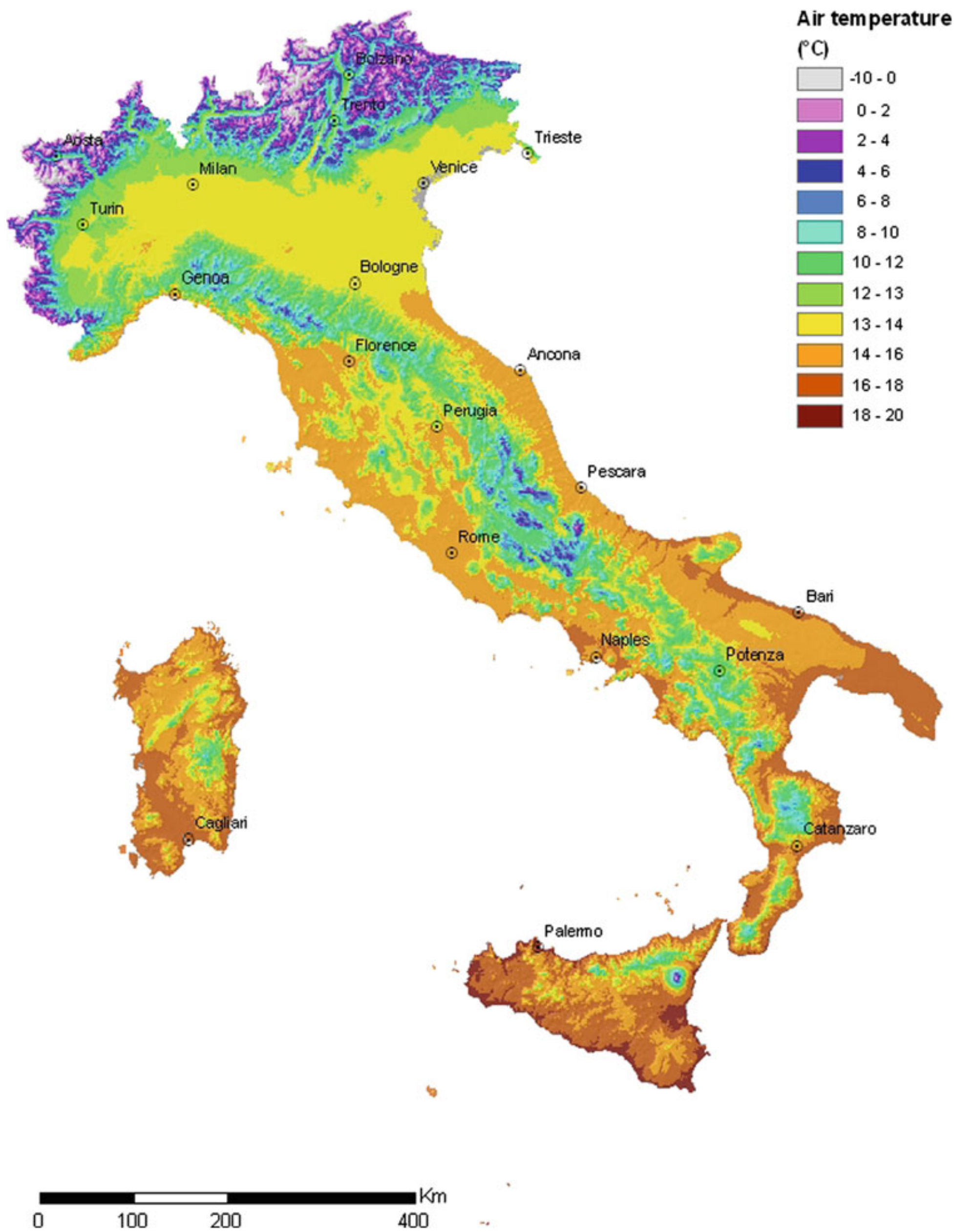


Fig. 2.3 Long-term mean annual air temperature (1960–2008)

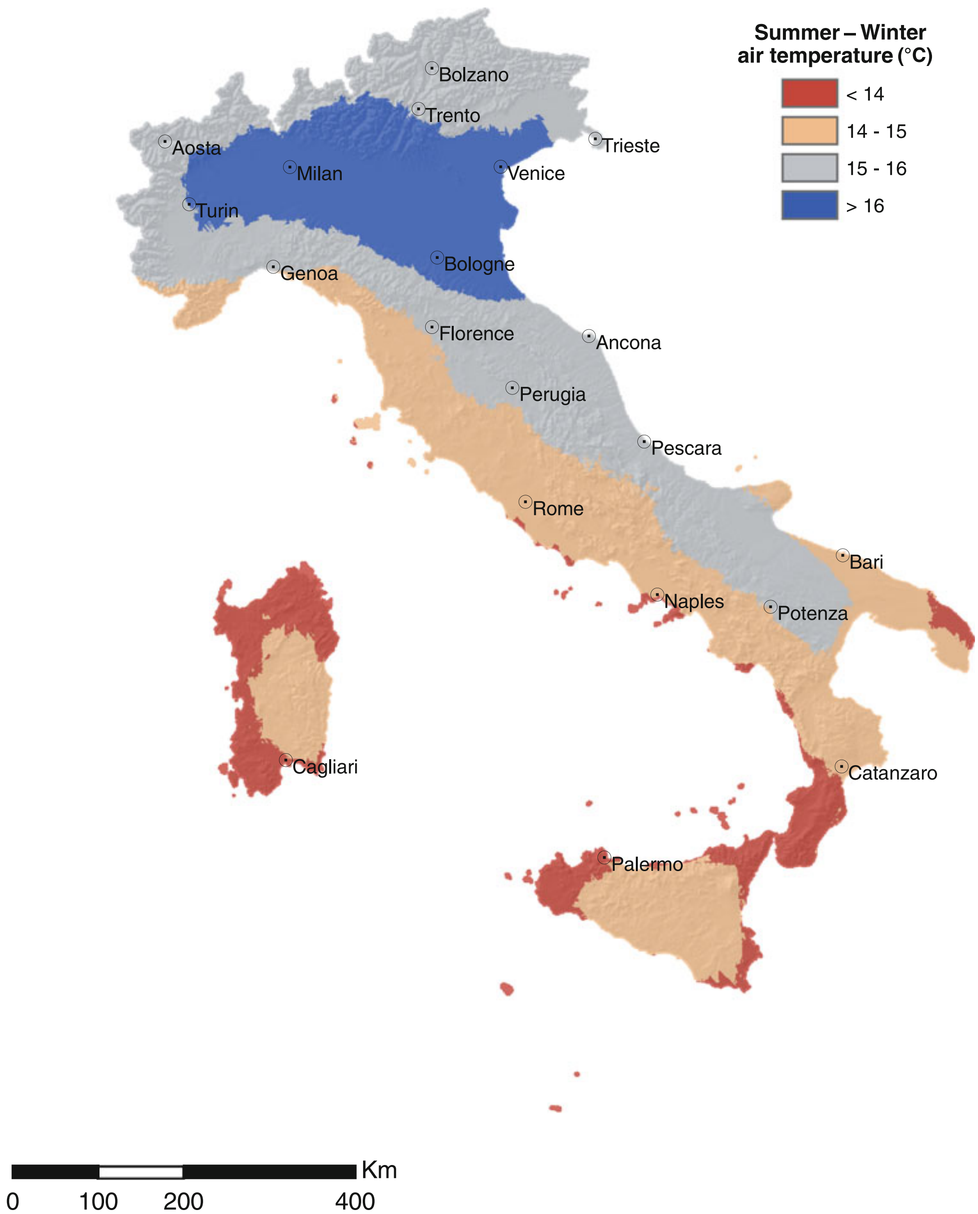


Fig. 2.4 Mean summer – winter air temperature (Continentality index) (1960–2008)

The average value of rainfall erosivity in Italy, expressed as Fournier index (Arnoldus 1977), highlights the high risk of erosion that threaten Italian soils (Table 2.1). The corresponding map (Fig. 2.6[7]) marks a distinction in the average values between the different parts of Italy, with a minimum of about 43 mm, in Apulia, and a maximum of more than 210 mm in Friuli, Tuscany, Campania and Calabria. The areas with the most concentrated precipitations partially coincide with the rainiest territories (Friuli, part of Lombardy and Piedmont, northern part of Tuscany), but they also extend to the coast of Liguria and the southern regions of Italy facing the Tyrrhenian Sea (Campania, Basilicata, Calabria). Other critical areas are located in Sicily, between the Etna Mountain and the Ionian Sea, and in eastern Sardinia, between the Gennargentu Mountain and the Tyrrhenian Sea. On the other hand, the plains and hills shadowed by mountain relieves against perturbations show the lowest long-term values of rainfall intensities (Po Plain, Apulia region, inner and southern parts of Sicily, southern Sardinia).

Precipitation seasonality, that is, the difference between the amount of long-term rainfall fallen in the most and in the least rainy months, proportioned to the total long-term annual rainfall, is on country average 11 % (Table 2.1). The index reflects the seasonality of the precipitations, which is another typical trait of Mediterranean climates. It is

[7] The ordinary kriging prediction map was obtained by interpolating the values of Fournier index of 1,546 meteorological stations. Differences between legend classes are larger than the standard errors.

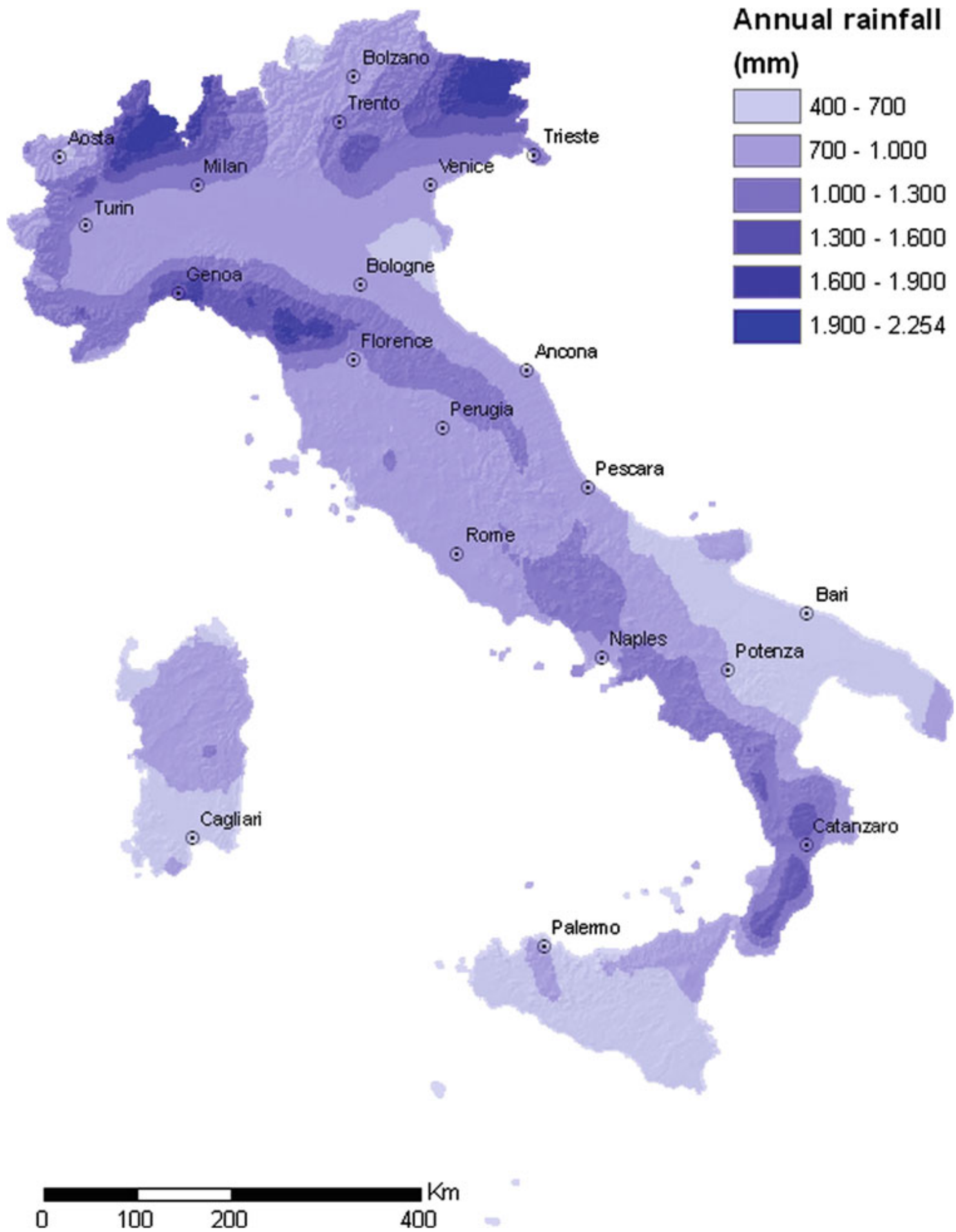


Fig. 2.5 Long-term mean annual rainfall (1960–2008)

worthwhile to compare the map in Fig. 2.7[8] with that of continentality (Fig. 2.4). As a rule, areas with the most characterized features of Mediterranean climate may have a precipitation seasonality more than double than those with more continental climates, which show a more regularly distributed precipitation pattern. The northern, innermost part of the Alps makes exception, but it must be stressed here that, contrary to Mediterranean types of climate, the highest rainfall falls during summertime (see for instance the meteorological station of Faloria, Fig. 2.13).

2.4 Potential Evapotranspiration and Aridity Index

Mean long-term country value of potential evapotranspiration (ETo, Penman Monteith, Allen et al. 1998) is 1,002 mm (Table 2.1), ranging from around the 600 mm in the Alps and the Northern Apennines to more than 1,300 mm of some parts of Apulia, Sicily and Sardinia

[8] The map was obtained by computation of raster datasets of mean summer, winter and annual precipitation. The rasters of mean summer and winter precipitation were the ordinary kriging prediction maps of 1,297 stations. Differences between legend classes are larger than the standard errors.

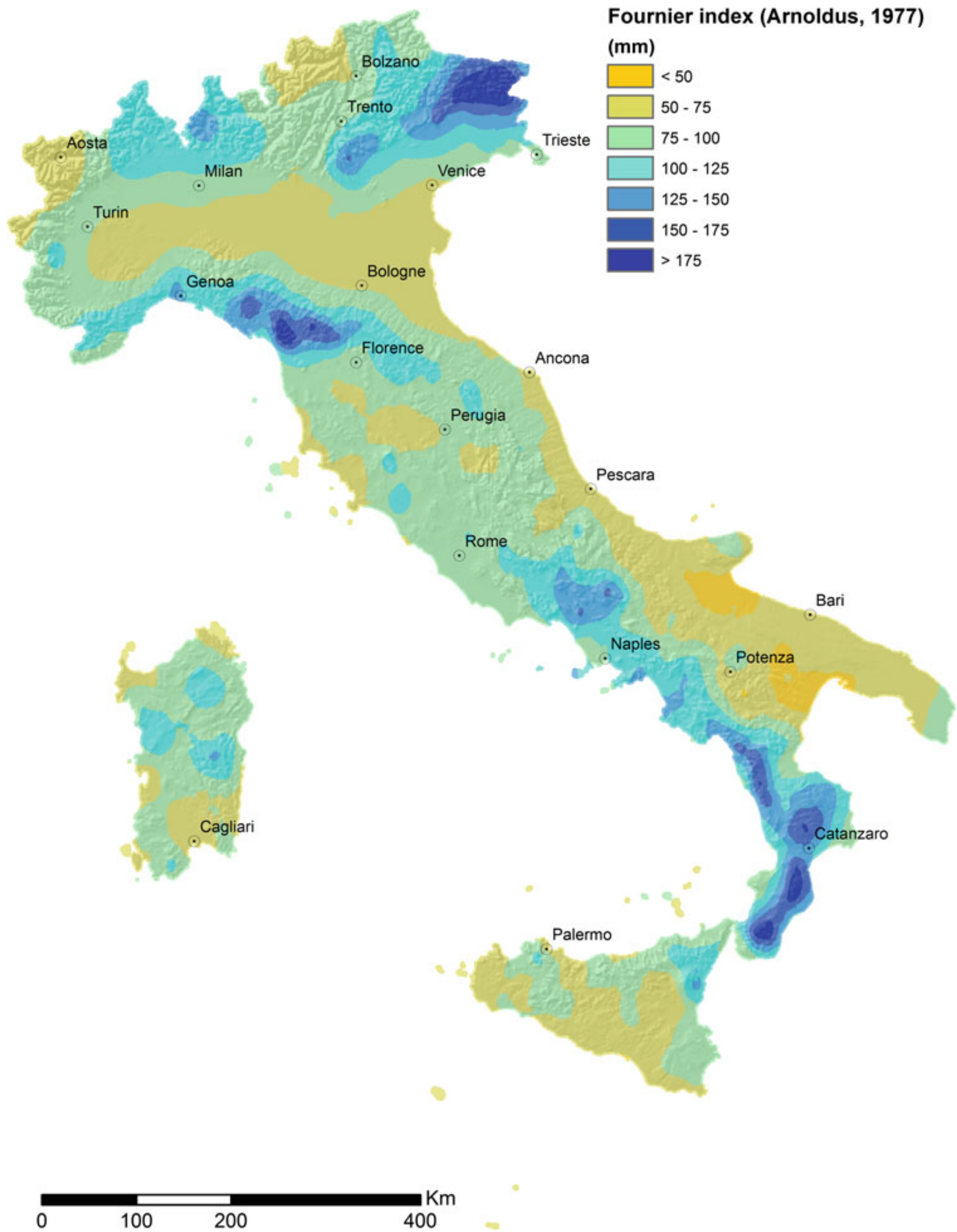


Fig. 2.6 Fournier index (1960–2008)

(Table 2.1 and Fig. 2.8[9]). Average values exceeding 1,000 mm are widespread in most parts of southern Italy and along the coasts of the Tyrrhenian Sea in central and northern Italy, up to the Liguria region.

Although the mean country value of annual precipitation is almost the same of potential evapotranspiration (Table 2.1), the climatic deficit, that is the ratio between rainfall and ETo (aridity index, UNEP 1992) less than one, dominates Italy (Fig. 2.9[10]). Lands where precipitation exceeds evapotranspiration are only located on the Alps, the northern part of the Po Plain and parts of the Apennines. On the other side, many territories of southern Italy are classified dry sub-humid or semiarid, especially in Sicily, Apulia, Sardinia and Basilicata.

[9] Mean values of 544 cells (ETo according to FAO Penman–Monteith; Perini et al. 2004). Differences between legend classes are larger than the standard errors.

[10] The map was obtained from the raster datasets of annual precipitation and potential evapotranspiration. Differences between legend classes are larger than the standard errors.

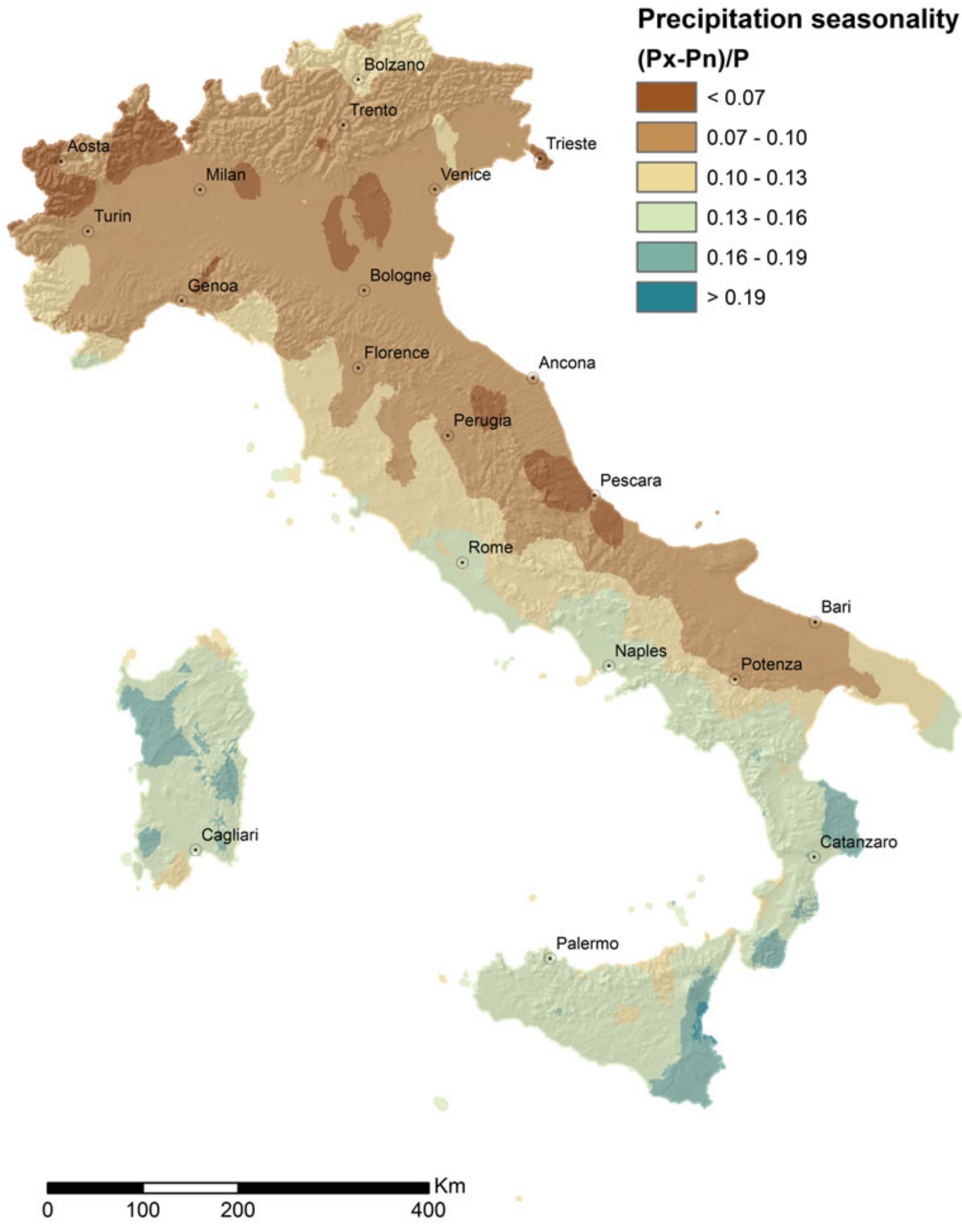


Fig. 2.7 Precipitation seasonality (1960–2008). Px is the precipitation of the rainiest month, Pn is the precipitation of the driest month, P is the annual precipitation

2.5 Climatic Regions of Italy

Following, as a reference, the climatic classification suggested in the georeferenced soil database for Europe[11] (Finke et al. 1998) and its most recent updating (Hartwich et al. 2006) in Italy there are 14 of the 35 climatic regions occurring in Europe. In particular, there are 4 of the 14 temperate climates and 10 out of the 11 Mediterranean climates[12] (Table 2.2, Fig. 2.10). Temperate climates dominate the Alps and the Northern Apennines; they are as follows:

T1-temperate continental climate influenced by mountains,
T2-temperate subcontinental influenced by mountains,
T3-temperate to warm temperate subcontinental, partly arid,
T4-temperate mountainous.

The T1 climate overlooks the highest mountains, and it is the coldest and least evapotranspirative environment (Table 2.2). Here, the snow cover distribution is a key

[11] The map of the "Soil Regions of the European Union and Adjacent Countries 1:5,000,000 (Version 2.0)" is published by the Federal Institute of Geosciences and Natural Resources (BGR), in partnership with the Joint Research Center (JRC, Ispra).

[12] The Mediterranean to warm temperate oceanic climate is present in Portugal but not in Italy.

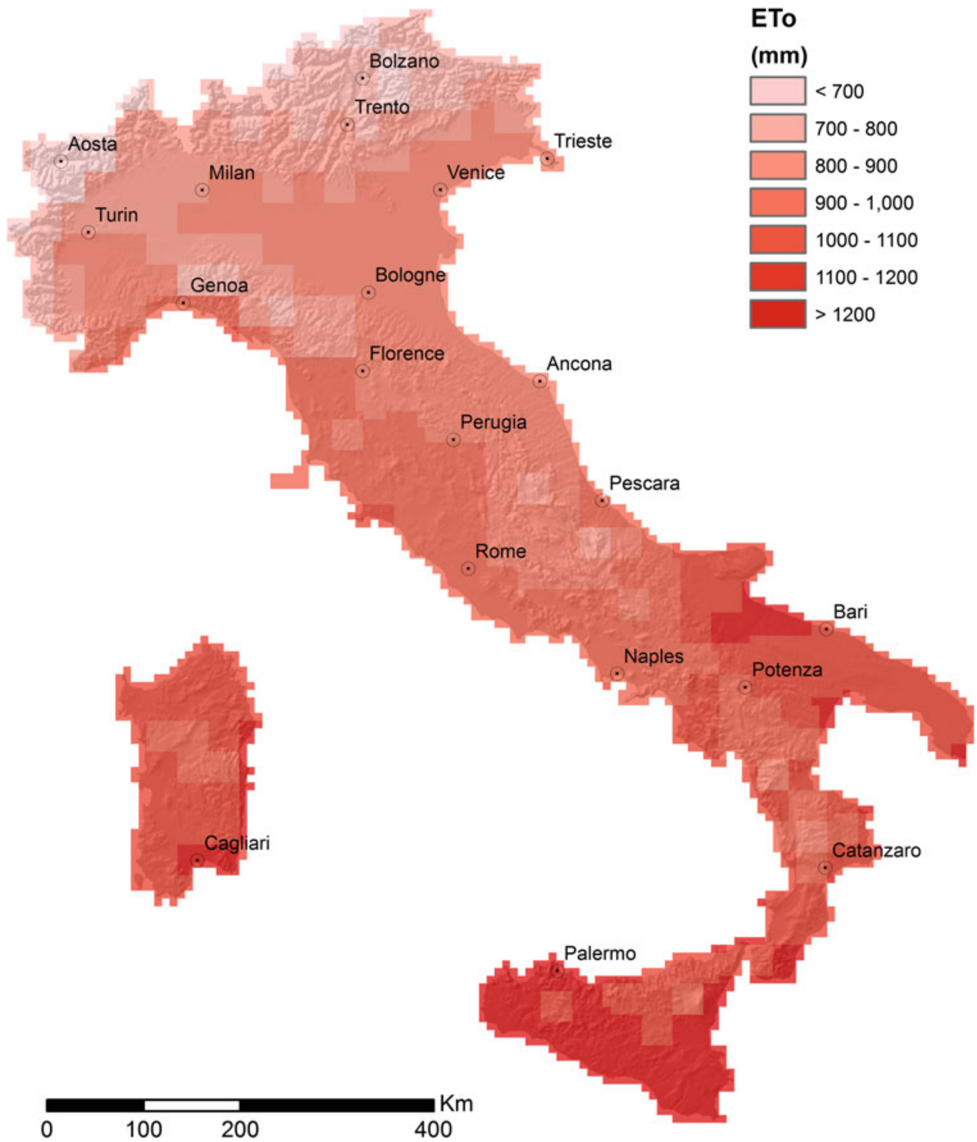


Fig. 2.8 Potential evapotranspiration (1961–1990)

factor, influencing, for example, the soil temperature (e.g., permafrost occurrence) and the soil water and nutrient availability. Most of Italian Cryosols can be found in this region. The T2 and T3 climates dominate lower elevations and have similar values of average temperature, degree of continentality and evapotranspirative demand, but are significantly different in terms of rainfall. Actually, soils located within the T3 climatic region receive average precipitations more than a third less than T2 (942 versus 1,356.2 mm) as a consequence of the more protected physiographic position. The different amount of water that can potentially percolate through the soil profile gives reason to the different distribution of typologies in these two climatic regions, in particular Podzols and Umbrisols.

The temperate mountainous climate (T4) is significantly warmer and moister than the others, in dependence of the exposition to the Atlantic as well as to the northern and eastern perturbations. This kind of climate can induce a large organic matter accumulation in soil, with the formation of Umbrisols and Phaeozems.

The intermediate Mediterranean to warm temperate climates, suboceanic (TM1) or mountainous (TM4) are actually widespread in the mountainous lands of both the Alps and the Apennines. They are much warmer than the previous ones, which motivates their intermediate Mediterranean classification, with different amounts of rainfall, significantly higher in the suboceanic climate. Cambisols are the dominant kind of soils, but at the highest elevations of TM1, Podzols are widespread. The other two intermediate climates, that is, Mediterranean suboceanic to subcontinental (TM2 and TM3) typify Po Plain and adjacent low hills. They are relatively warmer than the other climates of northern Italy, with a characteristic degree of continentality, that is, a rather high temperature difference between

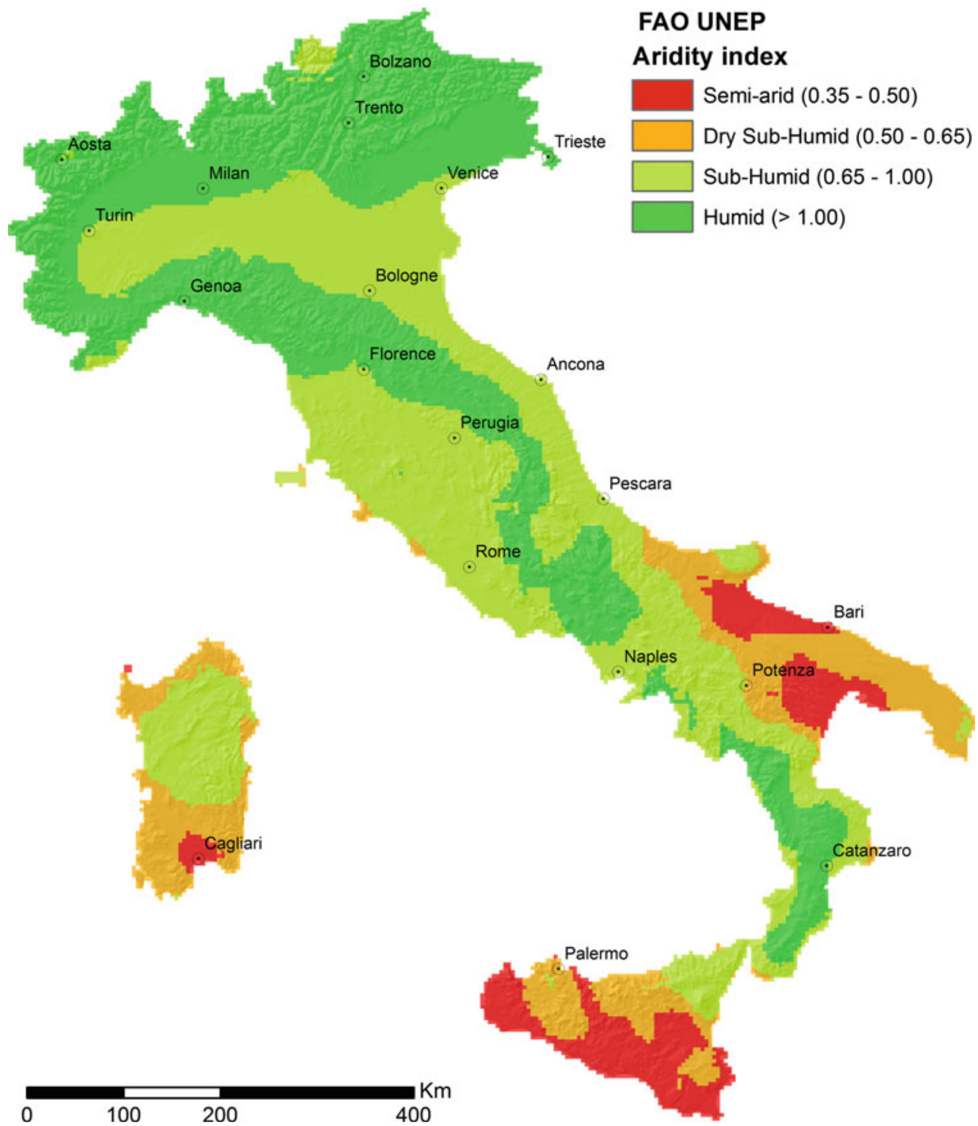


Fig. 2.9 Aridity index (precipitation/potential evapotranspiration, 1960–2008)

summer and winter and a quite regular precipitation pattern. Continentality influences markedly the vegetation, limiting the presence of olive tree and other Mediterranean species like cypresses (Cupressus sempervirens), bay laurel (Laurus nobilis) and Holm oak (Quercus ilex) and favors the accumulation of calcium carbonate in the subsurface horizons of soils formed on calcareous sediments. The relatively warm temperature and the rainfall pattern enhance weathering of the soil parent materials; therefore, on stable morphological positions, neogenetic clay can accumulate in depth and Luvisols dominate the soilscape.

Among the Mediterranean types of climate, two of them, namely M1 and M2, have suboceanic traits, that is, they are relatively more humid and have less evapotranspirative demand than the other Mediterranean ones. They are widespread all along the hills of the peninsula. More precisely, they are more frequent in central Italy, while they progressively shrink within the lands far from the sea in southern Italy and in the heart of the main islands, giving progressive way to the more characterized Mediterranean climates. The two climates are different in terms of degree of continentality, having M1 a significantly larger seasonal difference between mean temperatures, which induces the formation of Calcisols and Luvisols, when the other factors of soil formation are favorable. The M2 type of climate, instead, is more appropriate for the formation and preservation of Andosols on the widespread volcanic sediments.

A large part of the soils in the Southern Apennines have a so-called Mediterranean mountainous climate (M3), where Mediterranean traits of climate, like warm but seasonally contrasted temperatures, little continentality and large variability in winter precipitations, are counteracted by the relatively high amount of total rainfall and evapotranspirative demand, which vary markedly according to

Table 2.2 Descriptive statistics of the climatic regions of Italy

Variable	Temperature (°C)		Continentality index (°C)		Precipitation (mm)		Potential evapotranspiration (mm)	
Climatic region	mean	std	mean	std	mean	std	mean	std
T1 Temperate continental, influenced by mountains	1.6	2.5	15.6	0.2	925.5	145.6	716.3	38.8
T2 Temperate subcontinental, influenced by mountains	5.7	2.6	15.7	0.3	1356.2	149.8	774.1	61.2
T3 Temperate to warm temperate subcontinental, partly arid	6.9	2.4	15.7	0.4	942.0	111.8	772.8	62.7
T4 Temperate mountainous	9.0	2.6	15.6	0.3	1856.1	163.9	846.6	48.1
TM1 Mediterranean to warm temperate, suboceanic	11.3	1.7	15.6	0.4	1387.9	139.1	882.6	62.4
TM2 Mediterranean suboceanic to subcontinental, influenced by mountains	12.4	1.2	16.0	0.2	1066.1	105.3	899.6	37.0
TM3 Mediterranean suboceanic to subcontinental	13.5	0.5	16.4	0.3	800.5	74.1	921.3	23.9
TM4 Mediterranean to warm temperate mountainous	11.4	2.0	15.1	0.3	983.1	106.2	954.7	46.4
M1 Mediterranean suboceanic	13.5	1.4	15.2	0.2	840.9	90.5	1012.0	47.2
M2 Mediterranean suboceanic, influenced by mountains	13.9	1.6	14.5	0.2	870.8	91.0	1069.0	38.3
M3 Mediterranean mountainous	13.6	2.2	14.3	0.3	1205.7	130.5	1072.4	63.3
M4 Mediterranean subcontinental to continental, partly semiarid to arid	15.0	1.2	15.1	0.3	603.9	66.6	1155.4	43.4
MST1 Mediterranean to subtropical, influenced by mountains	15.5	1.2	13.9	0.3	811.3	110.4	1140.6	40.7
MST2 Mediterranean to subtropical, partly semiarid	16.7	1.0	14.2	0.3	606.6	66.8	1210.6	41.7

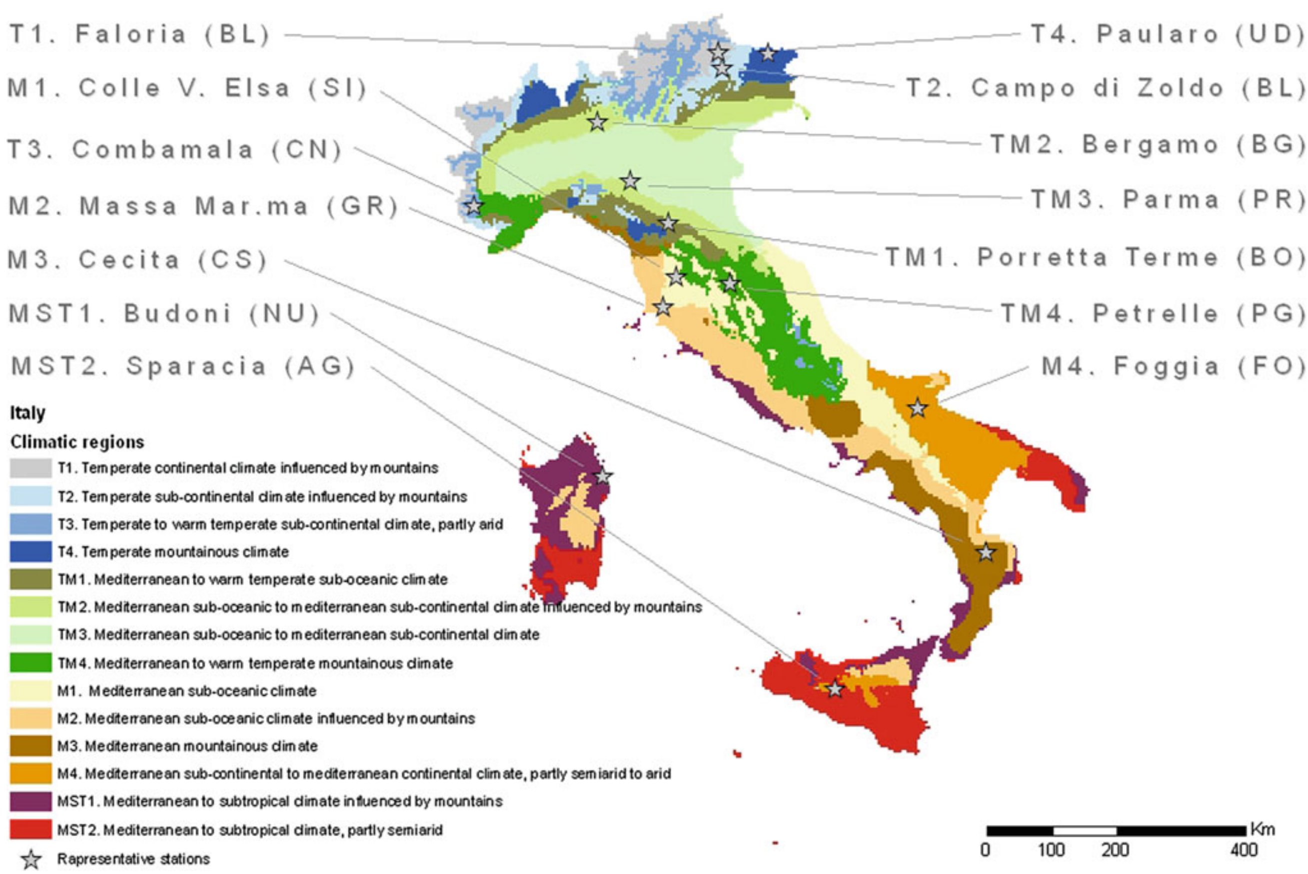


Fig. 2.10 Climatic regions of Italy and representative meteorological stations

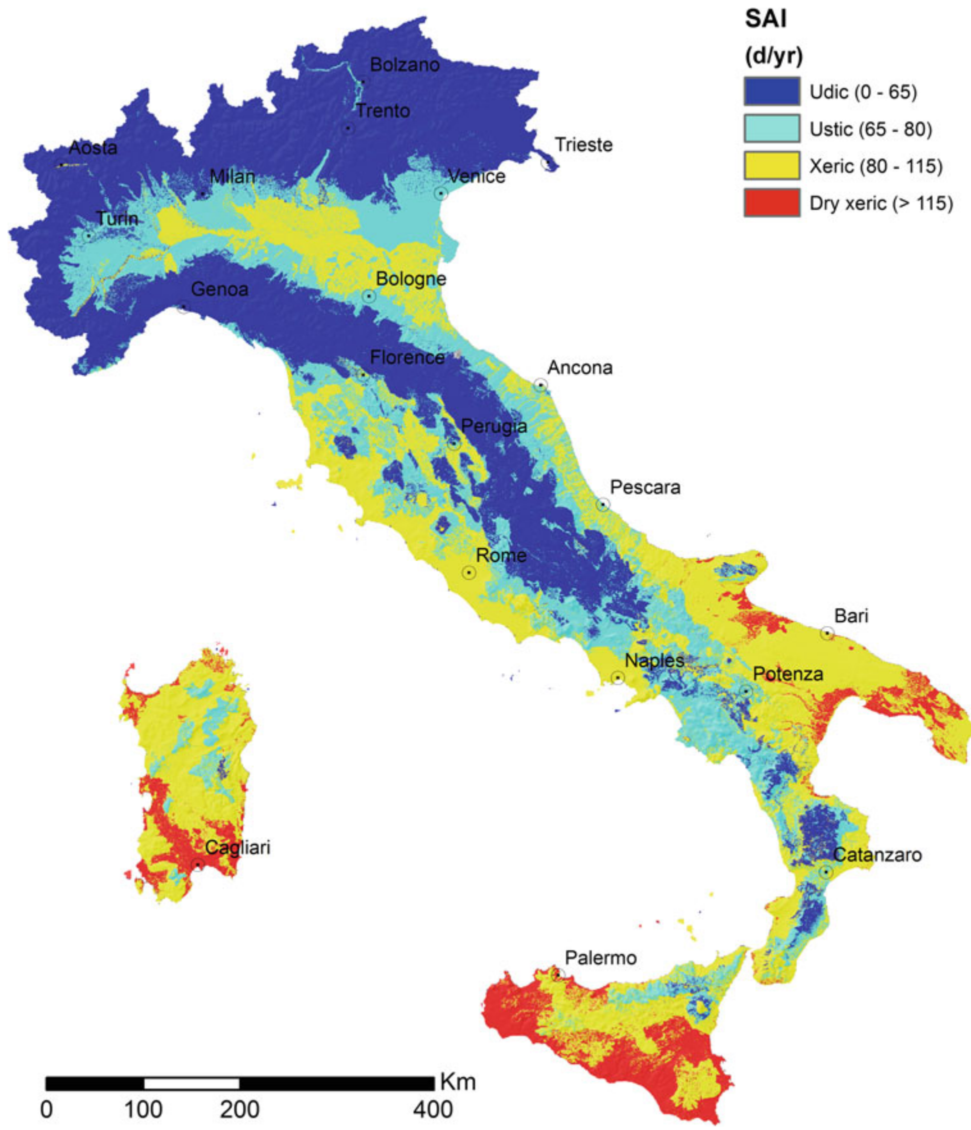


Fig. 2.11 Soil moisture regime and soil aridity index (Costantini et al. 2001)

elevation. On the highland, in particular, climatic conditions allow the formation and persistence of andic as well as umbric soil properties.

The Mediterranean subcontinental to Mediterranean continental climate, partly semiarid to arid (M4), characterizes large parts of the low hills and plains of the Apulia and Basilicata regions and some internal hills of Sicily. This climatic region, along with the two having intermediate Mediterranean to subtropical characteristics, are those where the most prominent traits of mediterraneity are emphasized by natural and cultivated vegetation. In addition to the plants of the Mediterranean macchia, the dwarf palm and prickly pear are endemic on well-drained soils. Among cultivated plants, the characteristic citrus fruit cultivation is present in irrigated lands. Evapotranspiration here is high, as well as continentality, while precipitation is low, so that most lands are affected by aridity. Salt accumulation in soils, in particular calcium carbonate, can be favoured by the limited leaching, and Calcisols development is favoured. In addition, the pronounced seasonal contrast supports the widespread formation of either Vertisols, on fine sediments and lowlands, or Chromic and Rhodic Cambisols and Luvisols, on better drained rocks and morphological positions (Mediterranean "Terra rossa" soils).

The last two climatic regions belong to the Mediterranean to subtropical climates, either partly semiarid (MST2) or influenced by mountains (MST1). Both are characterized by rather elevated air temperatures, with low seasonal differences and a high evapotranspirative deficit, notably larger in the semiarid climate. Pedogenesis here is slow, and soil either on instable morphological positions, or deeply affected by man-driven erosion, are often shallow and

Fig. 2.12 Soil temperature regimes according to Soil Taxonomy

poorly developed, so that they frequently belong to the classes of Regosols and Leptosols. On the other hand, on stable and preserved surfaces, the accumulation of organic matter and the formation of Chernozems and Kastanozems are favoured (Mediterranean "steppe").

2.6 Pedoclimate

To estimate the soil moisture regime according to Soil Taxonomy (Soil Survey Staff 1999), we calculated the soil aridity index (SAI), that is, the average number of days per year when the soil moisture control section[13] is dry (Costantini et al. 2002, 2005; Costantini and L'Abate 2009). The SAI can be used for the classification of the soil moisture regime, as well as to single out areas with a diverse degree of desertification risk (Costantini et al. 2009).

The average number of dry days in Italy ranges conspicuously, from nil to almost 5 cumulative months, in the driest xeric conditions (Table 2.1). Figure 2.11 shows that the ustic soil moisture regime is the relatively most widespread udometric regime, being present both in the Mediterranean and in the intermediate Mediterranean to temperate climatic regions. While the udic regime dominates the Alps and the Apennines chains, xeric and dry xeric

[13] The soil moisture control section makes reference to the upper part of the soil, where roots of herbaceous species concentrate. SAI (days/year) = 44.532605 + [mean annual air temperature] × 7.310365 − [rainfall] × 0.061497 − [cumulative available water up to 50 cm, in mm] × 0.229448.

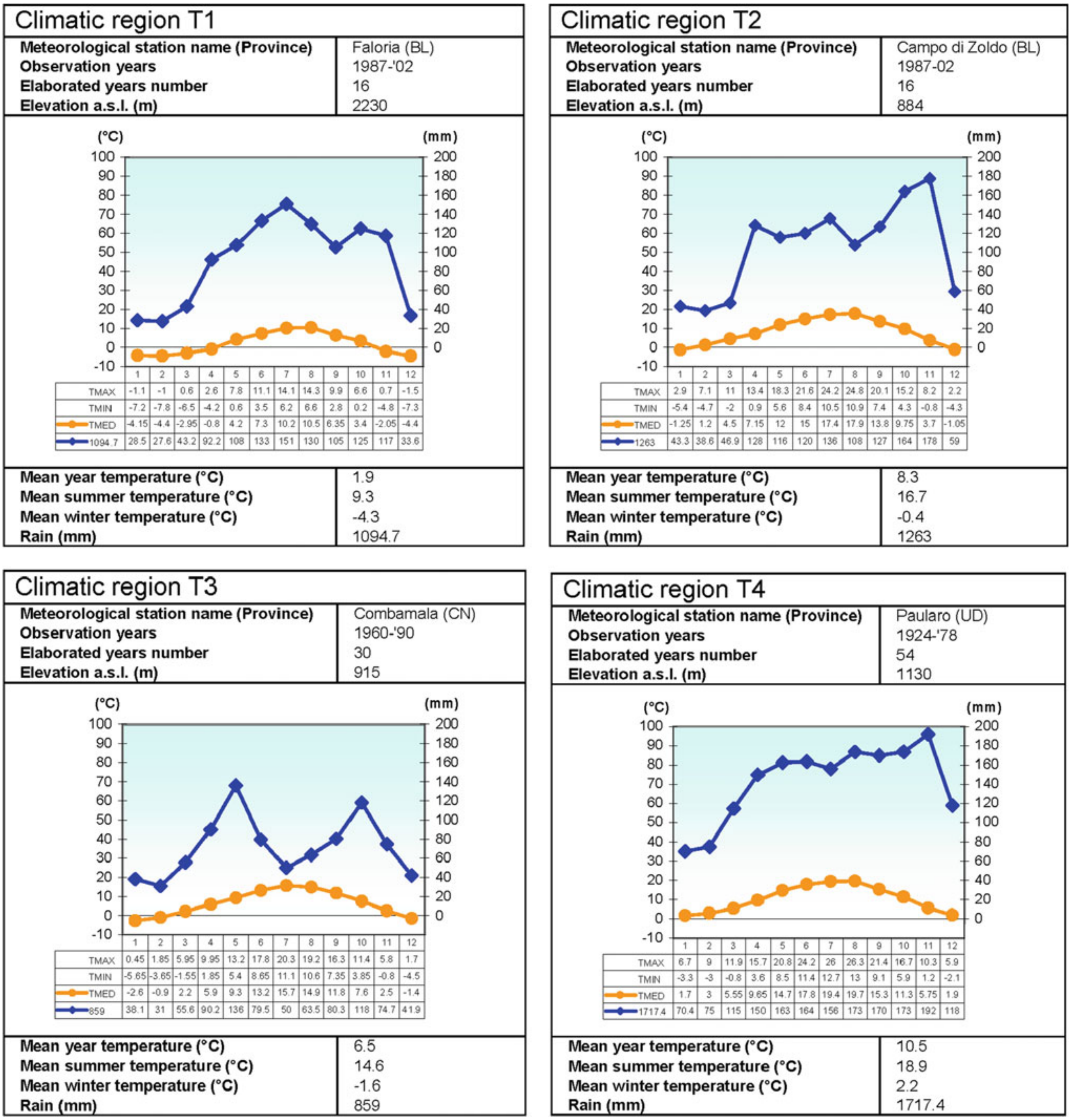


Fig. 2.13 Representative meteorological stations for the temperate climates of Italy

are well correlated with lands with the highest aridity. It is interesting to note that soils with xeric moisture regime are also present in the Po Plain and in central Italy.

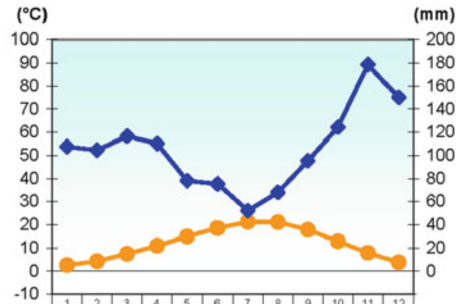
As for soil temperature regime classification (Soil Survey Staff 1999), that is, average soil temperature at 50 cm (MST),[14] the mesic soil temperature regime dominates most part of the country (Table 2.1). The thermic regime dominates southern Italy, but is also frequent in the central part of the country and even in northern Italy. The map reported in Fig. 2.12[15] highlights the occurrence of the frigid and cryic

[14] Soil temperature was calculated in function of the mean annual air temperature and soil water content at field capacity (see note 15).

[15] The map was obtained from raster datasets of field capacity (FC) at 50 cm depth (not shown in this atlas) and long-term mean annual air temperatures. The first raster was obtained by geographical join of FC values of 18,449 soil sites to land components (features belonging to

Climatic region TM1

Meteorological station name (Province)	Porretta Terme (BO)
Observation years	1956-'84
Elaborated years number	28
Elevation a.s.l. (m)	349

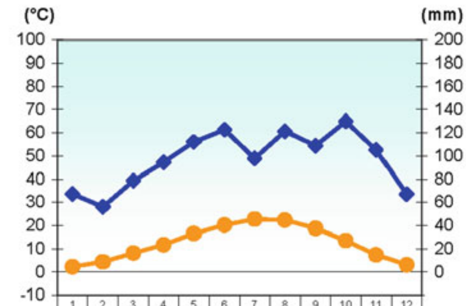


	1	2	3	4	5	6	7	8	9	10	11	12
TMAX	7.4	9.5	13.1	17	21.7	25.6	28.9	28.7	24.6	18.8	12.8	8.4
TMIN	-2.1	-0.8	1.9	4.9	8.2	11.6	13.6	13.6	11.1	7	3.1	-0.7
TMED	2.65	4.35	7.5	11	15	18.6	21.3	21.2	17.9	12.9	7.95	3.85
1261.2	108	105	117	110	78.1	75.4	52.1	68	95.5	124	179	150

Mean year temperature (°C)	12.0
Mean summer temperature (°C)	20.3
Mean winter temperature (°C)	3.6
Rain (mm)	1261.2

Climatic region TM2

Meteorological station name (Province)	Bergamo (BG)
Observation years	1958-'01
Elaborated years number	44
Elevation a.s.l. (m)	266

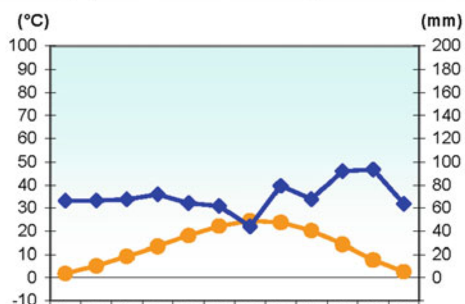


	1	2	3	4	5	6	7	8	9	10	11	12
TMAX	6	8.6	12.9	16.7	21.8	25.7	28.3	27.7	23.8	17.9	11	6.7
TMIN	-1.5	0.2	3.5	6.8	11.4	14.8	17.3	17.1	13.8	9.3	3.8	-0.5
TMED	2.25	4.4	8.2	11.8	16.6	20.3	22.8	22.4	18.8	13.6	7.4	3.1
1161.8	67.3	56.2	78.8	94.5	112	123	97.9	121	109	130	105	67

Mean year temperature (°C)	12.6
Mean summer temperature (°C)	21.8
Mean winter temperature (°C)	3.3
Rain (mm)	1161.8

Climatic region TM3

Meteorological station name (Province)	Parma (PR)
Observation years	1961-'80
Elaborated years number	20
Elevation a.s.l. (m)	56

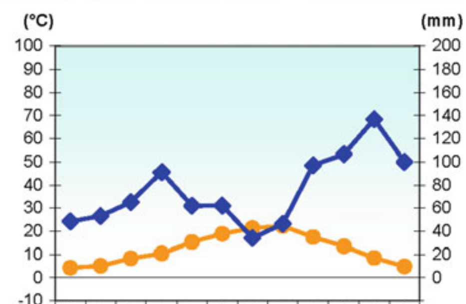


	1	2	3	4	5	6	7	8	9	10	11	12
TMAX	4.6	8.8	14	18.8	23.9	28.3	30.6	29.6	25.5	18.7	10.6	5.3
TMIN	-1	1.5	4.6	8.2	12.3	16.1	18.4	17.9	14.9	10	4.8	-0.1
TMED	1.8	5.15	9.3	13.5	18.1	22.2	24.5	23.8	20.2	14.4	7.7	2.6
839.4	66.5	66.5	67.6	72	64.3	61.8	44.1	79.4	67.8	92.2	93.5	63.7

Mean year temperature (°C)	13.6
Mean summer temperature (°C)	23.5
Mean winter temperature (°C)	3.2
Rain (mm)	839.4

Climatic region TM4

Meteorological station name (Province)	Petrelle (PG)
Observation years	1991-'02
Elaborated years number	12
Elevation a.s.l. (m)	362



	1	2	3	4	5	6	7	8	9	10	11	12
TMAX	8.7	10.8	14.5	16.4	22.1	26.2	29.2	30.4	24.2	19.1	12.9	8.8
TMIN	-0.1	-0.5	2.2	4.4	8.6	11.5	13.5	14.1	10.7	8	4.2	0.9
TMED	4.3	5.15	8.35	10.4	15.4	18.9	21.4	22.3	17.5	13.6	8.55	4.85
903.1	48.4	53.2	65.2	91.2	62	62.2	34.1	46.3	97.2	107	137	99.9

Mean year temperature (°C)	12.5
Mean summer temperature (°C)	20.8
Mean winter temperature (°C)	4.8
Rain (mm)	903.1

Fig. 2.14 Representative meteorological stations for the intermediate Mediterranean to temperate climates of Italy

regimes in a large area of the Alps. In the Apennines, however, it could be underestimated, because of the scarcity of both meteorological and pedological data.

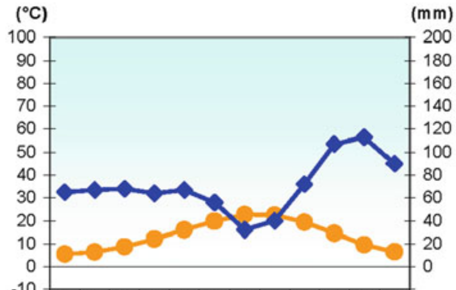
(Footnote 15 continued)
different soil region and with different lithology, land use and physiography) obtained from a 500 m grid and other databases. MST = [mean annual air temperature] + (([FC] × 100) − 20.7)/7.9. Frigid–cryic regime makes reference to both annual and summer mean air temperatures.

2.7 Characteristics Ombrothermic Diagrams

The long-term temperature and precipitation trends of some meteorological stations, selected as a reference of the different climatic regions of Italy, are illustrated in the following figures (Figs. 2.13, 2.14, 2.15, 2.16) (see Fig. 2.10 for their placement).

Climatic region M1

Meteorological station name (Province)	Colle V. Elsa (SI)
Observation years	1951-'89
Elaborated years number	39
Elevation a.s.l. (m)	235

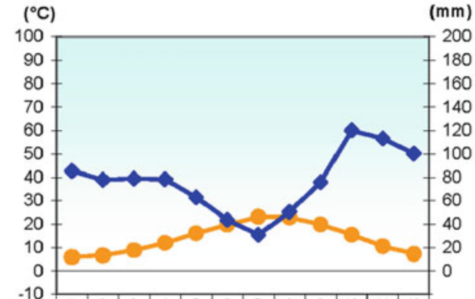


	1	2	3	4	5	6	7	8	9	10	11	12
TMAX	10.5	11.8	14.5	18.4	22.8	26.9	30.4	30.2	26.4	20.7	14.9	11.2
TMIN	0.6	1.1	3	5.7	9.2	12.7	14.9	14.8	12.4	8.3	4.4	1.8
TMED	5.55	6.45	8.75	12.1	16	19.8	22.7	22.5	19.4	14.5	9.65	6.5
841	65	67	68	64	67	56	32	40	72	107	113	90

Mean year temperature (°C)	13.7
Mean summer temperature (°C)	21.7
Mean winter temperature (°C)	6.2
Rain (mm)	841

Climatic region M2

Meteorological station name (Province)	Massa Mar.ma (GR)
Observation years	1951-93
Elaborated years number	42
Elevation a.s.l. (m)	370

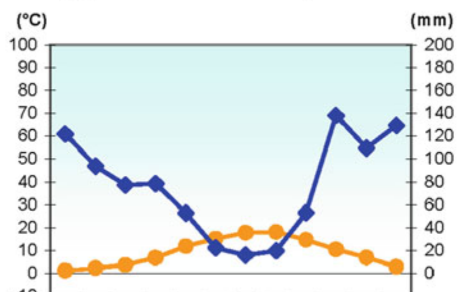


	1	2	3	4	5	6	7	8	9	10	11	12
TMAX	9.8	10.8	13.5	17	21.6	25.6	29.2	28.9	25.5	20.2	14.6	11.1
TMIN	2	2.5	4.2	7	10.7	14	17.1	17	14.4	10.8	6.5	3.5
TMED	5.9	6.65	8.85	12	16.2	19.8	23.2	23	20	15.5	10.6	7.3
918.4	85.4	78	79	78.3	62.9	43.7	31	50.4	76	120	113	100

Mean year temperature (°C)	14.1
Mean summer temperature (°C)	22.0
Mean winter temperature (°C)	6.6
Rain (mm)	918.4

Climatic region M3

Meteorological station name (Province)	Cecita (CS)
Observation years	1955-'70
Elaborated years number	15
Elevation a.s.l. (m)	1180

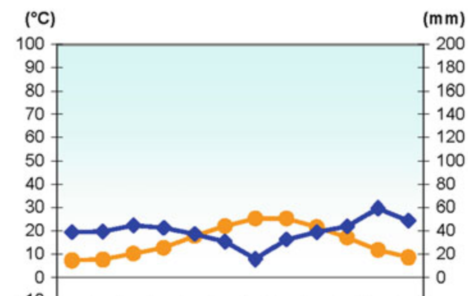


	1	2	3	4	5	6	7	8	9	10	11	12
TMAX	4.6	6.5	7.8	11.6	17.6	21.4	24.9	25.3	20.8	15.6	11	6
TMIN	-2	-1.7	-0.3	2.2	6.2	9.1	10.8	11.1	8.7	5.4	2.9	0
TMED	1.3	2.4	3.75	6.9	11.9	15.3	17.9	18.2	14.8	10.5	6.95	3
912.4	122	93.9	77.4	78.6	52.7	22.2	16	19.8	53	138	110	130

Mean year temperature (°C)	9.4
Mean summer temperature (°C)	17.1
Mean winter temperature (°C)	2.2
Rain (mm)	912.4

Climatic region M4

Meteorological station name (Province)	Foggia (FG)
Observation years	1977-1997
Elaborated years number	21
Elevation a.s.l. (m)	70



	1	2	3	4	5	6	7	8	9	10	11	12
TMAX	11.4	12.3	15.5	18.5	24.2	28.9	32.2	31.9	27.6	22.3	16	12.6
TMIN	3.2	3	4.7	6.8	11.4	15.3	18.5	18.8	15.7	11.9	7.4	4.6
TMED	7.3	7.65	10.1	12.7	17.8	22.1	25.4	25.4	21.7	17.1	11.7	8.6
472.5	39	39.4	44.8	42.6	37.2	30.6	15.7	32.4	38.9	43.9	59.3	48.7

Mean year temperature (°C)	15.6
Mean summer temperature (°C)	24.3
Mean winter temperature (°C)	7.9
Rain (mm)	472.5

Fig. 2.15 Representative meteorological stations for the Mediterranean climates of Italy

2.8 Climate Change and Soil

The World Meteorological Organisation has defined as the "norm" of a climatic variable the calculated average value for a uniform period of three consecutive decades (World Meteorological Organization, 1984, 1989). The climatic thirty years 1961–1990 have been used as a reference for many climatology studies (Beltrano et al. 2007). According to Vento (2004), a general climatic change occurred in Italy in the period 1961–2000, with a general reduction in mean annual precipitation and the number of rainy days, and a

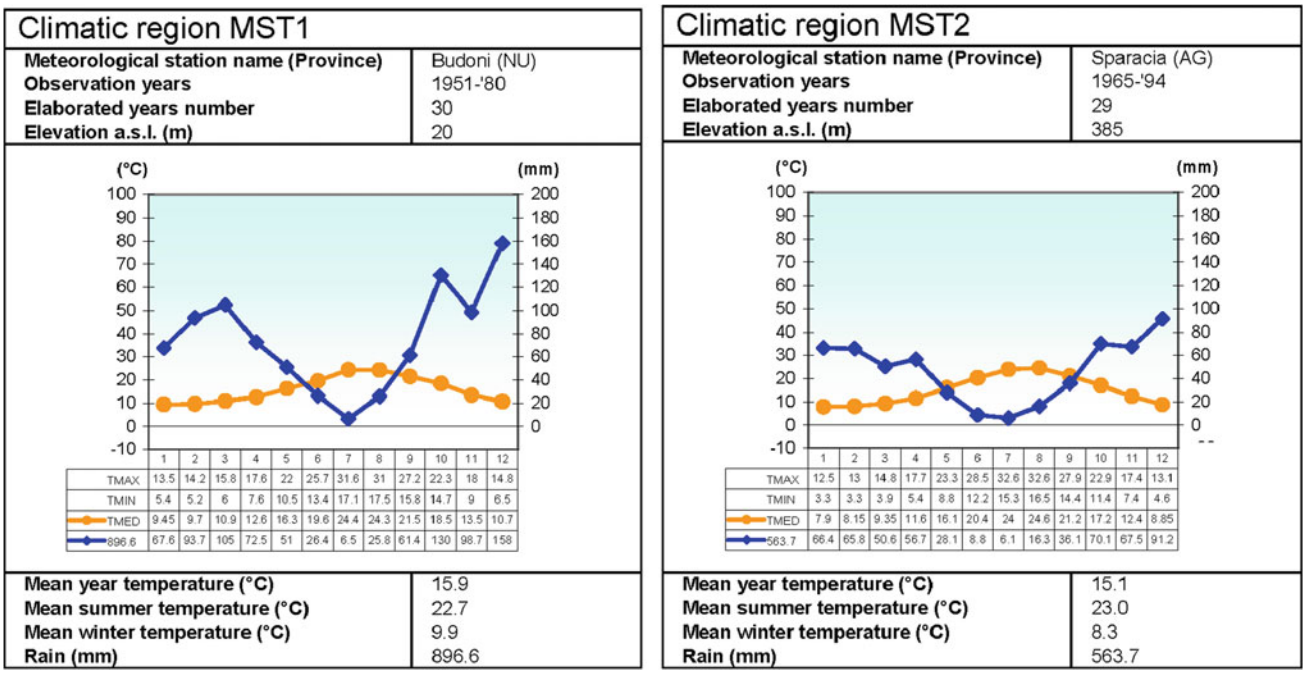


Fig. 2.16 Representative meteorological stations for the intermediate Mediterranean to subtropical climates of Italy

Table 2.3 Mean annual air temperature and annual precipitation in Italy before and after the year 1990 (significance of the difference between the means checked with the Student's statistical t-test at the $P < 0.01$ level)

	1978–1990	1991–2006
	Mean	Mean
MAT °C	13.02 B	13.72 A
MAP mm/year	811.56 A	722.66 B

Elaboration conducted on the national meteorological grid (Perini et al. 2004)

general increase in mean air temperatures. Regional studies confirmed this trend with some local exceptions (Cacciamani et al. 2001; Buffoni et al. 2003; Brunetti et al. 2004; Maugeri et al. 2004; Genesio et al. 2006; Barbi et al. 2007).

Fantappiè and collaborators (Fantappiè et al. 2010, 2011), who investigating the soil organic carbon stock variations in Italy during the last three decades, also found a significant increase in mean air temperature (MAT), which was 13.02 °C in the time frame 1978–1990 but reached 13.72 °C between 1991 and 2006 (Table 2.3[16]). Mean annual precipitations (MAP) significantly decreased from 811.56 to 722.66 mm/year. Figures 2.17 and 2.18 describe

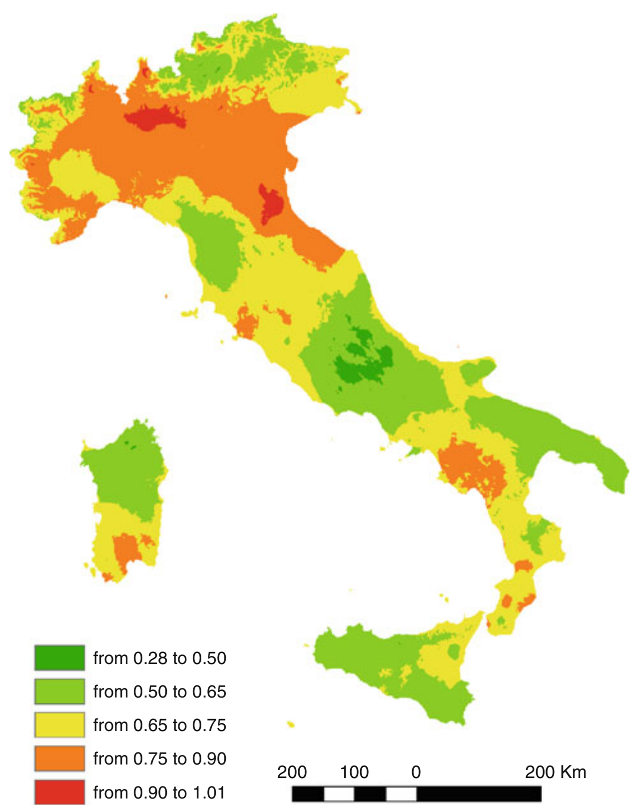


Fig. 2.17 Mean annual air temperatures variations (°C) in Italy from 1978 to 1990 and from 1991 to 2006 years. Differences between legend classes are larger than standard errors

[16] Elaboration conducted on the national meteorological grid (Perini et al. 2004).

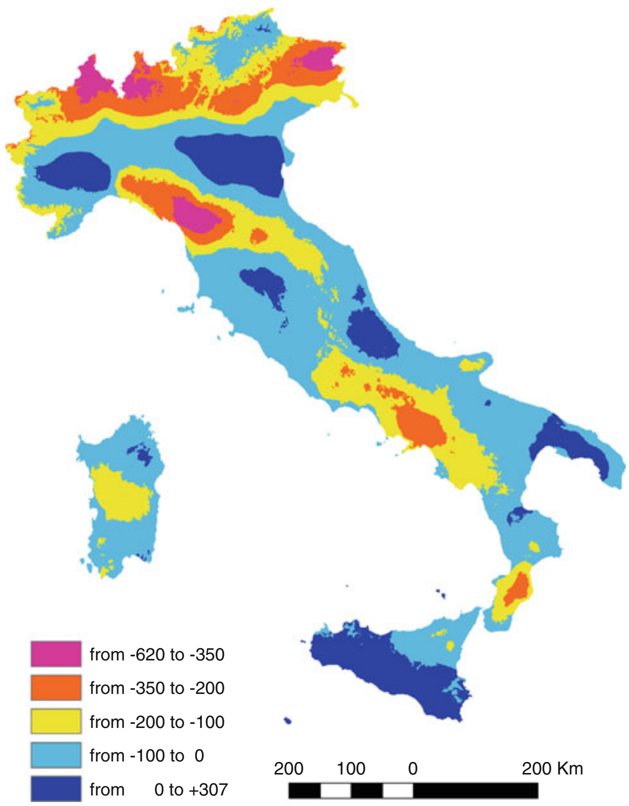


Fig. 2.18 Mean annual precipitations variations (mm y^{-1}) in Italy from 1978 to 1990 and from 1991 to 2006 years. Differences between legend classes are larger than standard errors

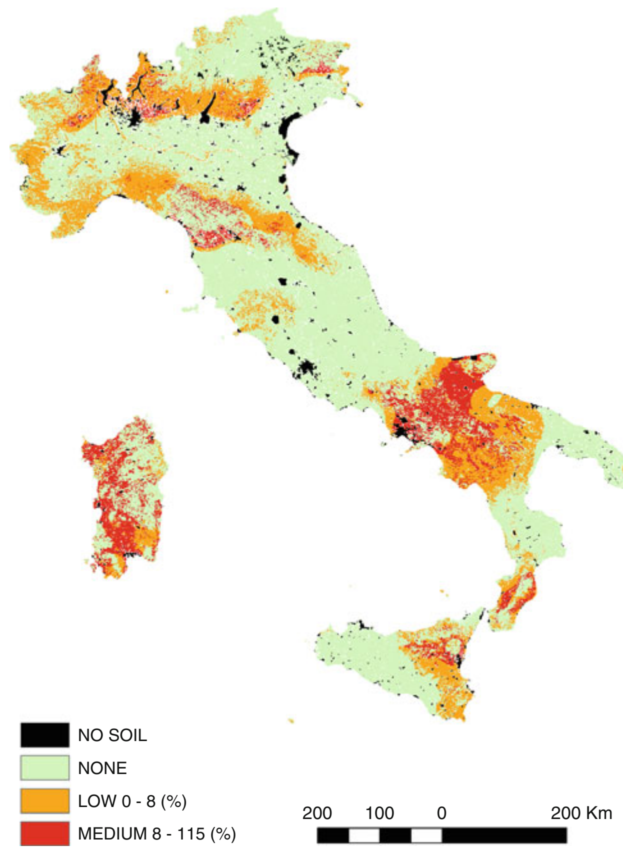


Fig. 2.19 Index of climate change influence (%) on SOC content variations between the years 1978–1990 and 1991–2006. Differences between legend classes are larger than standard errors

the spatial pattern of variations. Figure 2.17 highlights that temperature increased especially at lower altitudes and higher latitudes. In particular, the Po Plain showed the highest MAT increases, whereas some parts of central Italy (Abruzzo and Lazio regions) the lowest. MAP generally decreased between the two reference periods all over the country, with the exception of southern Sicily and of some limited areas of southern and northern Italy (Fig. 2.18). The most prominent decreases were localized in different parts of the country (the Alps, the Apuan Alps, the Tosco-Emilian Apennines, Campania and Calabria regions).

Organic carbon content (SOC) is a soil property that can be affected by climate change (Siegenthaler et al. 2006). The mentioned authors (Fantappiè et al. 2011) found that the observed climate change which occurred between the two periods had a general low influence on SOC variations (Fig. 2.19). Nevertheless, the relatively higher climatic influence occurred in meadows and in arable lands with a moderate or high MAP decrease (<-100 mm/y) and a moderate to high MAT increase (>0.62 °C). The decreasing SOC content of lands with increasing hot and arid climate could be a soil indicator of the consequences of the extension of the Mediterranean subtropical climatic regions in Italy.

A reduction in snow cover associated with global warming may be another important effect of climate change on areas at higher elevation, in particular in the montane belt. As warming progresses in the future, regions where snowfall is the current norm will increasingly experience precipitation in the form of rain. Deep persistent snow cover may keep the soil free of frost throughout the winter, while shallow, ephemeral snow packs tend to promote soil freezing, with important consequences on soil nutrient dynamics (e.g., increase in N losses) (Edwards et al. 2007; Freppaz et al. 2007, 2008; Filippa et al. 2009).

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3 Geology and Geomorphology

Claudio Bini

3.1 Introduction: An Overview on the Geological, Morphological and Lithological Outlines of Italy

Italy is a geologically young land, with contrasting relief energy and a great variety of lithological types and landscapes. The fundamental outlines of the Italian orography are essentially the result of crustal deformations induced by orogenetic forces that gave origin primarily to the two mountain structures which constitute the present skeleton of the Italian peninsula: the Alps and the Apennines. Yet, the compression of the sedimentary basin (the mythic Thetis) located between the European and the African plates, originated two of the most impressive mountain ranges of Europe, culminating with the Monte Bianco (elevation 4810 m asl). The evolution of the two chains occurred in the frame of the last orogenetic cycle (Cretaceous–Eocene for the Alps and Oligocene–Miocene for the Apennines), whose tectonic deformations, superimposed over rocks and structures from previous orogenetic cycles, gave rise to imposing landscapes reflecting a complicated geological history (Carnicelli and Costantini, this volume).

Of relevant importance is also the spatial disposition of the Alps and Apennines. While the Alpine chain extends substantially 600 km along a west-to-east arc (approximately 8° in longitude), the Apennines stretch for 1,140 km in the peninsular land (approximately 11° in latitude), over a narrow space, at some places reduced to a little more than 100 km between the Tyrrhenian and the Adriatic Seas. The strong territory elongation has an evident climatic importance: while part of the country falls at mean latitude (latitude 45° N in the Po plain), the northern regions are contiguous to the meso- and microthermic regions of Northern Europe and the southern regions are close to subtropical Africa (Costantini et al., this volume).

The high variability of landforms of Italy, within a relatively restricted area, is a consequence of the extremely variable lithological composition (Canuti 1982) and of the complicated events of past and recent geological history (Fig. 3.1).

All these factors have left a profound imprinting in the surface morphology, due to the morphogenetic activity of erosion agents. Indeed, the variety of mountain and hilly landscapes has its origin in differential erosion phenomena called *morphoselection*: the presence of more resistant lithologies (e.g., massive limestone and dolostone), in comparison with less resistant ones (e.g., marls and shales) creates contrasting landscapes in terms of nearly vertical walls, more or less steep slopes or gently undulating landforms. A unique and spectacular example is given by the Dolomites area (Fig. 3.2), as reported by Zilioli and Bini (2009), Bini and Zilioli (2010) and Zilioli et al. (2011).

Intimately connected to the geological history of Alps and Apennines is the formation of the main alluvial plain in Italy, the Po River basin. The Po plain is a subsiding basin, bordered by the Alps to the north and by Apennines to the south. The essential features of this region, as outlined by Fontana et al. (2004), were already established in the middle Miocene, when also the Apennines chain was uplifted during the final orogenetic phase. During the upper Miocene, in coincidence with sea regression, most of the mountain margins and parts of the neighbouring plain emerged and were either eroded or subjected to continental sedimentation.

Pliocene in Italy began with a new sea level rise that rapidly re-established an open marine environment for a long tract in the Apennines, in the whole Po area and within the Alpine valleys, and determined the deposition of marine sediments, with a clear unconformity between Miocene and Pliocene sediments. In Northern Italy, sediments of the Pliocene facies are discontinuous and have limited thickness.

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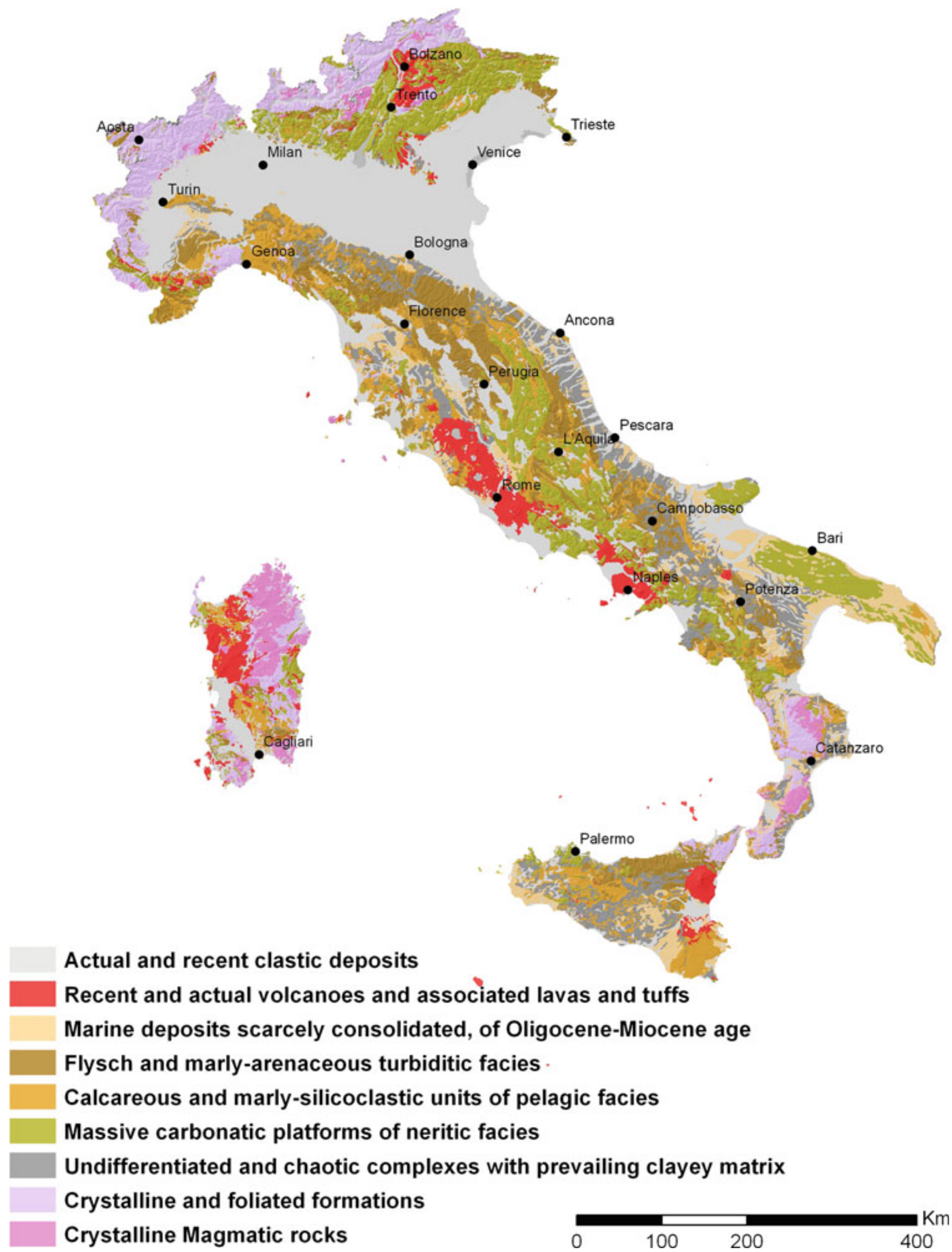

Fig. 3.1 Lithological map of Italy, derived from the soil systems geodatabase (see chap. 4)

The typical sedimentary succession of the sub-Apennine Pliocene facies, instead, is represented by bluish clays and yellowish sands, with some intercalation of calcareous and volcanic materials. These formations outcrop along the Adriatic shoreline south of Rimini, forming a gently undulating belt up to 45 km wide in the Marche region and very thick (up to 4,500 m). The prevailing lithology is clay and marls with some clayey sand intercalations, and the mineralogical composition is mainly illite (Mancini 1978). The Pliocene marine sedimentary succession also occurs in western Tuscany, where sands and clays form a gently undulating landscape, admirably depicted by Ambrogio Lorenzetti, a fourteenth century painter, whose fresh paints are visible in the Municipal Palace of Siena (Fig. 3.3).

More southwards, along the ionic coast of Calabria region, Pliocene sediments of the same type outcrop in the Crati River valley and in the Crotone basin. Because of the sea level rise, in early Pliocene Sicily was nearly all covered by the sea, thus allowing sedimentation of fine materials in both internal and coastal areas of the island. Successively, intense tectonic activity determined dislocation, faulting and erosion of these sedimentary successions, that now outcrop only at some places, particularly in the NW coast (Desio 1973).

Fig. 3.2 The impressive landscape of the Catinaccio group (*Val di Fassa, Trentino*) in the Dolomites. Mountain groups constituted of platform/reef carbonatic rocks with nearly vertical walls dominate over the gentle conterminous areas, modelled in glacial and detrital deposits. (*Photo* Bini)

Fig. 3.3 "The good land management" ("il buon governo del territorio"), painted in 1337–1340 AD by A. Lorenzetti in the municipal palace of Siena represents the typical clayey landscape (*crete senesi*) in the neighbouring of Siena

Another element of complexity in the geomorphological evolution of Italy is given by environmental modifications occurred during the Quaternary.

These variations were determined by the well-known global climate fluctuations, with alternating glacial–interglacial cycles, occurred in the last million years. The last glacial period, known in the Alpine region as *Würm*, had its maximum extension about 20,000 YBP, when the ice cap covered large part of the Alpine belt, and also parts of the Apennines, with maximum thickness of hundred metres. The direct action of glacial processes was much more effective than presently, with erosional and depositional landforms (cirques, valleys, moraines and terraces) that mark deeply the morphology of large parts of the land (Fig. 3.4).

Impressive glacial deposits, for example, constitute the moraine amphitheatre surrounding both Rivoli Torinese to the west and Rivoli Veronese to the east, now occupied by sub-Alpine lakes.

During glaciation, the main Alpine rivers were supplied by seasonal melting water and had hydrological regimes and transport capacities greater than the current conditions. Therefore, maximum aggradation of depositional systems occurred. Consistently, the sea level dropped at about 120 m below the present level, leaving emerged plains extending so far, as in the Adriatic Sea. Since 12,000 YBP, the environmental conditions became similar to the present and this is considered the boundary between Pleistocene and Holocene (Donnici et al. 2011). With progressive melting and ice cap reduction, a fundamental role in morphogenesis was taken up by surface waters organised in new hydrological networks. Glacial deposits were strongly eroded and re-distributed by the fluvial systems in alluvial fans and valleys; landslides also accumulated detrital materials which contribute to outline mountain and pre-Alpine landscapes in the post-glacial period (Fig. 3.5).

The sea level (eustatic) rise determined an important marine ingression during the Holocene (the Flandrian ingression, approximately 5,000 YBP), particularly in Northern Adriatic, and the formation of internal lagoons, like the one of Venice (Donnici et al. 2011), limited by littoral sand bars. Concomitant with sea level raise, the diversion of rivers determined the subsidence of the conterminous land and the formation of depressed and wetland areas now reclaimed.

Only concurrent with the deep valleys of the sub-Alpine lakes (Maggiore, Como, Iseo, Garda), there are gradual transitions, caused by the frontal moraines of the Quaternary glaciers. South of the moraine ridges there is a series of terraces that extend into the plain. Southwards, these sedimentary bodies gradually loose their morphological individuality and merge into a single level area, coinciding with the main level of the plain which extends almost down to the Po River (Cremaschi 1987).

At the Apennines fringe, Pleistocene marine and continental deposits occur. The marine deposits are of coastal and littoral facies and differ from the Pliocene marine deposits only with respect to their biostratigraphy (Ruggieri 1965). They crop out in thick sequences along the Apennine margin. The continental deposits consist of gravel, sand and clays, representing different facies of a fluvial system which can be described as piedmont alluvial fans and alluvial plains. In contrast to the Alpine fringe, moraines and fluvio-glacial deposits are completely absent but loess abounds (Cremaschi 1987). The first systematic studies on the continental deposits of the Apennine piedmont have been carried out by members of the Study Group on the Quaternary Geology since the second part of the 1960s (Venzo 1965; Ferrari and Magaldi 1968, 1976). All along the piedmont margin that separates the foothills of the Apennines from

Fig. 3.4 The imposing morphology of the Croda Rossa group, near Cortina d'Ampezzo, with its glacial cirque (*Courtesy* D. Zilioli)

Fig. 3.5 The typical morphology of glacial deposits affected by landslides near Cortina d'Ampezzo (*Courtesy* D. Zilioli)

the alluvial deposits of the Holocene plain, the continental Quaternary deposits occur as a narrow but continuous belt, forming deep soils (Busacca and Cremaschi 1998). Terraces, glacis and related erosional surfaces have been cut in these deposits. The oldest terraces with rubified paleosols dated back to the Mindel-Riss interglacial age, in analogy with the Alpine "Ferretto" (Magaldi 1979; Cremaschi 1987; Rasio 1988).

The lithological composition of Pleistocene sediments is variable as a function of sea level oscillations, ranging from clayey to sandy clay or peaty clay and to coarse sand with fine gravel intercalations. Quaternary terraced deposits are formed along the coast of both the Tyrrhenian and the Adriatic Seas in stratigraphic contiguity with Pliocene sediments (Boenzi 1980; Scarciglia et al. 2006). The lithology is nearly the same than previously described: silty clay with sand intercalations, yellow sand with clay and fine gravel at the top. Particularly interesting are the marine abrasion surfaces formed during the Tyrrhenian ingression at several sites (Tuscany, Apulia, Sicily), where large outcrops of an organogenous limestone (*panchina*), and of red clays of colluvial/aeolian origin, strongly pedogenised, occur. Quaternary (Pleistocene–Holocene) terraced deposits were investigated by Alioto and Sanesi (1986) and by Mori (1986) in the coastal plain in southern Tuscany. A toposequence of soils with different pedofeatures (mottles, clay coatings, rubefaction, base leaching) was identified, with Ultisols on the oldest terrace, Alfisols and Inceptisols on the more recent ones.

Outcrops of organogenous limestone (*panchina*) are common in western Sicily and along the coasts of Sardinia (Carboni et al. 2006) and are referred to as Tyrrhenian II (i.e., Riss-Würm interglacial period), a period with climate and environmental conditions similar to the present ones. The sea retreat in Sardinia during that period has been calculated to have lowered the sea level by at least 50 m with respect to the present-day coast line, and the immediate effect was an accumulation of aeolian sand on top of the *panchina*, particularly in the western coast, most exposed to prominent winds coming from NW direction.

The dominant feature of the Pleistocene continental sedimentary cycles was alternating warm and cool climate conditions, with progressive cooling conditions towards the upper Pleistocene, when a big ice cap extended over the northern hemisphere, up to 40° N latitude within the Alpine belt, leaving evident cryogenic features (Cremaschi and Van Vliet-Lanoe 1990).

Continental Pleistocene in Italy left alluvial deposits in the Po River valley and in minor plains, both internal and coastal; pyroclastic and lacustrine deposits, terraced fluvial deposits, tills and cave fillings also are common features of that period. Till deposits of the Southern Alpine fringe are the most prominent late Pleistocene landforms, as observed in the Garda Lake, NE Italy (Venzo 1965; Mancini 1969), in the Piedmont at Ivrea and in Lombardy near Como (Rasio 1988). The lithology of these deposits is extremely variable as a function of the source materials; primary minerals are strongly weathered, and a red clay matrix with clear signs of illuviation in the soil profile points to these materials as being strongly pedogenised (i.e., being paleosols). Most of these soils have truncated profile, and a variable amount of loess covers the argillic horizon like a blanket, as in Lombardy (Rasio 1988), Veneto, Friuli and also in Emilia (Cremaschi 1987). Glacial records were also observed in Northern and Central Apennines and in the Gran Sasso-Maiella group, where at least 50 small glaciers, today disappeared, were identified (Giraudi and Frezzotti 1997).

3.2 Rock Degradation, Weathering and Soil Parent Material

Major factors in determining rock weathering and soil formation are chemical and mineralogical composition, grain size, landscape position, and the composition and thermodynamic activity of circulating waters (Macias and Chesworth 1992). As phases inherited from parent materials, most earth surface systems contain inorganic compounds that are predominantly silicate. A second important group are the carbonates, particularly calcite and dolomite. The principal secondary phases are aluminosilicate clay minerals, oxides and hydroxides, with carbonate precipitation common in some environments (Chesworth 1992). Precipitation of sulphides, sulphates and chlorides occurs under special circumstances, such as abandoned mine areas (Bini 2011) or evaporite outcrops (Dazzi and Monteleone 2001), and may influence the weathering path.

The parent rock effect can often be masked by the effects of climate and of vegetation, but parent material may play a considerable role in determining soil properties. For example, sandy soils are likely derived from granite and silty-clayey soils from basalt (Jenny 1941). In Italy, given the variety of geological substrata (see Fig. 3.1), A and B horizons of the relatively shallow and youthful soils (Leptosols and Cambisols) are fairly distinct from the underlying C horizons. For example, pumice alteration on pyroclastic flows at Vico Lake, an old volcano (approximately 100,000 YBP) in Central Italy, formed the older yellow–brown pumice soils (Fulvic Andosols and Dystric Andosols WRB), which are better developed than the recent soils (Vitric and Andic Cambisols/Regosols WRB) (Lulli 2007).

Sometimes, however, it is difficult to distinguish between C and R horizons (i.e., between soil and rock), particularly in fine sedimentary bodies. Marine clays and young dune sands, with discontinuous vegetation cover (Fig. 3.6), are typical examples of such difficulty (Bini 2002). Similar is also the case of alluvial deposits composed of mixed lithology (partly crystalline and partly calcareous), as in the Brenta River basin, in contrast to the uniform lithology (calcareous) of the Piave River, in the Venetian territory (Donnici et al. 2011).

Hydrolysis is perhaps the most characteristic chemical reaction in the weathering zone under temperate climate, like in Italy (Costantini et al., this volume). According to Chesworth (1992), weathering processes by hydrolytic alteration show three separate tendencies:

1. Fersiallitic weathering, characteristic of stable landscapes under warm climate (Mediterranean);
2. Andosolic weathering, characteristic of volcanic areas;
3. Podzolic weathering, affecting well-drained siliceous materials under humid and cool climate.

Fig. 3.6 The fragile ecosystem of coastal dunes in north–east Italy, with alternating sandy sediments and scarcely developed soils (Psamments USDA, Arenosols WRB) (*photo* Bini)

In the fersiallitic trend, a relatively high temperature, availability of water and long periods of weathering result in near an approach to equilibrium mineral assemblages as can be expected on the terrestrial land surface. The mineral sequence goes from a stage of incipient weathering, with bulk composition not very different from the parent material, through a stage where 2:1 sheet silicates are common (*bisiallitisation* as defined by Pedro 1968), to an intermediate stage with 1:1 sheet silicates (*monosiallitisation*) and to an end stage made of a four component system (SiO_2, Al_2O_3, Fe_2O_3, H_2O) that can be considered a residual system of weathering (Chesworth 1992). The achievement of a near-equilibrium mineralogy requires a long time (more than 100,000 years) and many intermediate stages. A common soil sequence (WRB) from acid parent rocks is the following:

Leptosols (Dystric)—Dystric Cambisols—Haplic Acrisols.

Basic rocks progress more rapidly in the weathering path; initially, they produce soils with a mollic epipedon, which turns to an ochric horizon with decarbonation and partial base leaching, following the sequence:

Leptosols (Rendzic)—Eutric Cambisols—Haplic Luvisols.

The andosolic trend concerns soils developed from volcanic parent rocks. Andosols are typically formed in regions of recent volcanic activity, and for this reason tend to contain a high proportion of glass, and have a low bulk density and a high water retention capacity. The clay fraction is dominated by Al-rich allophanes, and Al-humus complexes dominate the surface horizon. More than other soil types, Andosols are ephemeral, due to the re-organisation of amorphous materials into crystalline aluminosilicates (halloysite), loosing some specific properties. A possible evolutionary sequence (WRB) is:

Leptosols—Andosols—Cambisols—Luvisols

The podzolic trend is developed under cool to temperate climate, when humus tends to accumulate at the surface, to form complexes with Al and Fe, and migrate in the spodic horizon. Yet, the typical morphology of such soil profiles is a Al–Fe-organic-rich spodic horizon underlying a Si-rich albic horizon. As the likely time of soil formation is estimated as 10,000 years or less, quartz and alkaline feldspars are residual (primary) minerals, while ferromagnesian minerals are lacking at all. Newly formed minerals are beidellite and iron hydroxides, with amorphous aluminosilicates (imogolite). The mechanism of podzolisation has been widely investigated (Farmer 1982; Dahlgren and Ugolini 1991), and the more accepted theory is the classic view whereby Al and Fe are transported as organo–metallic complexes.

Podzolic soils are widely diffused in the alpine belt; however, the podzolisation process is not always fully developed, and therefore possible intergrades may form, as follows (WRB):

Leptosols (Rankers)—Dystric Cambisols—Spodic Cambisols*/Entic Podzols—Haplic Podzols.

*new suggestion (not present in the last WRB draft).

3.3 The Quaternary Soil Cover: Role of Geomorphic Agents (Ice, Water, Wind, Gravity)

3.3.1 Ice

The climate variations that provoked glacial expansion in the Alpine region determined a substantial change in the morphological configuration. Glaciers activity superimposed glacial morphology on pre-existing landforms produced essentially by fluvial erosion. The main Alpine valleys that underwent the glacial advances down to their outlet in the plain are easily recognisable due to the imprinting left in the cross profile of the valleys (Fig. 3.7), in their shoulder, in the ice-sculptured surfaces of *roche moutonnée*-type knobs, sparsely jointed or plucked out when the jointing is closely spaced (Desio 1973), or in abrasion forms as "cetaceous-like humps".

According to the traditional scheme, the Alpine region has been subjected to four major glacial advances. Geologists use the term *drift* to refer to materials carried by ice; glacial sediments vary from unsorted, boulder-rich till to stratified silt and clays.

Traces of these events are the till deposits left by glaciers at the mouth of their valleys, where typical moraine amphitheatres, composed of several circles of different ages, juxtaposed or overlapping, attest the various glacial expansions (Castiglioni 2004). The erosional activity of glaciers, however, was not limited to modelling valleys. Glacial masses, trespassing from one valley to another, contributed to polish rocky outcrops and to enhance fluvial erosion activity, modifying the hydrological system of the whole area.

Fig. 3.7 The Adige river valley south of Trento has a typical glacial conformation with "U" shape. The flat bottom and the alluvial fans are intensively settled and cultivated with orchards and vineyards (*Photo* Bini)

Soil genesis from such landforms depends on the time of glacial sediment deposition. Most till soils are fairly young, having formed in till deposited by the last major ice advance (Würm). Buried soils (paleosols) are routinely found in older till deposits. In many landscapes, the till itself is buried by loess that carries the modern soil at its surface, as it was observed by Mancini (1969) in the Garda moraine amphitheatre. Strongly rubified, slightly subacid, fairly leached soils (Chromic Luvisols WRB), historically known as the "ferretto", are buried under a loess layer bearing reddish-brown, calcareous soils (Calcaric Cambisols).

3.3.2 Water

Quite different is the geomorphological evolution of river valleys in non-glacial areas, where the water erosion effect is very marked in the transverse and longitudinal configuration, with modified original V profile, steep flanks, formation of rocky steps or shoulders, irrespective of the lithological composition.

Materials transported and deposited on flood plains and in alluvial fans are called alluvium. Most alluvial deposits are stratified. Because of their stratification, they get progressively younger towards the top. They also can exhibit many sudden changes or breaks in sediment texture, which affects dramatically pedogenesis, creating lithological and textural discontinuities (Schaetzl and Anderson 2005).

Several landforms are related to surface modelling by water. Alluvial plains may be completely flat and delimited by a rather stable scarp, or they may show a terrace of limited height, excavated in strongly consolidated gravel and sand, as in the proximal part of the river Brenta (Bertoldo (2008), Caratterizzazione dei suoli lungo l'asta del Brenta tra Bassano del Grappa e Piazzola sul Brenta, "unpublished thesis").

Typical fluvio-glacial landforms are the terraced systems which are found at several non-glaciated sites. In the Mugello watershed (Tuscany, Central Italy), Sanesi (1965) recognised a set of five orders of fluvio-glacial terraces formed during Pleistocene glacial periods. Soil development on these terraces provides clues to the time of terrace building. Yet, consistent with the terrace ageing, the soils present different evolution, and the recorded sequence (USDA) is the following:

Entisols (Fluvents)—Inceptisols (Udepts)—Alfisols (Udalfs)—Ultisols (Udults).

Alluvial facies may be continuous for many kilometres, or they may be highly discontinuous, with mid-channel bar sand deposits. The differential composition and structure of the sandy materials along the main river beds when compared with that of the surrounding clayey soils have repercussions on the microrelief, which presents a band rising highly above the generally flat area, which is also recognisable due to the coarse texture of the bar deposits. The consolidation of finely textured and compressible soils is responsible for difficult drainage of some areas with gleyic properties developing. The main utilisation of these morphological structures, defined as "natural levees", is for settlements and the agriculture land use (Fig. 3.8).

Alluvial fan deposits are also notorious for being highly variable across space. They may originate from mass wasting deposits starting with the weathering of soft formations and outwash of clayey material. They are often constituted of heterogeneous materials, and extend for tens as well as for hundred of metres, may have very gentle slopes (<2 %) or be steeper (up to 10 %) towards the valley bottom. In general, alluvial fans have coarse (gravelly) grain size in a sandy-loamy matrix and therefore are freely drained and constitute an important water reserve. Hence, soils may develop rather quickly from shallow Entisols to deep leached profiles (Alfisols). Human settlement and agriculture, therefore, are privileged on these landforms, as it can be seen along the Adige valley, in Northern Italy.

Fig. 3.8 Vineyard is a common land use in soils (mostly Eutric Cambisols WRB) of the high plain. The above picture is taken along the wine road in the Lison district, Venice. (*Photo* Bini)

3.3.3 Coastal Areas

One widespread group of parent materials associated with coasts include marine sediments and coastal plain deposits. Most coastal sediments are sandy, and the landscapes that result are of low relief. Common to all sea coasts and nearby environments are the recent geological changes in sea level. Italian peninsula has been strongly affected by sea level changes during the Plio-Pleistocene period. During Pliocene, owing to large sea rise, the coast line was much retired with respect to the present. Afterwards, during Pleistocene, several sea ingression/regression movements determined frequent variations of the shoreline, until eustatic (global) sea level rise during the Tyrrhenian ingression. The melting of the last ice sheet determined a sea level rise of 120 m, as testified by erosion traces along the west coast of Sardinia. The recorded changes forced the coasts to retreat, forming offshore sandy barrier islands, swamps and lagoons, often with dunes at the landward side, as in the case of the Northern Adriatic belt (Bini 2002).

3.3.4 Wind

Although Italy is not as highly affected by wind erosion as other countries, wind may act as a significant landscape modelling agent, and a source of allochthonous materials in soils. A variety of soil parent materials are transported through the atmosphere. Some, like sand and silt, are picked up by the wind and moved to a certain distance, depending on wind velocity and grain size. Others, like pyroclastic materials, either settle out of the air or are moved still farther by wind (Schaetzl and Anderson 2005). It is known, for example, that cinders from Pinatubo volcano in the Philippines circled three times around the world before settling. Once wind velocity drops, transported substances can be added to soil and contribute to modify soil properties.

One of the most common airborne materials is dust brought from desert regions. Yet, significant fluxes of Saharan dust over the Mediterranean basin have been recorded (Molinaroli and Masiol 2006). Saharan dust

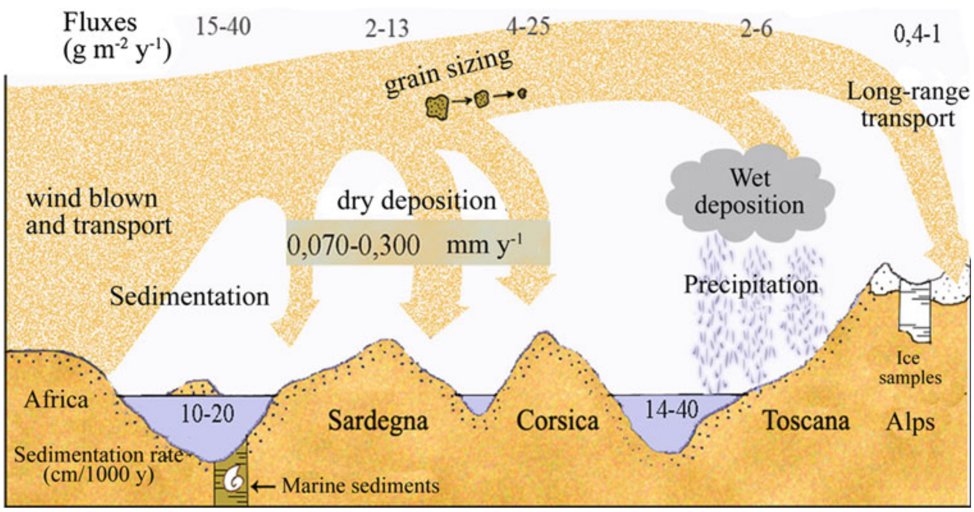

Fig. 3.9 Saharan dust fluxes over the Mediterranean sea (Modified after Molinaroli and Masiol 2006)

contributes substantially to the soil cover in the circum-Mediterranean region (Fig. 3.9), where *terra rossa* is a typical soil (Rhodoxeralf) whose physical and chemical properties (e.g., texture, pH, CEC, base saturation) are likely changed by dust addition.

There are still contrasting interpretations among scientists on the origin of *terra rossa*, whether it consists mainly of a residuum of limestone weathering (Moresi and Mongelli 1988), or it is mainly allochthonous (wind transported) dust (Yaalon 1997), or colluvium from the surrounding slopes (Yassoglou et al. 1997). Verheye (1974) found that *terra rossa* soils are primarily found on stable uplands, where erosion is minimal; on other landscape positions less developed, brown to yellow soils occur. Some, however, observed that red residual sediments are also accumulating in karst depressions as thick deposits and on accretionary slope position. It is likely that all the three sources could contribute to red soils genesis, but it has now been determined that the majority of the parent material is colluvial and aeolian dust, as reported by Priori et al. (2008) and Bini et al. (2007).

The main effect of chemical weathering of massive limestone in Southern Italy, according to Moresi and Mongelli (1988), is the transformation of illite to kaolinite in the residuum (monosiallitisation according to Pedro 1968). Yet, kaolinite is found as a residual clay mineral in red soils. Soil reddening (rubefaction), enhanced by warm temperatures, is a major process in *terra rossa*: iron oxyhydroxides released by weathering are dehydrated and precipitate as haematite, imparting a red colour to the soil (Bech et al. 1997). Moreover, a sufficiently wet season allows a rapid turnover of organic matter and clay illuviation (Boero and Schwertmann 1989).

A second type of aeolian sediment, most widespread in post-glacial areas, is loess added to soil during cold and dry periods of Pleistocene, particularly in the Alpine region, where wide areas were denuded of vegetation and became susceptible to wind erosion (Legros 1992). As loess deposition slowed down near the end of the glacial period, soils began to form. In Northern Italy, thin loess sheets have been recorded in many sites, covering the landscape like a blanket (Venzo 1965; Mancini 1969). Loessial soil cover is widely diffused in all the pre-Alpine fringe and in the Po plain, as reported by Cremaschi (1990) and Borsato (2009). Small areas covered by loess, however, are also present in the Apennine fringe, in both northern and southern exposition (Sanesi 1965; Ferrari and Magaldi 1976).

A third source of airborne materials is volcanic ash disseminated during eruptions occurred in the Plio-Quaternary period. Plio-Quaternary magmatic rocks in Italy exhibit a large range of petrological characteristics and cover almost all the different compositional fields, ranging from sub-alkaline to alkaline and from mafic to silicic (Peccerillo 2005). Therefore, the chemical composition of volcanic ash varies, being often rich in iron (up to 10 %) and aluminium (20 %).

In humid climate, acid volcanic deposits contain Al- and Si-rich materials which weather to form soils rich in short-range-ordered minerals, like Andisols, while basic materials tend to weather to form soils rich in halloysite (Vacca et al. 2003; Lulli 2007). In dry climate, volcanic materials weather more slowly, and much more time is required to form Andisols. Oxyhydroxides of Fe, Al and Si along with Fe- and Al-organic matter complexes can form as these cations are released from primary minerals (Dahlgren and Ugolini 1991).

3.3.5 Gravity

Slumps, slides, flows and soil creep are all results of the influence of gravity on the regolith. Slumps occur as rapid failures along curved shearing surfaces, usually in more or less homogeneous soil masses. The swelling clays of the chaotic flysch formations, widely diffused in the Apennines, are especially prone to landslides. Soil creep occurs generally as a gradual, continuous movement of the upper soil layers on slopes of low gradient (>12°) and results in minor undulations, bulging surface forms and crumpling of the turf (Rodolfi and Zissel 1989). Slope failure occurs because the shear strength of the material is compromised. Undercutting the slopes by rivers, jointing of the parent rock, devegetation and water saturation all act to weaken the cohesiveness of the sediment/soil and initiate failure. The two factors that contribute most to slope instability are slope gradient and vegetation cover. Colluvial material is usually quite heterogeneous in size and composition, depending on the source material composition. Unlike many other soil parent materials, it contains pre-existing weathered and pedogenised material (buried soils or soil sediments) reflecting the episodic nature of its deposition. Hence, soils are generally subjected to mass movements, landslides, erosion and therefore are immature or rejuvenated (Leptosols and Regosols WRB), as recorded by Rodolfi and Zissel (1989) in the Northern Apennines and by Zilioli and Bini (2009) in the Cortina d'Ampezzo territory.

3.4 Morphology and Parent Material: The Main Italian Landscapes

3.4.1 The Alpine Environment

It is difficult to include the relevant spatial variability and the distribution of soils in the Alpine environment within models or schemes, since the type and the intensity of the geomorphic factors (wind, ice, water, runoff, gravity, landslides, etc.) change over short distances and in short time, determining strong differences in landforms (Previtali 2002).

Combining various factors (climate, morphology, vegetation, time), petrographically similar parent rocks may determine an evolutionary divergence, originating very different soils (e.g., Cambisols—Podzols—Luvisols). Conversely, petrographically different parent materials may determine an evolutionary convergence (e.g., granite rocks → podzol ← calcareous rocks). Moreover, a progressive diachronic evolution towards the edaphic climax stage, or a regressive evolution to the parent rock (rejuvenation or entisolization) is likely to occur with changing environmental conditions.

In terms of chemical and physical behaviour of soil parent materials, the major Alpine environments as defined by a given rock, and the resulting soils, may be related to two main rock categories, irrespective of their origin:

- Siliceous rocks, with their high SiO_2 content (up to 70 %) and acid reaction;
- Calcareous rocks, with their low SiO_2 content (<40 %) and alkaline reaction.

Yet, the mineralogical and chemical composition of parent rocks drive and condition the soil formation, at least in the early stage of evolution.

3.4.1.1 Granular Crystalline Rocks

Magmatic activity was particularly intense in the Alps during the orogenetic cycles and has left large outcrops in the western (Gran Paradiso, Monte Bianco, Cervino, Monte Rosa) and central (Tonale, Adamello) parts of the Alpine range. Granite, granodiorite and quartz diorite are the prominent lithotypes, with associated gneiss and mica schists. Landforms present generally steep morphology with high relief energy, nearly vertical walls and talus accumulation at foot slope. Hence, soil formation is initially slow. The first step is physical disintegration and formation of a coarse textured regolith. Of primary minerals, quartz is essentially preserved intact; feldspars may be dissolved more or less quickly, depending on their composition; micas and chlorites are transformed slowly, producing a quantity of secondary smectite or vermiculite, particularly at low pH. Yet, the high SiO_2 content contributes to acidification of the soil environment. Brunification and podzolisation are the main pedogenetic processes in the sub-Alpine–Alpine belts, and a soil evolutionary sequence (Entisols → Inceptisols → Spodosols, Fig. 3.10a) is likely to form under cool and wet climate, as observed by Zilioli et al. (2011) in the Dolomites area (Fig. 3.11).

Magmatic and metamorphic greenstones are abundant, particularly in the inner Alps (Pennides and Austrian-Alpine domains). They are particularly rich in iron and magnesium. Atmospheric weathering of these rocks liberates the

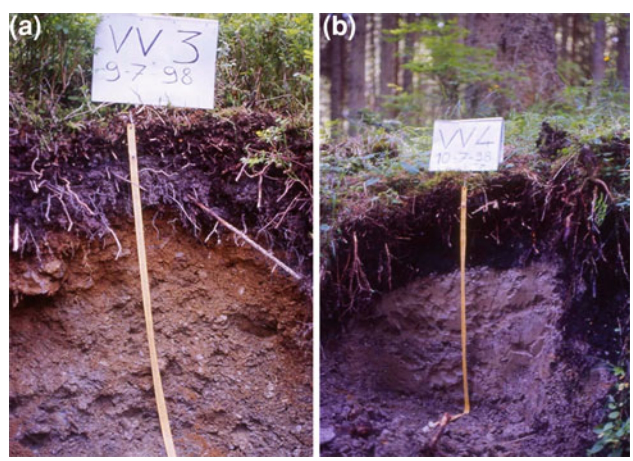

Fig. 3.10 Two typical soil profiles of the Alpine environment. **a** Typic Haplorthod on gneiss; **b** Typic Haprendoll on clayey marls. Val Visdende (BL). (*Photo* Bini)

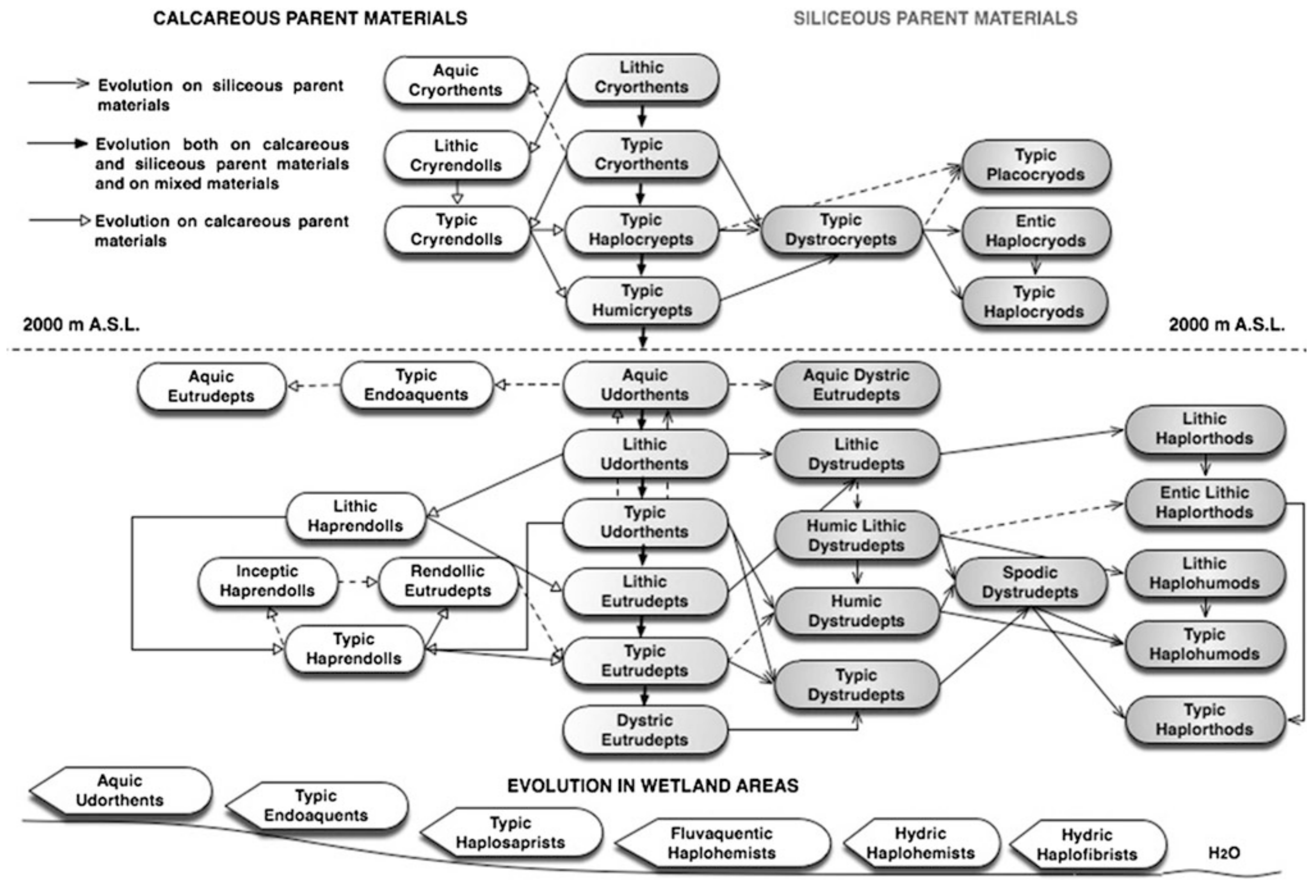

Fig. 3.11 Flow diagram of soil evolution in Alpine environment (Adapted from Zilioli et al. 2011)

components of their primary minerals (pyroxenes, amphiboles, chlorite, talc), but the limited amount of silica and aluminium makes mineralogical transformation limited, and a very small quantity of secondary clay minerals are formed. Hence, also soil evolution is limited to the first steps of Leptosols or Cambisols. A peculiarity of these soils is the composition of the adsorbent complex, that is saturated with Mg^{2+} covering over 60 % of the exchange complex, with pH never falling below 5.5 (Legros 1992).

3.4.1.2 Sandstones, Silts and Shales

These rocks outcrop more widely in the sub-Alpine than in the Alpine zone. Their response to weathering is quite different, depending on texture and mineralogical composition. Yet, sandstone is permeable to water, whereas silt and shales are rather impermeable; however, foliation allows water to enter joints and this favours percolation. Lithofacies rich in quartz and feldspars behave similarly to magmatic rocks, while platy rocks are more resistant to weathering. Landforms developed from these rocks present gentler slopes than crystalline rocks, with sub-rounded ridges and scarce erosion phenomena. Conversely, landslides are quite frequent. Slow weathering of these parent materials leads to formation of thin immature soils, brunification being the main pedogenetic process. Depending on other soil forming factors, such as relief, Leptosols and Cambisols are the most common soils.

3.4.1.3 Limestone

Carbonate Massifs, composed of Mesozoic limestone and dolostone, are present in nearly all the Alpine range and are widely diffused in the central and eastern parts, particularly in the Dolomites. Limestone containing less than 5 % non-carbonate residue is very resistant to weathering, and much of the soil cover is thin. Stratification and massive structure, karst phenomena and mineralogical impurities, all these characters, combined with soil forming factors, may drive soil evolution towards different typologies. The physico-chemical environment, rich in Ca^{2+} and Mg^{2+}, conditions the pedogenetic processes just until soil maturity. Two cases may occur: (a) accumulation of a surface horizon rich in Ca-saturated humus, lying directly over calcareous materials (mollic epipedon, Fig. 3.10b) and (b) mixture of high organic material with limestone fragments, as in the case of talus slopes. When the soil develops, surface acidification occurs, pH and base saturation drop; the surface horizon turns to umbric or ochric character, with organic matter content decrease. Decarbonation is the typical soil forming process in such conditions. Conversely, in talus, the presence of Ca-reserves in the coarse material contributes to lateral circulation of Ca-charged water that hampers acidification and enhances carbonation, while organic matter accumulates (Legros 1992); therefore, mollic properties are established. The mineralogical composition, in any case, is dominated by 2:1 sheet silicates (smectite, vermiculite, illite), as expected with humus and Ca-rich pedogenetic environment. Entisols, Mollisols and Inceptisols are the prominent soils that constitute the typical evolutionary sequence in such calcareous environments.

Similar findings have been described by Merkli et al. (2009) in toposequences on limestone of the Brenta Dolomites, and soil evolutionary sequences have been observed recently by Zilioli and Bini (2009) in the central Dolomites area, under different climate and morphological conditions (Fig. 3.11).

3.4.2 The Pre-Alpine Fringe

The pre-Alpine area extends from the steep ridges of the Alps to the gently undulating hills connected with the alluvial plain. The main mountain groups are separated by profound cuttings of rivers coming from the Alpine relieves in the back (e.g., the Adige, Brenta and Piave Rivers in the north–east), while a rather large belt of gentle hills, with some isolated relieves (e.g., the Montello) functions as connection with the plain. The highest elevation is up to 2,000 m asl, corresponding to the sub-Alpine belt, but in most cases, the mountain summit is in the range 1,000–2,000 m. Typical landforms are large undulating or nearly flat plateaux such as Cansiglio and Asiago, or narrow, sub-rounded crests delimited by steep slopes, as Monte Baldo. These big structures have their origin in the tectonic activity connected with the Alpine orogenesis and are coincident with folds and faults (i.e., they are *morphostructures*), successively modelled by erosion of the most erodible lithotypes through a *morphoselection* process. Big rocky scarps and steep slopes are generally related to outcrops of dolomite rock, in contrast to more gentle landforms developed on marly limestone. The marly landscape is characterised by long sub-rounded ridges with connecting slopes and higher drainage density than on massive limestone. In distal parts of the pre-Alpine belt, the contrasting action of morphoselection between massive rocks (limestone, sandstones, conglomerates) and soft rocks (marls, shales) is particularly evident due to the high dip of strata that generate long hogbacks.

Karst morphology occurs in this belt at sites with hard limestone outcropping (Fig. 3.12). Conversely, it is less evident in marly limestone. The development of glacial tongues, or local glaciers at higher elevation, and diffused periglacial processes at sites with minor elevation, constitutes the most relevant morphogenetic factor acting during the Quaternary. Glacial morphology has been intensely re-modelled by surface erosion in discontinuous, rounded and coalescent landforms.

Fig. 3.12 Karst morphology (karren) in dolomite erratic blocks at footslope of Croda del Becco (Cortina d'Ampezzo, BL). *Courtesy* D. Zilioli

Extended colluvial deposits and detrital fans coming from upslope soft rocks such as marls, shales and easily weatherable volcanites are related to more stable conditions. Detrital megafans occur nearly continuously on the ridges flanks and constitute the connecting surface with the conterminous alluvial plain.

The geomorphological impact of human activity on landforms of the pre-Alpine belt has been particularly dramatic in connection with the military operations along the Italian boundary during the First World War (1915–1918) that contributed severe damage to the original landscape, with tunnels opening, excavations, destruction of natural landforms, as in the Monte Grappa and in the Piave River watershed (Fig. 3.13).

3.4.3 Alluvial Plains and Coastal Areas

Alluvial plains form owing to the materials transported and deposited by major rivers descending from the mountains. The Po River is directly responsible for the central–distal part of the most important and broadest alluvial plain in

Fig. 3.13 A moment of pause of an Italian battery during the First World War at Forcella Mostacin (Belluno). A complex system of observatories and batteries has left visible traces, such as holes and trenches, on the slopes and in the summit of Monte Grappa. (*Courtesy* Regione del Veneto)

Italy (Po plain), while other major water courses contributed to the formation of the northwards and southwards sector of the plain, with big sedimentary bodies (Fontana et al. 2004; Mozzi 2005). A general characteristic of the alluvial plain is the highly sorted grain size and the marked separation of alluvial landforms in two different sectors, respectively, distal and proximal to the shoreline, and which correspond to two physiographical units, the high plain and the low plain. The high plain is constituted of a large surface gently descending downwards; the grain size is coarse, with prevailing pebbles and gravels embedded in a sandy-clayey matrix; while descending from the mountains, braided rivers deposited such materials, as well as large alluvial fans, at the valley outlet (Fig. 3.14).

Downwards, in the low plain, alluvial deposits present finer grain size ranging from sandy to silty-clayey, due to the lesser kinetic energy over minimal slopes (<0.1 %). Fluvial beds are generally organised as single channel, sometimes meandering; with time, they may depose in the active channel, or during flooding episodes, sandy bars 1–2 m high over the surrounding plain, which may extend up to tens of kilometres, constituting natural banks against floods (Fig. 3.15).

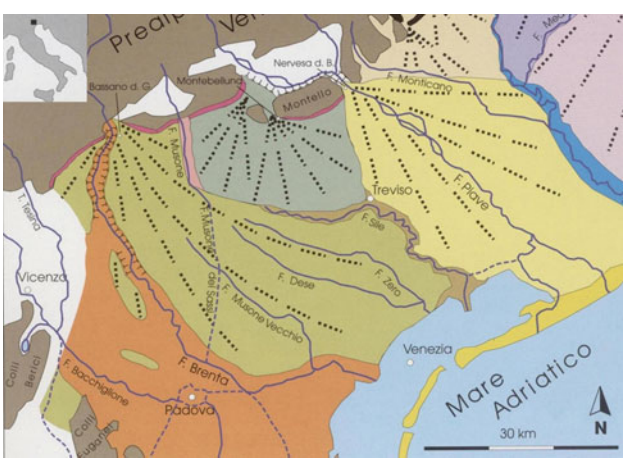

Fig. 3.14 Distal part of the northern side of the Po alluvial plain, with indication of the main river courses and traces of alluvial fans (*black dots*) (Adapted from Mozzi 2005)

Besides the already mentioned differences between high and low plain, a further element of differentiation is given by the age of formation of various parts of the plain. In depositional systems developed in the high plain, formed during Pleistocene, large surfaces formed during the last glacial period, ageing 18,000–14,000 YBP (Fontana et al. 2004) are present. Remnants of the Pleistocene surface outcrop only at sites where the sedimentary processes, during the Holocene, did not cover it. In some other systems, instead, the erosion of the fan apex during the final phase of glaciation (early Holocene), and afterwards the starting of fluvial activity, determined the excavation of the valleys, as in the plain downwards the Garda moraine amphitheatre. Locally, residual parts of the Pleistocene plain occur in the proximity of the shoreline, originating terraces and well-developed paleosols (Boenzi 1980; Mazzanti and Sanesi 1986; Scarciglia et al. 2006). Ancient surfaces may be exposed, in the absence of fluvial erosion, only where geomorphological conditions (e.g., little subsidence or distance from the river channel) did not allow effective depositional activity during more recent times. For example, the deactivation of the Piave megafan determined the exposition and pedogenesis of sedimentary bodies for a period of approximately 12,000 years, with subaerial weathering and formation of a buried calcic horizon in the lagoon of Venice and neighbouring territories (Mozzi et al. 2003; Donnici et al. 2011).

Coastal areas are distinguished for littoral sand bars nearly continuously parallel to the shoreline, the only interruption being the port mouth or the river outlet. They consist of marine sand beaches or dunes removed by wind or by sea waves, with an elevation of 5–6 m asl. Microtopography and hydrology regulate the development of the

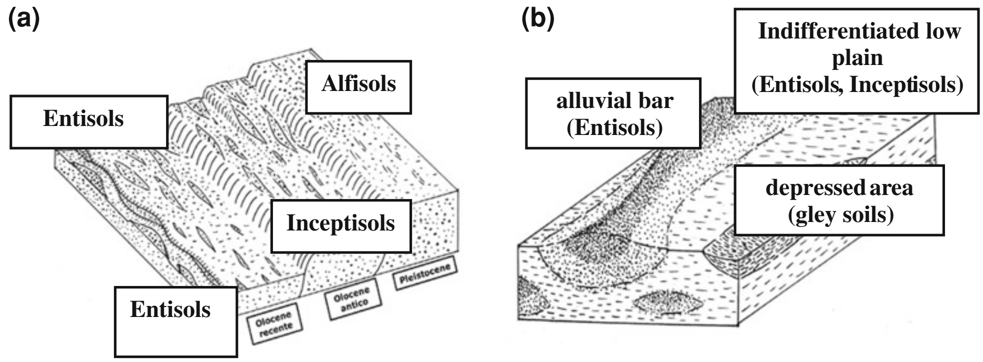

Fig. 3.15 Distribution model of soils in the alluvial plain (Adapted from Bertoldo P, 2008, Caratterizzazione dei suoli lungo l'asta del Brenta tra Bassano del Grappa e Piazzola sul Brenta, "unpublished thesis") **a** high plain; **b** low plain

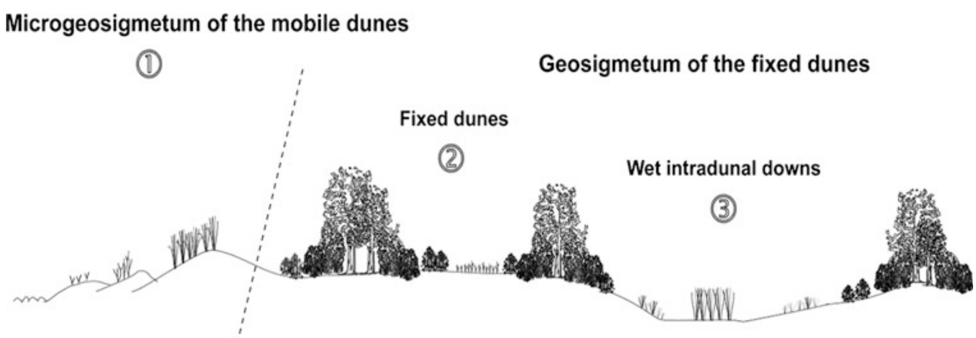

Fig. 3.16 Soils and coastal vegetation series in northern Adriatic area: **1** Udipsamment under *Salsolo-Cakiletum*, *Sporobolo-Agropyretum*, *Echinophoro-Ammophiletum*, *Sileno-Vulpietum*; **2** Edaphoxerophilous series of Holm Oak Wood (*Tortulo-Scabiosetum*, *Junipero-Hippophaetum*, *Vincetoxico-Quercetum ilicis*) on Arenic Eutrudept; **3** Edaphohydrophilous series of humid infradune downs (*Mariscetum serrati,Erucastro-Schoenetum nigricantis, Molinietum caeruleae, Salicetum cinereae,Carici elatae-Alnetum glutinosae)* on Psammaquent (Adapted from Buffa et al. 2010)

dune–interdune systems in coastal areas (Bini 2002), with depressed wetlands interspersed with drier, slightly elevated areas. Most of the wetland areas are characterised by shallow swamps, some of which recently reclaimed, as in the Venetian territory (Bini and Zilocchi 2004). The distribution of depressed and elevated areas has been partially modified by recent reclamation including terrain levelling, and most of these areas are artificially maintained as arable land. In relation to environmental conditions (topography, hydrology, subsidence, etc.), coastal areas present little developed soils, being influenced by land morphology, erosion/deposition processes, soil moisture regime, particle size, chemical composition. Psamments and Aquents are the prevailing soils, depending on microtopography. (Fig. 3.16).

3.4.4 The Apennines from North to South

The Apennine Range can be subdivided schematically into four main sections with different geology and lithology: Northern, Central, Southern and Apulia-Calabria Apennine.

1. Northern Apennine. This section of the Range, in Emilia and Tuscany, is characterised by different sedimentary successions: the tertiary autochthonous (miogeosynclinal) formations (Macigno and Marnoso-arenacea) and the allochthonous (Cretaceous-Eocene) eugeosynclinal chaotic complex. The former are mainly coarse detrital sandstone with more or less thin silty-clayey levels, intercalated with sandstone. The latter is constituted of a silty-clayey matrix embedding marly limestone (Alberese), detrital sandstone (Pietraforte) and mafic rocks (Ophiolites). Subordinate to the previous formations, in stratigraphic unconformity, are Miocene evaporites and Pliocene clays, which act as a connecting surface between the mountain belt and the Quaternary deposits of the alluvial plain. Solicited by the orogenetic forces responsible for the formation of the Apennine Range, the tectonic uplift determined dislocation, folding and faulting of this section of the chain. Consequently, present landforms show different morphologies in relation to differences in lithological composition. At sites where sandstone prevails, steep slopes with marked river channels are frequent; conversely, where the chaotic

complex is prominent, landforms are more gently undulating, with minor steepness, but are affected by creeping, flows and landslides active in the clayey matrix. Soils in this sector of the Apennine chain are scarcely to moderately developed, deep and fertile (mostly Inceptisols and Alfisols), but prone to erosion, in particular those developed from silty-clayey flysch formations.

2. Central Apennine. This sector of the Range, in Umbria-Marche-Lazio-Abruzzo regions, is composed of stratified formations whose lithology is essentially limestone and marl. Here, the physiography is variable from massive tabular relieves of carbonatic platforms, to steep slopes in correspondence of silico-calcareous materials, and gentle landforms corresponding to marly outcrops. Limestone is highly fractured with a set of faults and presents numerous karst features. Hence, soils here are generally thin and with little horizonation (i.e., they are mainly Entisols or Mollisols).
3. Southern Apennine. This part of the Range is mainly composed of heterogeneous flysch complexes with clayey matrix, diffused in Campania and Lucania regions. Limestone, sandstone and conglomerates outcrop at several sites. Because of its lithological nature, the flysch formation presents active morphological dynamics, with numerous landslides and strong erosion phenomena connected to heavy rainfall. Consequently, soils are thin Entisols and Inceptisols.
4. Apulia-Calabria Apennine. This section of the Range is characterised by two contrasting geological formations. Apulia is dominated by a massive tabular limestone of Mesozoic age, the Murge. This formation is very resistant and little weatherable; therefore, landforms are quite stable, with planar stratification crossed by profound river creeks, similar to canyons (e.g., Gravina). Red clay is the main constituent of soils developed on these rocks, the already mentioned *terra rossa* (Alfisols). The Capitanata, near Foggia, is characterised by Quaternary marine sediments of illitic-smectitic composition that originate clay soils with vertic features (Entisols, Vertisols).

   Calabria, instead, presents a nearly homogeneous granite lithology. This kind of rock is fairly weatherable, and therefore landforms are generally sub-rounded and little prone to erosion. Brunification is the main soil forming process, and acidic Inceptisols are the most common soils in the Sila and Aspromonte mountain groups. The west coast is mainly rocky; along the east coast, some Pliocene marine deposits outcrops originate calcareous clayey soils similar to those of the Adriatic coast.

Besides these four "zonal" sections of the Apennine Range, along the chain "azonal" rock outcrops of old magmatic (ophiolites) and recent (Quaternary) volcanic origin (Amiata, Vico, Vesuvio, Roccamonfina, Vulture) characterise the Apennine landscapes with peculiar aspects which will be discussed separately.

3.4.5 The Main Islands

Sicily and Sardinia are the main islands of the whole Mediterranean basin. Their geological history is quite different, since Sicily is mainly constituted of sedimentary rocks (limestone, sandstone, calcarenite, clay) with minor outcrops of volcanites (in the neighbouring of the Etna volcano, east side) and metamorphic rocks in the Peloritani range (northern side), while in Sardinia magmatic rocks belonging to the Caledonian-Hercynian orogenetic cycles, both intrusive and extrusive, prevail largely over sedimentary rocks. These are especially found in the north-western part of the island (limestone) and in the tectonic depressions southwards (Quaternary terraced alluvial plain of Campidano).

Due to their geological and climatic conditions, with high summer temperature and long dry periods, both islands present many characteristic features, with soils greatly influenced by the different parent materials. Yet soils, reflecting the natural pedogenetic factors, are very different between each other, ranging from the least (Lithosols) to the most developed (Luvisols), with specific features (e.g., andic properties in the volcanic soils, vertic properties in alluvial clayey soils, mollic properties in soils developed from limestone, calcic properties in Early Pleistocene alluvial terraces).

In Sardinia, six morphological regions were identified during an early survey (Aru et al. 1991), with a mosaic of soils corresponding to the main landscape units resultant from the evolution of the main tectonic features: large granitic or basaltic plateaux in the highlands (Gallura, Nuorese), the Gennargentu Mount, the Sette Fratelli complex, the south–west side, the terraced Campidano plain, the Tirso River valley. Recently, a detailed study by Carboni et al. (2006) described a sequence of paleosols developed on different landforms (Miocene to Holocene) in the Tirso River basin (Western Sardinia), and concluded that differences in soil formation in the proximal, middle and distal sectors of the depositional areas have been determined by climate variations occurred since Late Pliocene. Furthermore, new surveys of selected areas in the Flumendosa River basin, South–East Sardinia (Dessena et al. 2002), in the basaltic plateaux of the north–west (Vacca and Buondonno 2003) and in the north–eastern calcareous complexes (Buondonno et al. 2009) give an insight on the role of parent material and topography in soil evolution under Mediterranean climate. A general trend towards *entisolization* (i.e., formation of Entisols) caused by erosion/

degradation of more developed soils such as Alfisols, Andisols, Inceptisols and Mollisols is recorded in the studied areas.

In Sicily, several soil surveys allowed identification of eighteen soil typological units, which have been recorded in the soil map of Sicily drawn up by Fierotti et al. (1988), based on lithological and climatic features. Lithosols, the less developed soils, cover approximately 9 % of the land, and Regosols approximately 13 %, while Cambisols occupy about 44 %, Vertisols 9 %, alluvial soils 10 %, and the most developed Luvisols, including *terra rossa*, 13 %, Andosols cover only 2 %. Quite recently, in the frame of the regional pilot project for land planning and soil protection from desertification (Sicilia 2007), the previous surveys have been revised, and it was found that, besides the "natural" soil development, anthropogenic soilscapes may form in consequence of land use change (Dazzi and Monteleone 2007). Deep ploughing, excavation, land levelling and widespread vineyard cultivation instead of arable farming, olive and almond grove and Mediterranean maquis determined loss of pedodiversity (Lo Papa et al. 2011) and replacement of former soils (Entisols, Inceptisols, Vertisols, Mollisols) with Anthrosols (Miscic Geofragmexeranths).

Specific contributions have been recently devoted to the study of the north–east sector of Sicily, where the Mt. Etna is responsible for peculiar (volcanic) soilscapes. Vegetation cover and land use are generally considered as the prominent factors responsible for soil development, as reported by Certini et al. (2001), who described the contrasting effect of broom and pine on pedogenesis. Consistently, Fernandez-Sanjuro et al. (2003, 2011) studied a toposequence on basaltic pyroclastic deposits and evaluated the role of skeleton fines in young volcanic soils (Entisols). Agnelli et al. (2007) studied the origin of a sequence of paleosols on the flanks of the volcano, and Dazzi (2007) reported environmental factors and land use as major driving forces of the Etna volcano soilscape.

3.5 Peculiarities

3.5.1 Ophiolites

Ophiolitic rocks are rather common in different parts of the Italian peninsula, and especially in the Apennines, where they have been studied widely [see Bini (1991) and references therein]. Irrespective of their mineralogical composition, they form a typical landscape with steep morphology; being rather impermeable, ophiolite slopes are strongly affected by erosion, with deep cuttings and more resistant rocks outcropping from the conterminous less resistant lithotypes. Hence, also soils developed from these rocks are thin and skeletal and have scarce horizon differentiation (Entisols and Inceptisols). Moreover, they are characterised by a low nutrient content (i.e., N, P, K and Ca), an imbalance between Ca and Mg, and high metal contents (Co, Cr, Cu, Fe, Mn, Ni,…). The soil mineralogical evolution is firstly addressed to the formation of 2:1 sheet silicates (vermiculite and smectite) via transformation of serpentine and chlorite; afterwards, a partially congruent dissolution (partial hydrolysis) enhances formation of Al-interstratified minerals; under temperate climate, as in Italy, pH drops, Al, Fe and metals are leached away, and free silica may precipitate.

The unusual geochemistry is generally thought to be responsible for the low chemical fertility of these soils; chemical characters are negative for vegetation that frequently presents phytotoxic symptoms [what Jenny (1980), in his last book, dated 1980, called "the serpentine syndrome"]. Therefore, native vegetation growing on these soils shows a high rate of endemism due to the ecophysiological resistance to metals acquired by local species such as *Alyssum bertoloni*, *Thymus ophioliticus*, *Stachys recta* spp. *serpentini*.

3.5.2 Volcanic Soils

Volcanic soils of Italy have been described recently by Lulli (2007), who reviewed previous works. As stated by Peccerillo (2005), Italian volcanoes differ each other in terms of lava composition, ranging from Monte Amiata trachyte to phonolite at Vico, tephrite at Vesuvio and more basic rocks at Roccamonfina, Vulture and Etna. Nevertheless, depending on elevation and climate, soil formation is strongly influenced by the nature of parent material, and andosolisation is the main process (Chesworth 1992), driven by the vitreous component, already present in the parent rock. At Monte Amiata, however, at higher elevation, under beech, the andic character is accompanied by organo-metal chelation, and podzolisation becomes an effective pedogenetic process. At Vico, tephritic-phonolitic lavas alternate with pyroclastic material, giving origin to a gradient sequence from Andosols to Vitrandic Cambisols, Dystric Cambisols and Chromic Luvisols (Lulli 2007). The Somma-Vesuvio complex, near Naples, includes soils with weak differentiation and moderately expressed andic properties, calcareous soils developed on pyroclastic-calcareous deposits and weakly developed soils (Regosols) on lapilli of the last eruption (1944). At Roccamonfina (Southern Italy), parent material is mainly pyroclastic with different degrees of weathering; the most significant features here are clay translocation and andic properties, with cryptopodzolic soils at higher elevation (Lulli 2007). The Monte Vulture, between Apulia and Lucania, shows the following climatic sequence (WRB): Andic Podzol—Dystric Andosol—Andic Cambisol. This is consistent with elevation ranging from 1,300 to 850 m (Lulli 2007). The Mt. Etna volcano, as already reported, has been studied by Certini et al. (2001) and Lo Papa et al. (2003), who point out that all the soils show vitric features (Typic Vitrixerands, Typic Udivitrands, Vitric Hapludands) related to the recent age of deposition. More recently, Dazzi (2007) and Agnelli et al. (2007) found Typic Hapludands and Andic Eutrudepts on the flanks of Etna.

Besides actual Andosols, volcanic materials spread off over the land may contribute to form soils with some andic properties (e.g., low bulk density, alkaline pH_{NaF}), not sufficient to meet criteria for Andosols, as reported by Bini and Garlato (1998) for ancient (Eocene) trachyte and riolite soils at Euganean Hills (Northern Italy) and by several scientists during soil surveys in Central and Southern Apennine (Mt. Terminillo, Maiella, Sila).

All the quoted authors agree that differences in soil classification are related to elevation, exposure and vegetation cover. Yet, broom has been recognised as an early coloniser of volcanic materials also by the great Italian poetry Giacomo Leopardi, in his poesy "The Broom" ("*La Ginestra*"):

> "Or ti riveggo in questo suol, di tristi
> lochi e dal mondo abbandonati amante,
> e d'afflitte fortune ognor compagna.
> Questi campi cosparsi
> di ceneri infeconde, e ricoperti
> dell'impietrata lava,
> che sotto i passi al peregrin risona"….

(Giacomo Leopardi, *La Ginestra*, lines 14–20; Naples, 1836).

3.6 Concluding Remarks

Soil is the result of the combined action of soil forming factors, as stated by the early Hans Jenny (Jenny 1941). In this perspective, lithology and morphology should be related to climate conditions and vegetation cover of various sites, in order to attain a more effective outlook of soil evolution. In this chapter, I reported a synthetic picture of the most significant soilscapes of Italy, with emphasis on soils developed from the main parent rocks and with characteristic geomorphology. However, as previously stated, Italy is a geologically young country, and a variety of rocks and landforms makes difficult to include soil genesis and evolution in a well-defined framework. This is what I tried to realise.

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Vegetation and Land Use

4

Andrea Giordano

4.1 Introduction

Vegetation refers to the plants which are found in a particular area. It is necessary to make distinction between natural vegetation totally unchanged, sub-natural botanically changed, semi-natural botanically and structurally changed and cultural botanically and structurally substituted. The first two are normally identified as vegetation. The last two as land use or land cover according to the circumstances. Land cover is the observed physical cover of the earth's surface, land use is the description of socio-economic function of the same area (Eurostat 2003).

Without the human intervention, Italy would have been covered everywhere by forests, with the exclusion of altitude prairies, rocks outcropping, water bodies and glaciers, but the course of the very old Italian civilisation has greatly changed the original natural vegetation, and today, we are more concerned with land use. One-third of Italy is covered by forest, but the true original forest is reduced to some thousands of protected hectares, for the rest, it is a matter of secondary, semi-natural or artificial forests. The historical human influences on the Italian mountains and then on vegetation, and soil has been awful great as Hall (2005) notes "Since the mid-nineteenth century, dramatic migration away from most Apennine and Alpine valleys corresponded with rapid revegetation here or dramatic erosion there".

The agricultural land uses once were connected with the original soil fertility and with the reconstitution of fertility by means of an integrated model according which a part of the produced biomass returns to soil. Agriculture mechanisation and chemical fertilisation have made great distance from this model.

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It is not in the intention of the writer of this chapter to revise all the soil maps edited in the last 30 years by the different authors. Only some maps are mentioned for the relationships soil-vegetation and/or soil-land uses.

4.2 Vegetation and Land Use as Driving Factors of Pedogenesis

With reference to vegetation, three main lines will be developed as follows:

- the indispensable contribution of vegetation to the origin of the soil,
- vegetation components and their specific influence on soil,
- humus integration in the soil.

As far as the land use is concerned, items are agriculture, tree plantations, urban and infrastructures[1].

4.2.1 Vegetation

Soil starts living when some organic matter, even minimal, produced by vegetation is combined with the mineral fraction provided by weathered rocks. The first to start on the bare rock are the lichens with the following actions (Wilson and Jones 1985):

[1] What we call pedogenesis is a complex integration of several factors: lithology, climate and biotic organisms. This integration is taken as a paradigm in the modern approach to soil survey and cartography, being the rational base of the land regions and land systems methodology (Costantini et al. 2004). This methodology being integrated is useful not only for soil but also for other environmental components like vegetation (Dissegna et al. 1997 and Di Gennaro 2002). Vegetation, due its high variability in space and time, is not comprised in the set of parameters selected for the definition of the Soil Regions of Europe but the database of the European Soils makes possible the interpolation between the soilscapes and the natural ecosystems (Joint Research Centre 1998).

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Fig. 4.1 In this stony altitude barren land, the organic matter of the vegetation (*Cetrario-Loiseleurietum* association, Pignatti 1998) is the main agent for pedogenesis characterised by Turbic Cryosol (Skeletic). Valle Argentera 2,700 m of altitude, Sauze di Cesana (province of Turin). Coin diameter is 2.3 cm

- corrosion of the primary minerals (plagioclase, orthoclase, olivine, etc.) present in unweathered rocks
- precipitation of soluble and crystalline oxalates
- formation of oxides of iron and gel of aluminium and silica.

Next come the mycorrhyzae able to secrete oxalic and phenolic acids which on the one hand chelate organic matter with heavy metals and on the other hand continue the weathering of the rocks (Cecconi et al. 1989). Then is the turn of mosses, whose felt body absorbs water accelerating the rock weathering and creating an organic-mineral substratum, which favours the growth of superior vascular plants. Little by little, the organic matter grows up and undergoes transformations whose end is the formation of humus (Fig. 4.1).

At the same time, the vegetation cover becomes denser and starts the competition. The overcoming more resistant species define the influence of the vegetation type called climax.[2] The soil corresponding to this stage is called pedoclimax (Fig. 4.2).

The just presented scheme has many exceptions. In Mediterranean environments, the soils have been often influenced by ecological conditions different from the actual ones and so they are not in accordance with the vegetation (Mancini 1963). Since vegetation may be drastically changed by man, not always the soils reflect the influence of the vegetation climax. But in certain cases, the vegetation influence on soil is so determinant to have induced Palmann et al. (1949) to define *analogous soils* that, formed under the same vegetation canopy but on different lithology, show forms of humus and superficial horizons similar while the deep horizons are different. In other cases, it is the soil that conditions the vegetation: wise farmers seed Alfalfa (*Medicago sativa* L.) on calcareous substratum and Rabbit foot clover (*Trifolium arvense* L.) on a siliceous one.

Vegetation is strictly linked to climate, and the phytoclimatic belts are an indivisible whole of climate and vegetation. A detailed soil survey of the watershed Bitto di Gerola in the Alpi Orobiche (Marchisio et al. 1994) is an example of that whole. The watershed, being quite homogeneous as far as the lithology, has been divided in three altitudinal belts with the inherent soil temperature regime: the mesic belt (400–1,000 m) has Chestnut (*Castanea sativa Miller*) and Dystric and Humic Cambisols. The frigid belt (1,000–1,700 m) has Beech (*Fagus sylvatica L.*) mixed with conifers, and the same Cambisols already seen with the addition of Cambic Podzols. The third (1,700–2,400 m) has alpine prairie with, once more, the Cambisols but the Podzol becomes Haplic and appear Umbric and Humic Regosols and Fibric Histosols in some lowlands. The conclusion is that starting from a lowest common denominator of Cambisols, the pedogenesis changes according to vegetation and climate.

In the light of these examples, the role of the vegetation on the pedogenesis must be considered taking into account also the other factors of soil formation. A specific type of vegetation exists where climate, lithology, geomorphology and soil are suitable, and vice versa, a given soil is the result not only of vegetation but also of the other environmental factors related to vegetation. It results that to a certain extent is misleading to deal with only one environmental component independently from the others. Being aware of this limit about the influence on pedogenesis of the vegetation alone, the link soil-vegetation and soil-land use is nevertheless discussed with a special emphasis.

Vegetation contributes to the pedogenesis physically, chemically and biologically

Physically by as follows:

- breaking up of the parent material by action of the roots,
- alternation of humid and dry phases determined by the root growth,
- stabilization of the soil structure performed by rootlets enveloping soil constituents and by root exudates,
- creating channels corresponding to the dead roots that become preferential habitats for soil biotic organisms and for water circulation,
- increasing the soil water storage,
- decreasing the compaction of the clay soils,
- mitigation of excessive temperatures,
- reduction of the rainfall kinetic energy and the consequent splash erosion,
- protection against soil erosion of both types water and wind,

[2] From a theoretical point of view during the climax phase, as much elements are taken from the soil as are returned and as much activity is produced as consumed. This climax condition is not stable, due to the natural and human events. Progression towards a new climax and regression to the previous one are phases registered in the soil profile contributing to its high variability (Sanesi 2000).

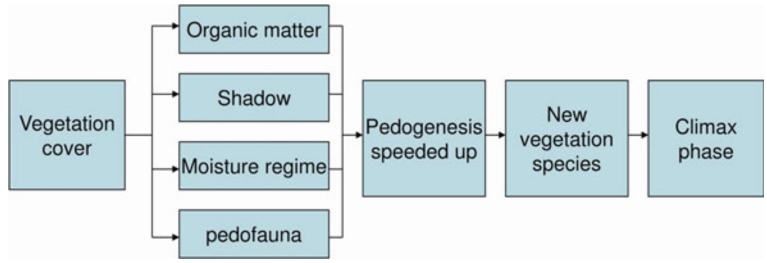

Fig. 4.2 Dynamic evolution of the vegetation and soils climax phases

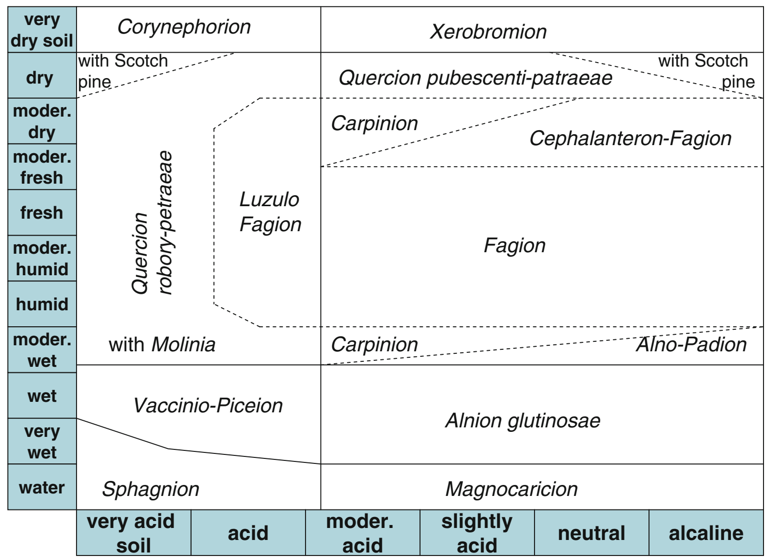

Fig. 4.3 Botanical alliances of medio-European woods and neighbouring herbaceous formations in relation to the soil pH and water content

- prevention of landslides, especially in case of trees of reduced height and well developed root system.

Chemically by as follows:

- modifying the chemical composition of the rain water (total deposition, throughflow and stemflow),
- continuous recycling of the bases,
- increase of carbonic acid active in weathering the soil mineral fraction,
- increase of the cation-exchange capacity,
- formation of chelating compounds in presence of iron and aluminium,
- creating a reservoir of nitrogen and other elements,
- favouring migration or accumulation of organo-mineral substances,
- acidification due to the organic matter accumulation in the biomass and in the soil.[3]

Biologically by as follows:

- creation of a medium suitable to microbiotic and fungal flora. Microbes and fungi produce, respectively, gums and hyphae which are stabilizers of the soil structure,
- production of carbonic acid able to alter rocks and mineral substances,
- recycle of the organic matter produced by vegetation.

This last point has become today crucial since it concerns the carbon balance and the function of soil as a carbon sink: in a well-managed forest, the amount of carbon entering in the soil is greater than the amount going out from the soil.

The different vegetation components (site, tree, branches, leaves, needles, roots, litter and humus) have specific influence on soil.

It has been underlined the importance of vegetation on pedogenesis, but we must not forget the soil suitability to specific botanical species. In the Fig. 4.3, we may note that the main medio-European botanical alliances (therefore those of north Italy too) are distributed according to pH and soil water content.

As a partial modification to the soil suitability to specific botanical species, we must note that the plants have, to a certain extent, the possibility to change the edaphic condition for their better adaptation. One impressive example is

[3] Plant assimilate more cations than anions. Hence, the production of biomass is associated to the release of protons in the soil. The reverse process takes course during the mineralisation of the organic matter which consume H^+. An ecosystem is in a steady status when production and mineralisation of organic matter are equivalent. If the biomass produced is subtracted to the forest, the rate of acidification increases.

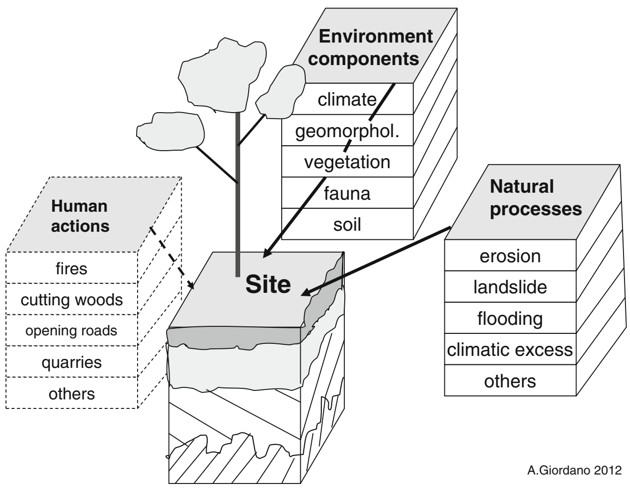

Fig. 4.4 The site is defined by environment components and natural processes. Human actions, strictly speaking, are not part of the site nevertheless they have to be considered for practical purposes

the presence of Chestnut tree on calcareous pliocenic sediments in the Langhe area in Piedmont. Initially, favoured by man, the Chestnut has created, along the centuries, a humus and an A horizon slightly acid favourable for its regeneration.

Site

This term "site" refers to "an area sufficiently uniform in soil, climate and natural biotic conditions to produce a particular climax vegetation" and then climax vegetation "is the highest ecological development of a plant community capable of perpetuation under the prevailing climatic and edaphic conditions" (Soil Conservation Society of America 1976, Fig. 4.4). The concept of site is very important in soil survey, because it has been used by CSIRO (Commonwealth Scientific and Industrial Research Organisation) as the most detailed level of land classification (Christian and Stewart 1968).

The forest site may be compared to a two-storied house (Galoux 1971). The highest floor is destined to the reception of the sun radiation and consequently to the chlorophyllian function and organic matter production. The ground floor has a double function: it supports the vegetal bodies and feeds the plants with the nutrients. The tree canopy not only intercepts the sun radiation but also the rainfall whose kinetic energy is reduced. The stemflow concentrates water, which is often acid for air pollution, in a limited area that becomes acid. Leaching and podzolisation processes are frequently enhanced close to the foot of trees. From the canopy, there is a large contribution of organic matter: leaves, needles branches and wood when trees have come to their end (Table 4.1).

Roots

The growing roots fill the large pores which, due to the pressure, have the tendency to close the small pores. Both

Table 4.1 Influence of the different tree components on pedogenesis

Tree components	Modifications: hydrological cycle	Modifications: biochemical cycle
Branches and leaves	A rainfall fraction is intercepted	Chemical status of the rain water is modified
litter	Rainfall kinetic energy is lowered	Microfauna metabolism is activated by the raw material
roots	Water permeability is decreased (young plants) is increased (old plants)	Elements from the soil and from the rocks are extracted
humus	Infiltration and water storage are increased Soil compaction is prevented	Base of the nutrient cycle
Fall of branches and dead trees	Superficial runoff is modified	Biological activity is increased
Fall of living trees	Big clods retained by roots are exposed to the air	Regeneration of some species is encouraged

the actions reduce the soil hydraulic conductivity, especially during the pioneer phase (Quinton 1996). When the roots decay the large pores become empty and the hydraulic conductivity is improved counterbalancing the reduction operated by the young roots. The fine roots of the plants are renewed every year at the rate of 60–90 % giving to the soil an organic matter contribution of several tons per hectare.

Litter

Litter contributes to the site equilibrium: recycles the bases necessary to plants, protects the soil against water erosion and makes an easy water percolation in the deep soil layers.

Different plants produce litter of different characteristics: broadleaves have a litter with C/N ratio[4] ranging from 12 for Elder (*Sambucus nigra* L.) to 45 for Beech when conifers have a C/N ratio ranging from 48 for Norway spruce (*Picea abies* (L. H. Karst) to 77 for European larch (*Larix decidua* Mill.) (Susmel 1970 in Zanella et al. 2001).

The production and decomposition rate of the litter varies in accordance with the botanical species having effect on the amount of organic matter accumulated in the soil and on the distribution in the soil profile. Usually, the accumulation is in the O and A horizons, but in the Spodosols, for instance, there is a consistent accumulation in the B horizon. During the decomposition of the organic matter, the C/N ratio diminishes and gets stabilized according to the humus type: 10–15 for forestry mull, 18–25 for moder and 25–40 for mor (Duchaufour 1984).

Litter of coniferous trees or heath shrubs is rich in lignin, lipids, resins and waxes. These last are inhibitors of organic matter alteration. Conifers litter takes approximately

[4] C/N is the ratio between the total organic carbon and the total nitrogen. This ratio provides a general assessment about the litter decomposition rate which is faster with low values.

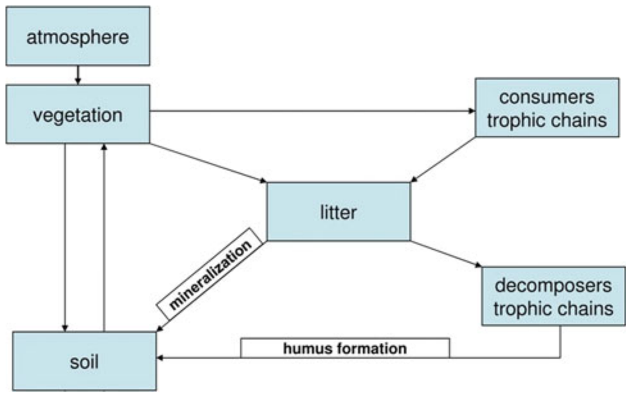

Fig. 4.5 Vegetation influence on pedogenesis (UNESCO–UNEP–FAO 1980)

6 years in temperate climate to be transformed into humus when one year is enough for deciduous trees (Toutain 1987). Litter of decidous trees produces nitrogen compounds, carbohydrates and cellulose. Litter tends to accumulate on the soil where the climate is cold, the vegetative period is short and where the microbial activity is poor. Slowly or fast, the litter is transformed in humus through complex phases summarised in Fig. 4.5.

To transform litter in humus, it is especially necessary the action of micro-organisms, which present a large spectrum of physiological and metabolic fluctuations that enable the micro-organisms to set on-going pedogenesis nearly everywhere. Wilde (1958) describes the link "vegetation-soil biology" in an impressive way: "few events in our planet can match in complexity and immutable wisdom the drama performed on the forest floor and inside the forest litter by the legions of beetles, larvae, centipedes, millipedes, ants, sow bugs, ticks, mites, nematodes, rotifers, protozoa, and many creatures too small to be seen. All of these are engaged in destruction, metabolism, reproduction, and mortal struggle to free the world from piling-up organic remains".

Humus

Humus maintains the soil with a high microbiotic activity which improves the soil structure, ameliorates the soil permeability, increases the water storage and conditions the mineral nutrients for trees (Duchaufour 1989). An excessive accumulation of humus may depress the natural regeneration. Litter and humus not only liberate the elements necessary to plants but influence the seeds according to an inverse correlation between the biomass of sprouts and the thickness of organic material accumulated on soil surface (Vos 1991 in Dowgiallo 1998). In addition to this certain humus have phytotoxic substances inhibiting the growth of grasses under canopy. This may be the reason why in a dense Beech stand the grass cover is absent. An example of phytotoxicity is provided by the humus of *Cistus monspeliensis* L. which is toxic for other botanical species, so the *Cistus* has the tendency to grow alone. With these considerations, it seems that the influence of humus surpasses sometimes that of the soil, but this distinction is misleading because humus cannot be considered independently from vegetation and soil in accordance with the concept of "ecotessera sampling both soil and vegetation" (Buol et al. 1980). In certain cases, the human influence has minimised the role of humus on soil formation. A clear example comes from the Chestnut litter that has been harvested for centuries to be used as straw for animals and then as fertilizer for the cultivated fields.

Due to the importance of humus, many authors have undertaken its classification: Kubiena (1952); Wilde (1966); Hartmann (1970); Duchaufour (1977); Delecour (1980); Klinka et al. (1981); Green et al. (1993); AFES (Jabiol et al. 1995) and Zanella et al. (2011). The main forms of humus considered are as follows:

- mull (*eu*, *meso*, *oligo*, *dys* for the terrestrial forms of humus, and *limi* and *sapri* for the semiterrestrial) with rapid mineralisation and humification: the organic horizon is thin, on the contrary, the mineral horizon A is thick. Mull is the form of humus typical of some broadleaves trees and also of the prairies that contribute to the total amount of organic matter with grass roots rapidly decomposed. Soils with mull humus are fertile because nutrients in available form have a rapid turnover from plant to soil and vice versa,
- amphii, an unstable form of humus easily passing to moder or mor, is typical of the regions with long and dry summer (*pachy*, *eumeso*, *eumacro*, *dys* for terrestrial and *humi*, *mesi*, *fibri* for semiterrestrial).
- moder (*eu*, *meso*, *dys* for terrestrial, and *sapri*, *humi*, *mesi*, *fibri* for semi-terrestrial) has humification processes overcoming those of the mineralisation, has a reduced worms activity and an increasing importance of arthropods and collembolan,
- mor (*hemi*, *humi*, *eu* for terrestrial, and *mesi*, *fibri* for semiterrestrial), has no A horizon but has a strong development of O horizon with reduced influence of fauna. The O horizon is often felted by the fungi iphae modifying the water circulation,
- tangel (*dys*, *eu*) terrestrial form of acid humus on carbonatic rocks with sharp difference of pH according to the soil depth,
- anmoor (*eu*, *sapri*, *limi*), semi-terrestrial humus characterised by a thick, massive and plastic A horizon.

The scheme of the European tree of humus forms classification is presented in Fig. 4.6.

Main Pedogenic Processes Influenced by Vegetation and Organic Matter

All pedogenic processes are influenced by vegetation and by the inherent humus. "Probably the five most important pedogenic processes going on in a tessera are capture of

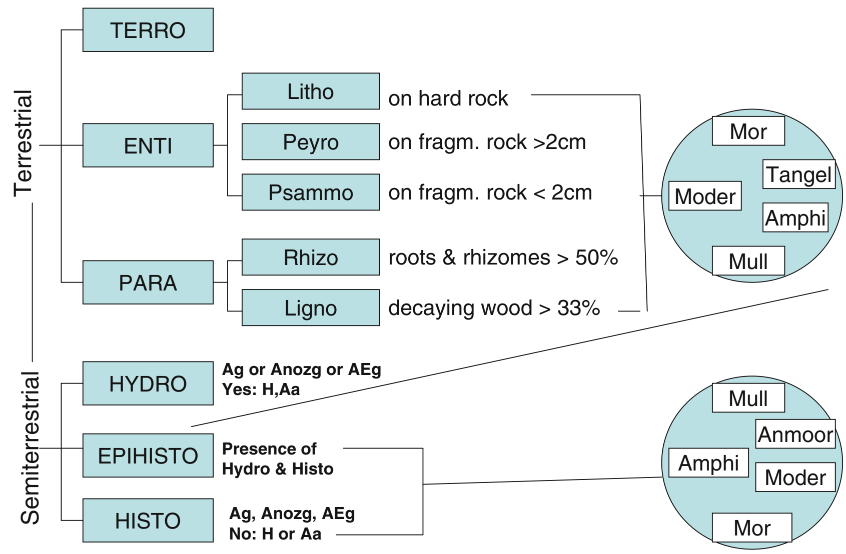

Fig. 4.6 First dichotomy separation of the European tree of humus forms (Zanella et al. 2011, mod:)

energy and substance through photosynthesis, the reverse of it which is decomposition of plant residues, resultant biocycling, cation exchange, and formation of organomineral complexes" (Buol et al. 1980). In this chapter are briefly described only three fundamental processes where the role of the vegetation factor is determinant for the soil evolution in some Italian environments.

- Melanization: It is the process which makes dark the soil (mollic or umbric horizon) for the influence of accumulation of resistant ligno-proteinic residues and translocation in the soil profile of organo-mineral colloids. Umbrisols, Phaeozems and Kastanozems refer to these conditions.
- Paludization: It is the accumulation of organic materials in a poorly drained site where the anaerobic conditions have allowed a net gain of organic matter through time. Histosols are soils characterised by this process.
- Podzolization: Organic matter belonging to the mor humus migrates and precipitates with iron and aluminium in an illuvial horizon which defines the soils as Podzols.

Several prefix qualifiers of the FAO et al. (2006) classification indicate an influence of vegetation, humus or organic matter in the soil profile. These prefixes are the following: folic, histic, lignic, humic, umbric, mollic, hemic, rendzic, plaggic, sapric and garbic.

4.2.2 Land Use

Before entering in specific aspects of the land use, it is worthy to remember that the soil has the maximum benefits from the natural vegetation and not from the harvested crops (Fig. 4.7). This means that is always necessary to compensate the losses of organic matter suffered by agricultural soils.

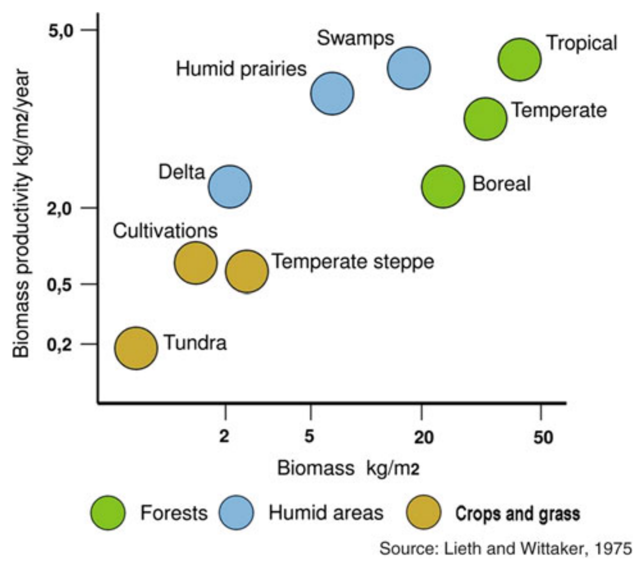

Fig. 4.7 Production and productivity of the main ecosystems

Agriculture

A short summary of the historical phases of land uses and their consequences on pedogenesis is presented in Table 4.2.

The old wise management of agricultural soils was based on an equilibrium between the fertility subtracted from the soil and the fertility given back to soil. Historical documents indicate that during the Middle Age and the Renaissance periods, the agriculture sustainability was reached by a system of combined crops and cattle breeding: one hectare cultivated with cereals was fertilised by the manure obtained by several hectares of grazing land. This

Table 4.2 Influence of land use on pedogenesis

Period	Land use	Consequences on pedogenesis
Civilization dawning	Collecting fruits, hunting fishing, negligible biomass drawing	None
Animals domestication	Forest fires to enlarge pasture land	Burning of humus soil profile rejuvenating Increase of erosion risk
Agriculture (mainly shifting cultivation)	Soil ploughing at a depth of 10-20 cm	Consumption of organic matter constituting the natural soil fertility. Soil profile acidification
Stable agriculture	Trenching and irrigation	Alteration or destruction of the original soil profile. Salinization if uncorrected irrigation
Modern stable agriculture	Mechanization New techniques irrigation and fertlization	The more and more complex management models make soil degradation risk increased

Source: Giordano 1999

belongs to the past and therefore to an entirely different socio-economic situation.

In the last decades, the agriculture has developed for many reasons because of the practices that have increased the production but contemporaneously have degraded the soil. Doubts exist about the sustainability of the modern agriculture. Each operation involving the soil has an impact. It is important to verify costs and benefits being aware that soil is a non-renewable resource. The main soil modifications caused by the agriculture intensification are listed below:

- modification of the natural sequence of soil horizons. Deep horizons deprived of nutrients are often brought at the soil surface,
- loss of organic matter. Intensive and deep tillage as well as the transformation of prairies in crop fields have reduced the amount of soil organic matter. Ten years after the change from prairie to agricultural field, the organic matter content is approximately two times less with respect to the initial prairie. If the manure, which is supposed to replace the consumed soil organic matter, is not strewn in the fields, the soil becomes poorer and weakly structured,
- loss of the soil structure. Probably, it is the most harmful effect determined by agricultural practices. A good soil structure with the inherent porosity and permeability is the best guarantee against soil erosion. The soil structure created by colloidal substances (clay, humus and oxides of iron and aluminium) is broken by the mechanical machineries used for ploughing and tilling the soil. What is good for crops not necessarily is good for soil. This is a frequent case in the vineyards that are worked with rotarytiller in order to avoid the water capillary rising and evaporation. After these operations, the soil becomes a powder prone to be eroded by splash and rill erosion,
- loss of chemical fertility due to monoculture and irrigation which reduce the nutrient availability,
- creation of an impermeable hard pan at the soil depth attained by the continuous ploughing. The roots of the crops cannot go down and sometimes suffer for the presence of a perched groundwater table standing on the hard pan,
- leaching processes, they are often favoured by irrigation practices. The soils may pass from Cambisols to Luvisols,
- salinization, the use for irrigation of salty or brackish water may create Solonchaks, or Solonetz in places where they did not exist before,
- soil pollution, pesticides and herbicides affect the pedofauna that faces a new soil chemical status determined by substances that do not exist in nature. The death or the replacement of the pedofauna changes the soil complex metabolic cycle.

In same cases, the deep ploughing may be beneficial. Soils developed on soft rocks like marl, siltite or weakly cemented sandstone may easily integrate the parent material with the superficial soil horizons accelerating the rate of the rock weathering and therefore the pedogenesis. Reclamation projects change in a drastic manner the pedogenetic process converting Subaquatic Histosols of naturalistic value but without crop possibilities to Lignic or Fibric or Hemic or Sapric Histosols with less naturalistic value but suitable for several crops. After drainage, a Luvic Gleysols may become a Gleyic Luvisols with relevant advantages for crop production. Petric Calcisol may be converted to Haplic Calcisol after breakage of the petrocalcic horizon.

Permanent meadows and prairies maintain the soil fertility in better conditions than annual crops. The reason is that part of the produced biomass returns to soil as manure, that is, organic matter enriched with micro-organisms. Permanent crops also provide the soil with some organic matter coming from the leaves and spontaneous weeds that at the same time protect the soil against erosion. Permanent crops must not rotary tilled as it was customary in a recent past, especially in vineyards.

The future common agriculture policy (CAP) foresees a proposal for increasing the importance of the link vegetation-soil resumed with the expression "greening the actual CAP" (Povellato and Longhitano 2011). Three environmental requisites shall regulate EU contributes as follows:

- diversification of the cultivations,
- maintenance of surfaces devoted to fodder,
- reservation of 7 % of the farm surface to areas of ecological interest.

Tree Plantations

Following the EU directive 2078/92 *set aside* and the successive directives 2080/92 and 1257/99, some agricultural fields have been transformed in plantations characterised by tree whose wood has an economic value or by the presence of plants able to produce in a short time an important biomass to be processed as energetic material. The soil can take benefit from these plantations from the important production of leaves and organic remains that every year reach the ground. The best soil enrichment in organic matter and nitrogen may be obtained with a wise consociation of the botanical species. The following consociation proves to enrich the soil in organic matter: Walnut (*Juglans regia* L.), Birdcherry tree (*Prunus avium* L.), Service tree (*Sorbus domestica* L.), *Sorbus torminalis* (L. Crantz) as principal species and Hazelnut (*Corylus avellana* L.), Oriental plane (*Platanus orientalis* L.), Willow (*Salix sp*.), Alder (*Alnus cordata* Loisel. Defs.), Elder, *Elaeagnus umbellata* L and Elm (*Ulmus sp*) as companion species (Buresti et al. 1997).

Urban and Infrastructure

In the urban environment, the soils not covered by buildings or roads are limited. They consist of public parks, private gardens, rows of trees along the avenues and banks of eventual water courses. These places are so intensively managed by man that does not exist a natural pedogenesis. In these conditions, the plants cannot use the organic vegetal remains that are accurately taken out, so the soil fertility is artificially maintained. One problem is the protection against pollution, considering that, especially in the parks and gardens, there are children around. The soil must be monitored for heavy metals and eventual other noxious components. The infrastructures have the same problems seen for urban areas. In the surroundings of some industrial towns, there are or there have been places contaminated by discharge of industrial toxic substances and entirely deprived of vegetation, called today *technologic deserts* with soils belonging to Spolic or Ekranic Technosols (Fig. 4.8).

Land take for urbanism and infrastructure is a national problem in Italy. The actual urbanised surface in Italy is 7.6 % with a maximum in Lombardy where it reaches 14 % (Bianchi and Zanchini 2011). Taking the example of Piedmont, we see that in the period 1991–2001, the surfaces occupied by urbanism and infrastructures passed from 7.5 to 8.01 % in the plain, from 7.6 to 8.01 % in the hills and from 1.07 to 1.09 % in the mountains (CSI Piemonte, Consorzio Sistemi Informativi 2008). The soils consumed are, nearly always, those belonging to the fertile and level, or gently sloping areas as indicated by Boni (2010) in Table 4.3.

Fig. 4.8 Toxic industrial waste disposal, approximately 30 years old. Technic hard rock within 5 cm Ekranic Technosol (Toxic, Ruptic). Basse di Stura, Turin

Table 4.3 Land take in Piedmont for urbanism and infrastructure

Class of land capability	1991 (ha)	2005 (ha)	land take (ha)	land take (%)
I	101,060	99,145	1,915	1,89
II	356,293	349,416	6,877	1,93
III	312,938	755,707	14,584	1,85

Boni 2010

80 % of the land of the plain belong to the I, II and III class of capability where the majority of the land take occurs (*Source* Boni 2010)

4.3 Vegetation and Land Use in Forming Soils of Italy

Vegetation

The production of biomass of woods is quite different from that of agricultural fields (Fig. 4.7). This consideration has to be kept in mind if we want a sustainable development, that is, the best possible compromise between the laws of the nature and the human laws.

Forest surfaces are increasing everywhere in Italy (Table 4.4) almost due to the abandonment of marginal agricultural lands where the pedogenesis after a number of agricultural cycles returns to that of the previous times but with differences imposed by the climatic changes. Afforestation and reforestation projects are today limited in comparison with the 1930–1980 period. In the present time, they are mainly carried out mixing conifers and broadleaves minimising the risk of fire and avoiding the soil acidification typical of the use of the conifers alone (Table 4.5). Coppices largely spread on the Italian mountains are in many places converted to high stands, and so, soils are returning to their origin. The institution of new natural parks (national and regional) create the premises for a pedogenesis more in equilibrium with the environment.

Forest fire is one of the main problems for nature conservation in Italy. The burning of the forest biomass have several noxious consequences for the soil:

Table 4.4 Forest surface (ha) in Italy (*Source* INFC 2005)

	Coni-fers a	Hard wood b	Mixed c	Unclas-sified d	Total a,b,c,d	Other forest surfaces	Total forest	Territo-rial surfaces
North West	280,379	1,278,349	218,195	137,260	1,914,183	172,697	2,086,881	5,794,614
North East	630,185	946,025	273,275	147,590	1,997,075	195,527	2,192,602	6,197,766
Centre	65,931	1,772,921	161,969	221,762	2,222,583	233,145	2,455,728	5,934,796
South	125,704	1,307,474	127,072	225,335	1,785,585	395,317	2,180,902	7,326,398
Islands	70,608	638,144	60,374	70,648	839,774	711,646	1,551,420	4,979,271
Italy	1,172,807	5,942,913	840,885	802,595	8,759,200	1,708,333	10,467,533	30,132,845
					29.1%	5.6 %	34.7%	100 %

Source: INFC 2005

Table 4.5 Main soil changes after reforestation with conifers (*Source* Giordano 2002)

Physical	Bulk density	Tendency to decrease.
	Structure	Degradation and instability. Decrease of porosity.
	Particles translocation	Eluviation of upper horizons and illuviation down.
Chemical	pH	Decrease for three main reasons: cations absorption, organic acids dissociation, aluminum from weathering.
	Exchange acidity	Increase owing to the hydrogen substituting cations
	Loss of bases	Greater than decidous due also to the rapid growrh
Biological	Humus	Organic matter scarcely decomposed. Discontinuity between organic and mineral horizons.
	Micro-fauna	Arthropods development to the detriment of worms
	Micro-flora	Strong development of fungi

(A. Giordano 2002)

- loss of soil organic matter (litter and humus) with consequent emission of CO_2 in the atmosphere,
- combustion of organic colloids makes soil structure weaker and increases soil erodibility (Torri and Borselli 2000). At the same time, the neoformed hydrophobic substances, similar to tar, infiltrate into the soil for a few centimetres, become solid and form an impermeable layer that makes the upper soil easily eroded by a hypodermic water flux (Fig. 4.9).
- high temperature during the fire and pH change modify the microflora and microfauna and allow the invasion of unwanted botanical species.

Acidification of the forest soils is an other problem. Tendency to acidification is quite normal in forest soils where the presence in the humus of several organic acids contribute to lower the pH. The cut of wood and the transfer outside of the biomass deprive the soil of the mineral bases belonging to the biological cycle, and consequently, the soil cation-exchange capacity is saturated by an additional amount of hydrogen. The acid rain containing sulphuric and nitric acid exacerbates the problem, causing damages not only to the vegetation but especially to the soil (Fig. 4.10).

For evidencing the vegetation influence on the soil, it is necessary to indicate the main environments, and for this purpose, Italian vegetation may be conveniently divided in five broad belts (Pignatti 1997) as follows:

- Alpine belt with herbaceous cover.
- Sub-Alpine belt with conifers reaching 2,000–2,400 m of altitude.
- Mountain belt with Beech that usually goes from 1,000 to 1,700 m above sea level but in the south may reach 2000 m.

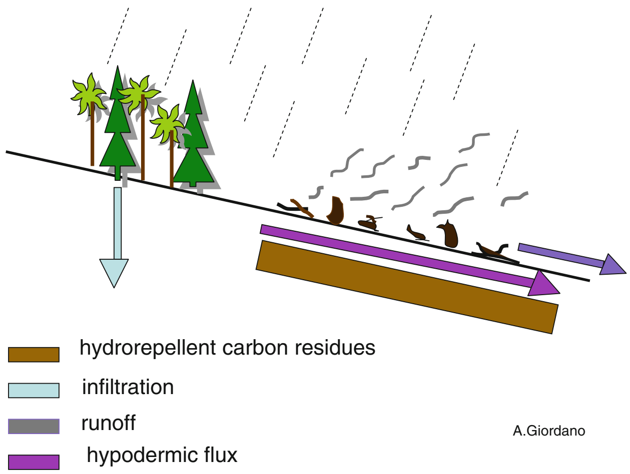

Fig. 4.9 Fire consequence on soil erosion

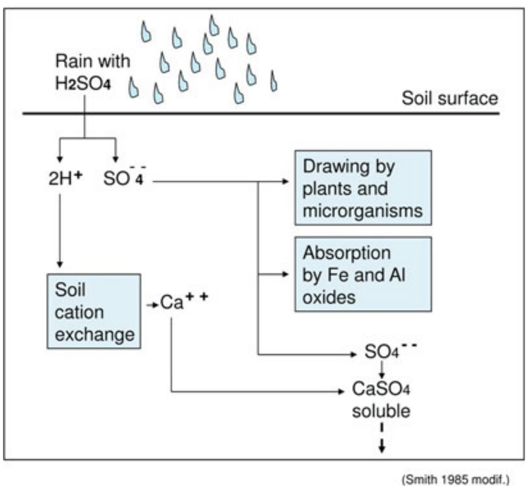

Fig. 4.10 Soil modification caused by acid rain

- Sub-Mediterranean belt characterised by oak formations Sessile oak (*Quercus petraea* (Mattuschka) Liebl.), Pubescent oak (*Quercus pubescens* Willd) and European oak (*Quercus cerris* L.), with altitudinal limits different according to the latitudinal position.
- Mediterranean belt with Holm oak. In warm areas, the belt can go from the sea level to an altitude of 1,000 m.

Land Use

In this section, only the general and widespread land uses are discussed.

Mixed agriculture (annual and permanent crops on the same field) typical of many small Italian farms was performed in order to minimise the risk of crops loss. Today, the traditional form has undergone several modifications, and we speak of *association* to indicate a combination of different annual crops on the same field and *consociation* a combination of different annual crops in different field of the same farm (Grillotti Di Giacomo 2000). Permanent crops are cultivated separately, but it must be observed that traditional, mixed agriculture is still present in several parts of Italy. The soil under the different form of mixed agriculture receives the benefit of a reduced loss of nutrients.

Open fields are today increasing following the actual augmentation of fields and farms sizes. The human impact on soil profile and on susceptibility to erosion is greater on open fields than on closed fields (*bocage*) characterised by small size and by elements of separation as ditches, tree rows, stone walls, tracks, etc.

The open fields may be also one cause of the decrease of soil organic matter. Once the cattle were distributed in nearly all the farms, while today they are concentrated in big cattle breeding farms. The consequences are as follows:

- loss of organic matter in the majority of the farms,
- substitution of meadows and permanent prairies with annual crops. Besides the loss of organic matter, annual crops exert a less effective soil protection,
- excess of animal wastes in a reduced number of farms with pollution problems for the soil and the groundwater table.

In the mountain prairies, a disequilibrium between the land-carrying capacity and the number of cattle often occurs. Some places are overgrazed, soil is compacted and eroded, whereas other places are abandoned, with invasion of unwanted shrubs and weeds that modify humus and soil. The terraced fields of the mountain agriculture are sustainable on condition of maintenance continuity. In the opposite case, landslide and erosion occur.

The risk of soil erosion is today very high in the hilly regions of Italy. In the past, the up and down ploughing was performed only for tree rows. The cultivations were practiced almost by contour lines. The steep slopes were managed with terraces. At the present, terraces, except specific cases, do not fit with mechanized modern agriculture; therefore, on steep slopes (>30 %), the alternative to forest or grass cover is the up and down ploughing which induces soil erosion.

Other operations typical of a modern intensive agriculture contribute to increase soil erosion risk. Among them, the levelling of the surfaces has an important place. With such operation, the natural drainage network is obliterated removing soil from relieves and filling up valleys. The soil profile is destroyed or buried. In addition, the buried old drainage network becomes preferential way for run-off and erosion. Land-use change with important earth movements is often questionable if not negative (Fig. 4.11).

In the plains, the substitution of the irrigation canals with underground tubes modifies not only the soil moisture regime close to the water canals but also the landscape,

Fig. 4.11 Change of land use from a *Ostryo-Carpinetum* coppice to agriculture. Earth movement has modified water circulation and soil stability. Abbadia di Naro (province of Pesaro and Urbino)

which becomes more banal for the disappearance of the running water and the tree rows that traditionally were bordering the canals. The fields increase in size and decrease in beauty.

New types of agriculture management are coming out: organic and integrated agriculture are the principal. Both of them being based on the use of different forms of organic matter are beneficial to soil, as it may be seen by the soil profile evolving towards types more similar to the original ones.

Green houses for horticulture and floriculture occupy surfaces every year larger. The soil in many cases is used as inert substratum for producing crops artificially fed with fertilizers and organic materials. In several cases, the soil develops a consistent A horizon. On the other hand, salts coming at the surface by capillarity remain at the surface without the normal leaching operated by rainfall.

Some agricultural surfaces have been covered in the last decade by photovoltaic panels. It is too early to verify which can be the modifications of soils under the panels. Researches are ongoing to ascertain two aspects: changes in soil biology and possible soil contamination caused by the lead and cadmium present in the panels (Dazzi and Lo Papa (2012), in this volume).

4.3.1 Soils of the Alps and Prealps

Western Alps, Part of the Central Alps and Prealps

Above 3,000 m, the influence of the vegetation is very limited even if some sparse specimens can grow. Mondino (2007) reports the presence of *Poa laxa* Haenke, *Ranunculus glacialis* L., *Saxifraga bryoides* L. and *Leucanthemopsis alpine* (L. Hyw.) at an altitude of 3,615 m on the southern side of the Monte Rosa range. In these conditions, what can be called “soil”, independently from the type of parent material, is usually a Hyperskeletic Cryosol[5] whose pH is very low due to the intensive water percolation.

Between 2,400 and 3,000 m above sea level, polygonal and reticular soils, similar to those of the Arctic zone, are associated with soils of small mounds tied up by tufts of grass or shrubs (Fig. 4.1). Then, the freezing and thawing with the consequent solifluction give rise to a humpy micromorphology, particularly represented in Valle di Susa, Valtellina, Val Chiavenna and Val Malenco. The soils are Lithic Cryosols.

In the belt between 1,800 and 2,400 m of altitude, pasture is a priority use; this area is rather homogeneous: prairies with or without trees, which are Larch, Cembran pine (*Pinus cembra* L.), and Mugho pine (*Pinus mugo* Mirb.), this last only on carbonatic rocks. Larch[6] being a pioneer species does not like soils too rich in organic matter. When the oligomull of the Larch becomes a thick dysmoder, germination decreases and the site tends to be occupied only by grasses. With a reduced production of humus, the site comes back to a pioneer phase allowing the larch to germinate again. Many human interventions in this cycle have created the good conditions for a permanent germination of the larch seeds. The Cembran pine, on the contrary, tolerates the accumulation of raw organic matter; therefore, it regenerates and favours the development of Haplic Podzols. In very degraded overgrazed environments, the Rhododendron (*Rhododendron ferrugineum* L.) becomes dominant, and the soil is covered by a thick layer of mor whose dense root network prevents other plants from growing, but at the same, time protects the soil against erosion. Invading non-palatable species is also *Nardus stricta* L. which forms a sequence of tufts rich in organic matter inter-mixed with roots. On carbonatic rocks, the organic matter, well stabilised by calcium cations, undergoes a limited decomposition and tends to accumulate giving minor opportunity to the Larch growth.

On unconsolidated materials on steep slopes, like lateral moraines or colluvial deposits, the vegetation has reduced possibilities to take root and makes the soil prone to be eroded (Fig. 4.12).

From 800 to 1,800 m of altitude on southern exposure, there are, or there have been, agriculture fields influenced by the organic matter resulting from the cycle *prairie-animals-dugs-manure-fields*. Places too steep are naturally covered by vegetation largely represented by Scotch pine

[5] The soils are classified according to the FAO–ISRIC–ISSS 2006.

[6] The Larch has been accepted on the mountain prairies, because on the one hand, its wood is very appreciated for construction of the mountain houses (*baite*), on the other hand because during winter, there is less snow under the Larch, so during the spring, the snow melt faster under the Larch that has no needles and the grass can grow one week or two in advance with respect to the prairie without Larch.

Fig. 4.12 Lateral moraine severely eroded due to the lack of vegetation protection. Neraissa watershed (Province of Cuneo)

Fig. 4.13 Haplic Leptosol (Calcaric Humic) on calceschists in a prairie with Scotch pine. Refour, Beaulard (Province of Turin)

(*Pinus sylvestris* L.) with dysmoder that tends to form a separate layer. Cambisols and Leptosols are the soils most frequently found (Fig. 4.13).

On northern exposure, the forest dominates with patches of prairie corresponding to the less steep slopes. On the best soils on calceschists and porphyritic rocks, there is a mixed forest: Norway spruce, Silver fir (*Abies alba Miller*), Scotch pine, Beech and other minor species. Due to the good moisture conditions all along the year, the humus (dysmull) is well decomposed by different classes of biotic species and integrated into the soil (Umbrisols and Haplic Cambisols (Humic). On soil laying on quartzitic rocks or gneiss, the vegetation consists mainly of Blueberry (*Vaccinium myrtillus* L.) and Norway spruce. The result is a dysmoder or mor that may bring to the formation of podzolic soils. In the case of pure Beech stands, the litter constitutes a compacted layer of slow decomposition, and the soil beneath shows a sequence of different L horizons. Alder (*Alnus viridis* Chaix) colonising the avalanche corridors is a particular case of vegetation strongly influencing the soil and in turn influenced by the soil. On one hand, it ameliorates soil fertility through its charge of nitrogen-fixing bacteria, and on the other hand, when it is bent to the ground by the avalanche passage, it is able to give out roots from the branches contributing to the stabilization of the site.

Below 800 m above sea level on igneous rocks, many surfaces are occupied by Chestnut tree whose humus is easily integrated into the soil (mesomull) forming Cambisols or Luvisols with a moderate leaching process. On calcareous rocks, the Chestnut is naturally substituted, according places, by a mixed mesophylous vegetation on Umbrisols or by xerophytic vegetation with Pubescent oak on Cambisols. Agriculture fields are spread everywhere, many of them have been abandoned and now are colonised by natural vegetation that slowly is transforming the original Haplic Cambisols (Humic) in Haplic Cambisols (Dystric or Eutric).

In this altitudinal belt in Piedmont region are places with ultrabasic ophiolites rich of magnesium and conditioning the sparse botanical species: Heath (*Calluna vulgaris* (L. Hull.), *Molinia arundinacea* (Schrank), Juniper (*Juniperus communis* L.) and some Birches (*Betula sp.*). These species develop a thin layer of dysmoder. The areas with ophiolites are very degraded due to the overgrazing along the centuries and the frequency of fires during the winter when the herbaceous vegetation is dry. Among the possible uses, pasture has to be discouraged, agriculture is out of question so the only possibility is afforestation, as it may be seen in several places, sometimes with questionable results.

On the more accessible places with deep soils (alluvial fans, dejection cones, moraines and some gently sloping areas), man has concentrated the fertility produced outside and transformed by cattle. Then, the organic matter in form of manure has been physically integrated into the soil that usually has not changed its classification unless the influence of the organic matter had been very great, as it is the case of horticulture close to the human settlements (Terric Anthrosols).

Eastern Alps, Part of the Central and Prealps

The Eastern Alps are colder than the Western, and consequently, the vegetation altitudinal belts are lower. At an altitude of 2,000 m, there are soils, already seen in the Western Alps at 2,400 m.

Fig. 4.14 Alpine prairie on Mollic Leptosol (Calcaric). In the background, the Torri di Lavaredo (Province of Belluno)

In the alpine belt above 2,250 m of altitude, if the land is not occupied by rocks outcropping and detrital deposits, there is the alpine prairie with soils whose profile is strongly influenced by organic matter scarcely decomposed. Haplic Regosols (Skeletic or Humic) are found on igneous rocks while on calcareous ones, there are Rendzic Leptosols. In small basins or in flat areas, hygrophitic vegetation originates peat bogs with Histosols that, according to the cases, can be identified with the prefix of Fibric, Hemic or Sapric. Mound-shaped Umbric Cryosols occur in the highest places, especially in Val Aurina.

Subalpine belt 2,250–1,800 m above sea level presents a landscape of clear forest made up with Cembran pine, Mugho pine and Larch on Umbric Cryosols, Umbric Leptosols, Haplic Cambisols (Calcaric) and Mollic Leptosols (Calcaric) on calcareous rocks (Fig. 4.14) and by Haplic Cambisols (Dystric) and Haplic Podzols on igneous rocks.

Superior mountain belt ranges from 1,800 to 1,500 m of altitude. This is the domain of Norway spruce with or without larch. The soils are Haplic Umbrisols, Umbric Podzols and Rustic Podzols. In this environment, the parent material plays a secondary role as it has been observed by Principi (1961) who noted that the leaching process proceeds very fast and determines soil profiles with chemical strong difference between the parent material and the soil on it, at the same time, the soil acidity and the low temperatures favour organic matter accumulation and formation of humiferous soils. Norway spruce reaches a good equilibrium with podzol because its root network is superficial, and water is not a limiting factor due to the frequent summer rains in this part of the Alps.

The inferior mountain belt (1,500–1,000 m), corresponding to the belt of *Fagetum* (Antolini et al. 1977), has a mixed vegetation with Scotch pine, Norway spruce, Larch and some areas with residual Beech. Here, the difference of lithology becomes more important, and we may find Haplic Cambisols (Dystric or Eutric according to the parent material), Haplic Luvisols and EnticPodzols.

The basal belt (1,000–500 m) is that of *Castanetum* with the typical vegetation *Quercus-Tilia-Acer*. Besides the Chestnut, there are coppices of Pubescent oak and Black hornbeam (*Ostrya carpinifolia* Scop.). Stands of Scotch pine occur by spots. Many places are cultivated. The majority of the soils are Cambisols with a reduced humus influence. The best agricultural soils are those made up with a mixture of different rocks.

We have seen that in this part of the Alps, podzolization process is quite common. It is encouraged by the abundant precipitations (more than 1,200 mm/year), the medium–low temperatures (yearly average 5–6 °C) and by the Norway spruce whose mor humus remains at the top of the soil profile without making integration with the underlying horizons.[7] Allophanic materials are created through reactions between organic matter and aluminium forming a fluffy structure. The water percolating the profile is rich in fulvic and humic acids that contribute to the intensive hydrolysis of silicates. Iron, aluminium and silica are liberated and migrate down forming the spodic horizon. Chelation process takes place between organic matter and iron. Eventual crystallisation of colloidal silica gives rise to a cemented hard horizon (*ortstein*). The pedological province "Alpi Retiche interne" has a consistent presence of Podzols (Skeletic and Endoskeletic Umbric) associated to conifers vegetation on gneiss, granite and schists lithology (ERSAF 2004).

Researches carried out for many years on the Beech wood of the province of Trento (Zanella et al. 2001) have demonstrated the influence of the forms of humus on pedogenesis. On calcareous or dolomitic material, the humus (Amphimull) is stabilized and well saturated with calcium cations (C/N 8–14 and pH 7,1–8,2 in the A horizon), the soils belong to the Haplic Cambisols and Haplic Phaeozems, both calcaric. On porphyritic material, the humus (Dysmoder and Humimor) is not saturated by calcium (C/N 15–33 and pH 4,1–5,1 in the A horizon) then is soluble and able to be combined with iron and aluminium to form chelates. The soils are Protospodic Dystric Cambisols (FAO classification 1989), and Hypohaplic Podzols. Figure 4.15 shows the relationships between Beech types, soil type and forms of humus.

In some cases, the influence of the vegetation and the form of humus is so determinant on podzolisation that this pedogenetic process may take place even on calcareous parent material. This is the phenomenon of *convergence*

[7] Norway spruce has a superficial root system. Its nutrition is almost provided by the humus. After cuts of a Norway spruce stand, it is frequently observed regeneration of Norway spruce on decaying stumps (Giordano 2009).

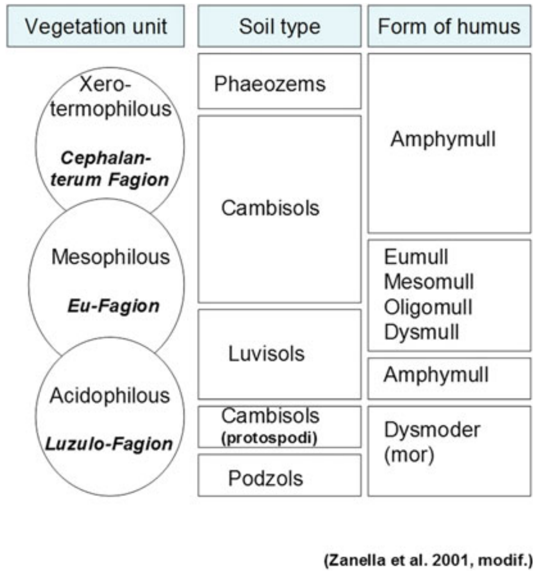

Fig. 4.15 Relationship between Beech unit, soil type and form of humus in the province of Trento

Fig. 4.16 Roots of Norway spruced horizontally spread in the mor humus. Paneveggio (Autonomous province of Trento)

evolution when, after a long phase of stability, the whole of the processes (decarbonatation, decalcification, leaching, hydrolisis and cheluviation) act contemporaneously (Previtali 2000). In the forest district of Longarone (province of Belluno) on calcareous formations, dating from Lias to Eocene Susmel (1956 and 1957) found Podzols in a sequence of soils that have been diversified by the vegetation and by the inherent form of humus.

Since podzols are favoured by the mor humus of the Norway spruce, and since this tree, having superficial roots, is dependent more by humus than by parent material, it is understandable that the combination "Norway spruce-Podzol" may be rather independent from the type of lithology (Fig. 4.16).

Nevertheless, the best for Norway spruce is the porphyric formation (Atesina platform) in the provinces of Trento and Bolzano, the deep and fertile soils of the huge porphyric formation permit many different land uses (pasture, forest and agriculture below 1,200 m). Concluding about podzolization, it has to be noted that this pedogenetic process may proceeds quite fast. In the year 2010, I have personally found near Passo Palombino (2,035 m of altitude) a Haplic Podzol on the protective embankment of a trench of the First World War 1915–1918.

On the Cansiglio high plateau (province of Vicenza) on calcareous marls under Beech cover, there are soils very rich in organic matter that, in cooperation with the abundant precipitations, contributes to an effective leaching, which makes the soil acid or sub-acid (Umbrisols, Cambisols). Accumulation of organic matter on clay soils of Cansiglio may slow down soil drainage developing Endogleyic Cambisols (Di Bona and Giordano 1977).

Moving to the extreme north east (conca del Tarvisiano), we are facing precipitations superior to 2,500 mm/year. All the surfaces are covered with forest, almost Norway spruce and Austrian pine (*Pinus nigra* Arnold.). The soils (mainly Podzols on silicate rocks and often on calcareous rocks) for the combined influence of vegetation and climate are protected by a thick and elastic layer of humus, and in spite of the large amount of rainfall, the soil erosion is very limited. We must be aware of the fact that once the soil is saturated, the time to reach a water course being zero, the risk of flooding and landslides is quite severe even if there is not an equivalent risk of soil erosion.

In the Alps of Friuli in several prairies, man has planted Alder (*Alnus glutinosa* (L.) Gaertn.) to ameliorate the soil and to increase hay production (Piussi 1998). The roots of Alder shelter a *streptomices* able to fix nitrogen. The soil nitrogen enrichment takes place when the leaves fall and are humified.

4.3.2 Soils of the Po Plain and Other Alluvial Plains

In the Italian plains, the soils are young in terms of geology, but they are old considering the land use. The fertility of these soils is not so related to the heritage left from primigenial forest, but it is rather connected with the rational agricultural practices followed for more than 1,000 years (Gasparini 1955). Unfortunately, the actual practices do not correspond to the ecologically sound practices of 60 years ago largely based on the contribution of organic matter which today is getting low. In the region of Piemonte, for instance, the soils of the plain have an organic carbon content of 1.58 % which is moderately low, the soils of the hills have 1.15 % and those of vineyards less than 1 % which is low (IPLA 2007). The soil compaction operated by heavy machineries is a new type of soil degradation affecting the majority of the cultivated soils.

The land use often cannot be associated to a specific type of soil as it was customary 100 years ago. A clear example, even if extreme, comes from the alluvial plain of the Tagliamento river in Friuli Region: once the fertile soils (Fluvic Cambisols Humic) cultivated with maize could be easily recognised and then separated from the unfertile stony soils (Haplic Fluvisols Skeletic) used only for grazing. Today, this distinction based on land use is uncertain because the farmers of the unfertile soils using artificial input (irrigation and fertilisation) can grow the same crops traditionally cultivated on the best soils.

The Po valley once covered by planitial woods has been transformed through the centuries in the hugest Italian agricultural area. Bosco della Partecipanza (Trino Vercellese) is one of the few remnants of the ancient planitial forest (*Querco-carpinetum*). Its pedogenesis can be taken as reference model for the climax soil evolution of the last centuries in that part of the Po valley formed by silicate alluvial parent material. The organic acids of the humus have activated a leaching process that, with the presence of a high water table, has produced a Gleyic Luvisol. Soils submitted to the influence of ground water table have been traditionally used for meadows. In recent times, some of them are planted with poplars or other rapid growing woody species (Fig. 4.17).

Fig. 4.17 Meadow associated with fast-growing woody species on a Gleyic Anthrosol. San Matteo delle Chiaviche (Province of Mantova)

At the foot of the Prealps, we see the fluvio-glacial terraces formed during the inter-glacial periods from Gunz to Wurm (600,000–10,000 years before present) (Fig. 4.18). The soils, formed under climatic conditions different from the present ones are deep paleosols (Gleyic Luvisols Fragic). In some cases, the influence of the old soil is reduced by a blanket of aeolian silt blown in during steppic phases of the inter-glacial periods, and the actual pedogenesis takes course on this aeolian material that anyhow is influenced by the underlying impermeable fragipan, locally called *murs*, *gherlun*, *teratun* (Fig. 4.19). With these conditions, the natural vegetation is a *Querco-Carpinetum* (Parco Regionale delle Vaude, regione Piemonte) but due to the heavy intensive cutting during the Middle Age, and the consequent use as a grazing land, the environment is quite degraded and

Fig. 4.18 Fluvio-glacial terraces located between the Prealps and the recent alluvial plain. Regional park of the Vaude, Lombardore (Province of Turin)

dominated by Heath (Hull) which produces slowly decomposed litter. Over time nitrogen accumulation facilitates the replacement of Heath by *Molinia arundinacea*, which produces a litter that decomposes more rapidly, leading to an increased nitrogen availability necessary for *Molinia* that is a fast-growing species (Berendse 1994 quoted in Van Breemen 1998).

The present spontaneous vegetation consists of fern (*Pteridium aquilinum* (L. Kuhn), *Molinia arundinacea*,

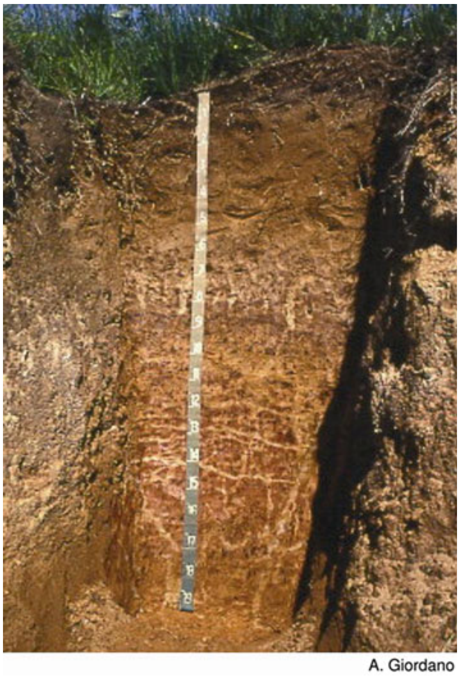

Fig. 4.19 Gleyic Luvisol (Fragic) on the fluvio-glacial terrace. Parco Regionale delle Vaude (Province of Turin)

Fig. 4.20 Rice field on recent alluvial soils. Cigliano (Province of Vercelli)

Fig. 4.21 Irrigated permanent prairie abandoned since 10 years (Haplic Luvisol Siltic). Cascina Il Chiosso, Leinì (Province of Turin)

Heath, Wild pear (*Pyrus pyraster* (L. Burgsd) and Birch (*Betula spp.*). Fluvio-glacial surfaces in Lombardy have often a forest cover of Scotch pine whose humus (dysmoder) produces leaching phenomena.[8] Black locust (*Robinia pseudoacacia* L.) is present too and, being a leguminous plant, its soft humus (eumull), rich in nitrogen is well integrated into the soil.

The majority of rice fields are located on the old fluvio-glacial terraces that have been managed at the end of XIX century[9] in big parcels (*camere*) prepared for periodical submersion which induces artificial episaturation ascertainable by the grey colour of the first 30–40 cm and by the brownish colour below. The soils are Anthraquic Gleysols if derived from the previous Gleyic Luvisols (Fragic) of the old fluvio-glacial terraces or Hydragric Anthrosols if located on recent alluvial Plain (Fig. 4.20). The hydromorphic conditions persist even in the absence of water submersion owing to the compaction of the subsoil performed by man (IPLA 2007).

On the high Po plain at an altitude ranging from 600 to 300 m (almost province of Cuneo and part of that of Torino), we find the permanent irrigated prairies. A wise land management keeps in all steady state the balance between manuring and irrigating. These operations together produce leaching processes forming Luvisols (Fig. 4.21).

Other land uses are maize on loamy soils and fruit plantations on skeletic soils close to the mountains. The rest of the terraces are covered by rainfed agriculture or agriculture irrigated through wells. The internal drainage being very slow reduces the suitability for different agriculture uses but makes these areas quite suitable for waste disposals.

The passage from high plain to the low is not only marked by the old fluvial terraces but also by the presence of water gushing from the ground. The water infiltrates in the coarse-textured soils of the high plain and appears on the surface when reaches the impermeable fine-textured soils of the low plain. The line interested by water is continuous from Cuneo to Trieste and in some cases originates true water courses like Sile, Limene, Livenza and Stella. The presence of this kind of water is indicated with local

[8] Darwin (1859) recorded that on a parcel of heathland (Staffordshire) afforested with Scotch pine, the modifications of natural vegetation and fauna were greater than the differences of vegetation one could find passing from a type of soil to another completely different.

[9] In that period had been dug the great Canale Cavour for providing the rice fields with water (see Corti et al. 2012 in this volume).

names: *olle*, *risorgive*, *fontanili*, *coli* and *risultive*. They represent a valuable resource for agriculture that reaches here a very intensive management. The distribution of water in the fields creates soil conditions of temporary or permanent gleyification. This water is utilised in the region around Milan during the winter for submerging the permanent prairies (*marcite*) with a thin layer of water whose temperature being always more than zero centigrade has the advantage to facilitate an early starting of the vegetative period at the end of the winter. The pedogenesis has been conditioned by man for the last 700 years, and the soils are now Hypercalcic Humic Gleysols (ERSAF 2004).

In Lombardy and Venetia, locally there is soil with a hardpan stopping the root penetration. This hardpan may be rich in iron and called *maltraverso* in the province of Lodi, a hardpan rich in calcium carbonate is called *castracane* in the province of Mantua, *ges*, *tuff* and *caranto* in other parts of the plain (Bini 2012 in this volume, Donnici et al. 2011). In the plain of Friuli, several actions of land improvements (drainage, irrigation and stone clearing practice) have determined changes in land use: from prairies and pasture to field crops (ERSA 2003), increasing the land value but lowering the natural fertility of the land.

The area on the right side of Po river may be divided in three parts: raised plain, depressed plain and delta plain (Servizio Cartografico Ufficio Regione Emilia-Romagna 1994). The first has Haplic Cambisols (Calcaric), Haplic Cambisols (Chromic) and Haplic Calcisols whose calcic horizon has been favoured by irrigation and deep ploughing. Calcisols and Cambisols are cultivated with field crops and fruit trees. The depressed plain has Vertisols (Eutric, Gleyic and Calcic) with cereals and industrial crops. The delta plain is characterised by Thionic Fluvisols, Thionic Histoslos, Gypsic Vertisols, Haplic Vertisols (Eutric), Haplic Calcisols, Haplic Cambisols (Eutric) and Haplic Arenosols (Calcaric). They are intensively cultivated with orchards, fruit trees and rice. Land reclamation has been performed in several parts of the Po delta digging parallel drainage canals spaced 10 m apart. The excavated earth creates risen fields. This operation (*mazzuolatura*) destroys the original soil profile and sometimes prime subsidence.

In very recent alluvial areas, the prevailing land use is wild vegetation in places close to the water courses and agriculture or poplar plantations in places a little far from the water. The influence of vegetation on pedogenesis is reduced because the soils are very young and the floods are frequent. The presence of Black locust, especially close to the water courses, improves the soil fertility fixing nitrogen from the atmosphere. This remarkable advantage becomes an obstacle after cutting because nitrofilous weeds invade the environment.

Making a synthesis of the Po environment, we can say that the principal land uses are the following: cereals, meadows, permanent prairies, oleaginous crops, fruit plantations, poplar plantations and vineyards. Spreading of crops to produce biofuel (colza, sunflower, etc.) is a recent phenomenon. The main Reference Soil Groups are the following: Histosols, Anthrosols, Technosols, Vertisols, Fluvisols, Solonchaks, Gleysols, Phaeozems, Calcisols, Luvisols, Arenosols and Cambisols. Where irrigation is practiced, there is a contribution to the leaching process with more consistent presence of Luvisols and subordinately Gleysols.

For the hills of Monferrato, bordering the right side of the Po plain, Mondino (1985) indicates the following vegetation scheme:

- *Physospermio-Quercetum petraeae* on sand with Haplic Cambisols (Dystric),
- aggregation of Pubescent oak and *Viburnum lantana* L. on marl with Haplic Cambisols (Eutric) and sometimes Rendzinic Phaeozems,
- mesophylous *Querco-carpinetum* with Pedunculate oak in the bottom valleys with Fluvic Cambisols.

The oak formations represent a minority part of Monferrato that is almost covered by vineyards and cereals, but there is a specific interest in maintaining oak woods which shelter truffles.

The hills of Oltrepò Pavese border also the Po river. Their marl and clay are covered by grape groves, sandstone and conglomerates by oak-mixed woods.

Proceeding East, we reach the Colli Euganei that are hills of volcanic and carbonatic origin isolated in the Po plain. They present a very complex pattern of different soils and different types of vegetation and land uses. For details, see Bini and Zampieri (2001).

The plains of central and southern Italy represent only one-third of the surface of the Po plain, but their historical importance has been and is far greater than the simple surface acreage (TCI 1957). The flat disposition is the common characteristic of these areas called “plains”, but it would be more reasonable classify them as “valley floors” since they are formed by river basins. Some of them were lakes or marshy bogs that have been transformed in very fertile areas.

Once the influence of natural vegetation on the soils of the internal plains has been greater than today, because many areas were swamps or marshy bogs with soils rich in organic matter (Eutric Gleysols and Umbric Histosols). These places have been reclaimed, and now, they have undergone a pedogenesis whose final end is a limited number of Histosols and Gleysols and a much more consistent number of Vertic Cambisols and Gleyic Luvisols.

Agricultural exploitation after reclamation projects is evident in the big alluvial plain of Metaponto which is a plain formed by the rivers Sinni, Agri, Cavone, Basento, and Bradano. The low watersheds of these rivers present impressive badlands with bare soil (Leptic Regosols Clayic) sheltering small island of *Inula viscosa* (L.) Aiton., *Tussillago farfara* L., *Artemisia cretacea* (Fiori) Pign, *Lygeum spartum* (L) Loefl., *Atriplex Halimus* L. and *Hedysarum coronarium* L. At the outlet of the Sinni river, there are the remnants of an ancient southern planitial forest with White poplar (*Populus alba* L.), Black poplar (*Populus nigra* L.,) Hornbeam, Elm, Ash, Oak and dense under canopy. The soil is a Endogleyic Cambisol.

Another important plain is that of the Sele river with intensive agriculture and buffaloes breedings specialised in the production of *mozzarella* cheese. Soils belong to Cambisols, Luvisols, Vertisols and few of them to Kastanozems.

Cultivation is carried out in dry conditions except some cases of irrigation by hill pools and rivers. Forage crops and pastures that are beneficial for the soils have different importance from a plain to another. For instance in the Marche region (Rusco et al. 2007), crop rotation represents 43.3 % of the total surface and fodder and forage crops plus pastures 37.4 %. These figures indicate the presence of breeding and the actual soil sustainability for the land interested by forage and pasture.

Internal plains are conflict areas between different land uses: crop cover, urban, industries, woodland and meadows.

4.3.3 Soils of the Apennines

The scheme presented in Sect. 4.2 (Pignatti 1997) is a general reference, but many variations occur. Chestnut tree (*Castanetum* belt of Pavari 1916) is spread largely in the Oak and Beech belts and in turn Beech is often mixed with conifers. Deciduous oaks are often found with Beech and also with Holm oak.

At low altitude at the foot of the relieves, Pubescent oak is largely represented. Its humus, combined with a climate that is milder than the Alpine, is easily mineralised and the soils range from Regosols to Luvisols, but for the majority, they are Haplic Cambisols (Eutric or Dystric). Oak formations traditionally used as coppice have today lost a part of their economic interest and form those landscapes that, due to their minor touristic appeal, have safeguarded biodiversity and nature integrity.

In previous times, the belts of Holm oak and deciduous oaks were cultivated, as it can be ascertained by many still visible terraces. Some areas continue to be cultivated but levelling and earth movements often prime soil erosion and contribute to the vanishing of the mixed agriculture landscape (Costantini and Righini 2002) and to the continuous soil rejuvenating. For the forest part of these belts (approximately 60 %), the main destination is the traditional coppice of oak (Pubescent oak and European oak on clay soils). The soils are shallow because cutting and harvesting have caused erosion. Other destination is Chestnut tree that in turn may be divided in two sectors: fruit trees and coppices. Where the interest for Chestnut fruit prevails, the soils are deeper and richer. On the Adriatic side, the oak area is mainly occupied by Black hornbeam and Flowering ash (*Fraxinus ornus* L.).

Between 1,000 and 1,700 m above sea level is the Beech domain with consistent presence of silver fir in the upper part. A good demonstration of the ecological importance of Beech can be derived from the naturalistic considerations written by the first ambassador of United States who reached Turin, capital of Italy at that time, in the year 1861 “The leaves belong to the soil. Without them it cannot preserve its fertility and cannot furnish nutriment to the Beech. The removal of the leaves deprives the soil of that spongy character which gives it such immense value as a reservoir of moisture and a regulator of the flow of springs; and, finally, it exposes the surface roots to the drying influence of sun and wind” (Marsh 1864).

Beech can grow on silicate rocks as well as on carbonatic ones. On the first lithology, it develops Luvisols and even Podzols, on the second Cambisols (Humic or Eutric). Beech on volcanic material develops Umbric Andosols. This general relationship between Beech and parent material would be valid if the forests would have not been disturbed. Since it is true the opposite, in the majority of the cases we have to deal with soils that have been interrupted in the normal course of their pedogenesis.

A few examples concerning some aspects of vegetation and land use will be here presented in accordance with the classic separation of the Apennine range in three geographical parts.

Northern Apennines

The Northern Apennines start from Liguria that in spite of being the region most rich in forest in Italy has many degraded woods with eroded and shallow soils, especially on southern exposed ophiolites, where direct reforestation is often unsuccessful due to the lack of preparation with pioneer shrubs and grasses for producing a minimum requirement of humus. The situation is better on northern exposure with fair woods of European oak and Chestnut tree. It must be noted that in the last decades, the less controlled wild boar populations attracted by acorns, Chestnuts and Beech seeds have been particularly active in these types of forest determining disturbance in the soil profile sequence.

The whole Liguria is a mountain region therefore has mountain agriculture whose extreme cases are the vineyards on terraces in the Parco delle Cinque Terre, which have suffered tremendous damages during the events of November 2011.

The soils of the Tosco-Emiliano Apennines chain are distributed according to a complex pattern; nevertheless, it is possible to organise them in rough phytoclimatic belts. In

Fig. 4.22 Haplic Calcisol (Clayic) on the low watershed of the Santerno river (Province of Bologna)

the pre-Apennine, the cultivations are prevailing and practiced on Haplic Luvisols, Haplic Luvisols (Ferric) and Vertic Cambisols. On the low Apennine, besides the usual cultivations, there are fruit trees and vineyards on Haplic Cambisols (Calcaric) and Haplic Calcisols whose calcic horizon is called *calcinello* (Fig. 4.22).

In the medium Apennines, important surfaces are occupied by woods (Pubescent oak, European oak and Chestnut tree) on Eutric Cambisols, Haplic Cambisols (Calcaric) and Haplic Regosols (Calcaric). In the highest belt, the Beech formation with Haplic Cambisols (Dystric) makes way, at a certain altitude, for pseudo-alpine prairies with Umbric Leptosols.

The lithology of the medium belt of Tosco-Emiliano Apennines chain consists mainly of sandstone, marl, clay of different typology, flysch and varicoloured skelly shales. This lithology combined with steep topography gives rise in some places to badlands whose total absence of vegetation has led Serafini (1879) to describe the soil of Montefeltro using the following words: "the soil of Montefeltro is disarticulated like an animal whose flesh and bones are not connected by mean of tendons and muscles". In the integral protected area of Sasso Fratino, research on soils under mixed formation of Beech and Silver fir showed that on flysch (marl and sandstone), the hydrolysis of the parent material is more related to the carbonic acid existing in the Cambic Umbrisols rather than to humic acids of the humus. Sandstone has a weak podzolization process (Olivari 2009).

At Vallombrosa, Camaldoli and Campigna on Miocene sandstone, the Silver fir has been introduced during the Middle Age in substitution of Chestnut and Beech, The soils rich in humus are Humic Cambisols locally called "*terre castagnole*", they have a pH around 7 in the humiferous horizon and around 5 in the deep horizon of weathered parent material. More than 60 years ago, Alinari (1948) explained this behaviour noting that the roots of the Silver fir make a continuous uptake of the bases that return to the upper part of the soil, initially as litter and subsequently as humus. The acid mull under Beech forest on Oligocene sandstone does not tolerate changes in vegetation canopy: an excessive cut in the Beech stand converts the mull into mycogenic moder supporting Blueberry and driving the soil evolution towards Podzol (Sanesi 1962). The litter of Beech maintains soil moisture conditions satisfactory for itself and for Silver fir regeneration which becomes difficult with fir needles only (Giacobbe 1962). This is the reason why clear-cutting is suggested to facilitate fir regeneration. At the same time, it has to be noticed that mull seems to have phytotoxic action on fir regeneration when moder and mor do not have (Ignesti and Paci 1989). Always at Vallombrosa, Austrian pine (ssp. *laricio*) and Silver fir, both of them at the same altitude and on the same sandstone, have differently influenced the pedogenesis since *Pinus Laricio* Arnold. is an acidifying agent much more efficient than Silver fir (Certini et al. 1998).

Patches of Norway spruce on silicate rocks in the Tosco-Emiliano Apennine prime a podzolization process (Panini and Penzo 1983). In the highest belt, above 1,700–1,800 m above sea level, the Beech is replaced by prairies similar to those of the Alps. The most common soils of the Apennine prairies are Mollic or Umbric Leptosols in well-managed areas or Lithic Leptosols and Leptic Regosols in areas that have been overgrazed and eroded.

Central Apennines

The dominant lithologies of central Apennine are calcareous, siliceous and volcanic. Central Apennine have some ancient volcanic formations that will become more important in southern Italy and in Sicily. On the slopes of Monte Amiata and Colli Albani, there are woods of Chestnut and Beech on Andosols (Fig. 4.23). The humus of these places has a particular role giving rise with aluminium to allophanic substances that explain the fertility of the sites. The volcanic influence is not limited to the places near the volcanoes since ash could have been deposited quite far away from the centres of emission.

From Colli Albani until the Garigliano river on the calcareous range of Monti Lepini, Ausoni and Aurunci, the centennial activity of the shepherds and the charcoal burners has caused an intense soil erosion and degradation. Many soils from their previous state of Haplic Cambisols

Fig. 4.23 Umbric Andosols in a Beech stand of Monte Artemisio (province of Roma). The layer of volcanic ash between 140 and 150 cm is preferred by the Beech roots

Fig. 4.24 Haplic Kastanozem on a karstic plateau. Piano delle Cinque Miglia (Province of L'Aquila)

(Humic, Eutric) have been transformed into Lithic Leptosols (Eutric).

Karstic landscapes in Central Apennine have slopes severely eroded, but where the eroded soil has been accumulated in the *dolina* or in *karstic plains* the soil is deep and provided with humus well stabilized by calcium (Fig. 4.24).

Correlation between vegetation and soils has been found in a flat area formed by karstic and orogenic processes at an altitude of 1,270 m in the Sibillini range. Hygrophytic vegetation alliance of *Caricion gracilis* has developed Histic Humaquept (USDA 1960) when the grazed xerophytic alliance of *Cynosurion* and *Bromion* has a Pachic Haplumbrept that would probably evolve again to Beech wood if the human activity would be interrupted (Cortini Pedrotti et al. 1973). Mixed with Beech is frequently present Silver fir that has a non-exclusive preference for silicate substrata and for clay since it tolerates soil moisture better than Beech (Amatangelo 2009).

At altitude higher than 1,700 m, we find conifers with production of raw humus: *Juniperus nana* Willd. on the Sibillini Mountains and Mugho pine on the Maiella Massif. In this last environment, the mor humus is very acid in the superficial horizon but becomes sub-alkaline close to the carbonatic parent material. The double face of the soil profile corresponds to the *tangelrendzina* of Kubiena (Mancini 1991). Going up from 2,000 m of altitude, we must observe that the combined action of dry summer and strong wind makes the environment generally more suitable to prairie rather than to trees. In the Apennine range of Marche, Umbria, Abruzzo and Molise, above the Beech belt, on the Mesozoic compact calcareous rocks, the altitudinal prairies (*Seslerietum apenninae*) are spread on Rendzic Leptosols, Haplic Cambisol (Humic) and sometimes Haplic Phaeozems or Luvic Phaeozems as reported by Morra di Cella (1996) on the Mesozoic carbonatic massif of Catria (province of Pesaro and Urbino). Prairies on sandstone and shales generate Leptic Umbrisols.

On the best grazing lands, areas of cattle rest (*riposi* or *meriggi*) are frequently found, where the excess of animal excreta has enriched the soil in nitrates, favouring an unwanted vegetation of *Asphodelus*, *Elleborus* and *Veratrum* (D'Errico 1959). In other places, the activity of the charcoal burners has contributed to the soil erosion (Fig. 4.25). In the low-belt earth movements may create problems for the site stability (Costantini and L'Abate 2007).

Southern Apennine

The geology of Southern Apennine indicates calcareous and volcanic formations and magmatic rocks, these last concentrated in Calabria region (Sila, Serre and Aspromonte ranges). In the Mediterranean environment, Mancini (1955) remarks that the Brown Mediterranean Soil (Cambic Umbrisols or Haplic Cambisols Humic), typical of the Holm oak stands, is a true *analogous soil* because the superficial horizons rich in humus and with granular structure present permanent characteristics independent from the type of parent material.

European oak substitutes the Pubescent oak on clay soils. After the cut of European oak at the beginning of the XX

Fig. 4.25 Charcoal pile and erosion on the corridors of trailing wood. Rio Vitoschio (Province of Pesaro and Urbino)

century for railroad sleepers, the humus was consumed and the clay started cracking. From good Haplic Cambisol (Humic), the soil becomes Haplic Vertisol.

In the region of Molise, one may notice that many Apennine prairies have deep and well-preserved Haplic Phaeozems or Haplic Kastanozems, like these of Matese and Montagna di Frosolone. Some of them have received a contribution of volcanic ash from Vesuvio or from the ancient volcanic apparatus of Vulture. The high productive forest soils of Vulture (Potenza province) are made up with volcanic ash that combined with the humus of the Chestnut tree gives rise to a Melanic Andosol.

Conifers with their influence on soil evolution are found in many places at altitude above 1,000 m. Among the conifers, the Silver fir is the most diffused rarely in pure stands because it regenerates better on humus of Beech or European oak. Other conifers are *Pinus nigra* Arnold. (*ssp. laricio*) and *Pinus leucodermis* Christ. The frequent presence of *Alnus cordata* close to the drainage network enriches the soil with nitrogen, and in addition, its humus is easily decomposable with a C/N around 15.

The heterotopic Beech formations of the hill belt of Gargano present the herbaceous cover typical of the surrounding communities with Black hornbeam and Flowering ash (Gualdi et.al. 2006). Probably, the rapidly decomposable humus of this herbaceous cover permits the Beech to go down from its natural location.

Fig. 4.26 Prairie on a Haplic Phaeozem rich in organic matter produced by the former Beech forest. (Parco Nazionale della Sila)

From Apulia to Abruzzo, there are many corridors on which the transhumance was practiced. Today, the heard of sheep are transported by lorries, but for more than 2,000 years, they were used to make a long journey on well-defined tracks (*tratturi*). These tracks tend to disappear, but with more accurate observation, they can be distinguished by the presence of nitrophilous vegetation on soils that have been fertilised twice in a year for more than 2,000 years (Haplic Umbrisols and Umbric or Mollic Leptosols).

Many afforestation programmes have been carried out, especially in Calabria, with the result of an improved soil water retention and a decrease in erosion. Research performed (D'Ippolito et al. 2011) in the watershed of Coscile (province of Cosenza) where the forest cover has been increased of 22 % after the 1950 have recorded a run-off coefficient of 0.48 instead of the previous 0.56. An environmental impact assessment would be necessary in certain cases because the reduction in soil erosion on the mountains may have the consequence of an increase in sea coastal erosion.

The parks (regional and national) created in the last 50 years protect also the residual soil fertility inherited by the former forests (Fig. 4.26). In the Sila Grande with Beech and *Pinus nigra* (ssp. *laricio*), we find Umbrisols and Luvisols, while in Sila Piccola with Beech and Silver fir, we find Umbrisols (Cassi and Giordano 1990).

Places in the protected area of Parco Nazionale della Sila are the clear demonstration of their ecology significance (Fig. 4.27).

4.3.4 Soils of the Hills of Central Italy

In this paragraph, the hills of the four regions forming the central Italy are considered: Tuscany, Marche, Umbria and Latium.

Fig. 4.27 The dead trees are left on the ground to become food for a long chain of decompositors and predators. On foreground small mounds resulting from the moles excavation. Bosco Gallopane (Parco Nazionale della Sila)

Fig. 4.28 Cereals, meadows, vineyards and eroded surfaces in the Marche hills. Ripatransone (Province of Ascoli Piceno)

Preliminary considerations point out the importance of agriculture in that part of Italy and the necessity to have basic information on the natural vegetation in order to follow the pedogenetic evolution.

Part of the hills of Central Italy has Mediterranean vegetation whose definition is difficult nevertheless two main aspects may be underlined (Mancini 1963) as follows:

- the warm and dry summer is a great limitation for the vegetation compelled to enter in a status of physiological rest,
- forest resources have been overexploited, and the soil has been eroded for centuries. So, secondary forests are everywhere present in anthropic or semi-natural landscapes.

On sandstones, conglomerates and sandy marly flysch, the main forest species belonging to the natural vegetation (*Quercetalia pubescentis*) are Pubescent oak, European oak, Maritime pine (*Pinus pinaster* Ait.) and *Erica arborea* L. Chestnut tree appears on acid soils in the whole Pubescent oak series (Mondino 1998). The soils are Eutric Regosols and Haplic Luvisols. At low altitude, we find a Mediterranean *macchia* with Holm oak. If the low slopes or the bottom valleys have drainage problems, we observe an inversion of the plant belts with the Holm oak climbing up the hill (Pignatti 1998). On the Pliocene clay, shales and marly clay, the woods are stunted, and the Pubescent oak is accompanied by sparse shrubs. The humus influence is limited, and the soils are mainly Haplic Regosols (Calcaric) and Vertic Cambisols.

On the Adriatic side, the woods are almost coppices of Flowering ash and Black hornbeam, with shallow soils due to the intensive coppice exploitation (Leptic Regosols and Calcaric Regosols). The landscape shows a sequence of rounded hills cut west–east by rivers. Most of the hills have Pliocene and Quaternary marine and continental origin. The soft consistence of these geological formations promotes on one hand the agricultural operations and on the other hand landslides and soil erosion (Fig. 4.28). Soils of the slopes are mainly Regosols and Cambisols while those of the internal small valleys are Cambisols and Luvisols (ASSAM 2006). The forest surfaces are very much reduced, and the majority of the hills are intensively occupied by agriculture whose long history is responsible for the lowest soil carbon content among the regions of Italy.

The history is also responsible for modifications of the ground topography by having created longitudinal mounds (*greppi* or *greppate*) bordering the fields and planted with Oaks (*querce camporili*), today protected by the Regione Marche as historical landscape.

The Tyrrhenian side is dissimilar to the Adriatic one for a more consistent presence of the natural vegetation due to the roughness of its topography and to its more complex geological framework.

In the internal hilly areas of Umbria, there is an elongated consistent belt of Marine Pliocene deposition intensively cultivated. The soils are Typic Ustorthents and Typic (Petrocalcic) Calciustepts (Giovagnotti et al. 2003) that can be translated in Haplic Regosols, Haplic Calcisols and Petric Calcisols. Part of the hills of Latium is covered by a blanket of volcanic ash. The natural Oak vegetation with Haplic and Umbric Andosols, owing to the high soil fertility, is substituted by permanent and annual crops. Lulli et al. (1990) notice that the cut of the woods and the subsequent cultivation cause the soil to loose the andic characteristics and to become a Haplic Luvisol.

Large part of the hills of central Italy is made up with clay belonging to Pliocene (Fig. 4.29), Oligocene (varicoloured skelly shales) and Mesozoic. The agriculture faces the problem of the low permeability of these soils (Mancini et al. 1979). For the solution of this problem, hills of central Italy

Fig. 4.29 Vertic Cambisol on Pliocene marine clay. Herbaceous land use suits this soil that in summer time opens cracks. Vicarello (Province of Pisa)

became places where it has been developed the tradition of a wise land set-up systems (*sistemazioni agrarie*) able to overcome the difficulties existing in an environment that is marginally suitable for agriculture. It started during the Middle Age as it is documented by the painting of Ambrogio Lorenzetti 1337, who was inspired by a particular didactic aim (Sereni 1979). For a complete description of the land set-up systems, (see Corti et al. (2012) this volume).

In the internal small plains with problems of excess of water, the historical type of land reclamation conceived by Leonardo da Vinci consists in uplifting the ground level using the soil eroded and transported by water from the surrounding hills and then allowing the water to die down and to deposit the material brought in suspension (*colmate di valle*). In that way, a new heavy-textured soil, Colluvic Regosol (Clayic), was created at the expenses of the hilly soil which in turn becomes younger. Examples are Val di Chiana and the watersheds of Lamone and Ombrone in Tuscany.

Benching and terracing are two fundamental land set-up systems on contour lines. The first modifies the original soil profile: the soil dug is levelled while the wall resulting from the excavation consists of the mineral horizons B and C. The wall is usually protected by grasses to prevent from erosion. Benches are not supposed to be done on clay soils due to the risk of landslides. Terracing is similar to benches unless the wall made with stones. Terraces are preferred to benches in dry environments. Clay-textured soils are often managed in a different way, "the agrarian arrangement and hydrographical government, so-called *rittochino* is unique in the world as an example on how to reconcile the need to cultivate in the direction of maximum slope combined with the rainwater control while maintaining the stability of slopes with medium–high steepness and presence of clay soil" (Rusco et al. 2007).

The general prevailing land use is crop rotation that gives way for vineyards and olive groves in suitable zones and for woods on slopes too steep for agriculture. Cultivation is mainly carried out in dry conditions, and irrigation is exceptionally used with the help of hill pools (*laghetti collinari*). The long wine tradition of the hills of Central Italy has determined in the last decades a better knowledge about the land suitability for vineyards (Costantini et al. 2006a, b). This point is of particular relevance because "the areas in which it is possible to combine complete eco-compatibility and top quality production are very limited with the current state of technologies. This is due to the fact that the plantation and husbandry model normally used for these specialised crops cause environmental damage which is often not eco-compatible" (Costantini and Barbetti 2008). Not all the soils are good for grape-growing. This is the case, for example, of the Miocene and Pliocene clay covering a huge area south of Siena and Volterra. Here, the soils called *crete*, *mattaioni* and *biancane* being affected by erosion and landslides during the rainy season and by cracks during summer time are suited for herbaceous crops but not for permanent tree culture.

Considering the regional data of Tuscany, Umbria, Marche and Latium, we notice that during the last decade, the surfaces with crop rotation have decreased of −8 %, permanent crops without vineyards −20 %, vineyards −18 %, forage crops, meadows and pasture −31 %. In the same time has decreased the number of animals: −10 % cattle and −16 % sheep. On the contrary, it has increased the number of pigs (+11 %). These data (ISTAT 2011) have repercussion on soils and their fertility since the virtuous circle *grass-animals-manure* is broken. Something negative for soil sustainability is the increase of pigs, especially if we consider that the number of farms breeding pigs has decreased ten times passing from 46,124 to 4,643. This means that the farms with pigs have become specialised and less integrated with the environment, creating possible problems of pollution. We must observe that in certain cases, the forage crops not necessarily are linked to animal breeding, for instance, the low hills between the rivers Foglia and Metauro in the Marche region have 48 % of their surfaces occupied by forage crops. The production goes to industrial processing for the extraction of proteins for fodder (Rusco et al. 2007).

A positive point for soil conservation concerning the four considered regions is the surface covered by forest: 49.4 % against the national average of 34.7 %. It is true that the majority of the woods are on the mountains but a consistent part is also on the hills. Another positive factor is the rehabilitation in the provinces of Siena and Grosseto of the hills that overexploited for centuries by a too dense agriculture population could find their equilibrium in the years 1960 when the land was abandoned and purchased or rented by Sardinian shepherds who proved that under an extensive and more ecological management, the land could recover its fertility and provide people with an interesting income.

The management of permanent crops, especially vineyards, has created in the past but still creates problems. Costantini et al. (2006a, b) demonstrated that "by means of a field experiment, the unfavourable effect of the common practice of deep ploughing before tree planting in increasing the formation of redoximorphic features, micritic calcite nodules and infilling, within the deeper horizon of calcareous soils". The operation of earth movement and levelling may also create problems facilitating soil erosion (Fig. 4.30) and making the Haplic Cambisols, which are the most common soils on the hills, to become Leptic Regosols where the soil is taken away and Haplic Cambisols Colluvic where the soil has been accumulated.

In hilly areas with sedimentary rocks and where a tectonic uplifting has created *cuestas* morphology, the natural vegetation is on steep but safe slopes where the soils are mainly Regosols. The gently sloping areas with Cambisols are cultivated although they present landslide hazard.

Fig. 4.30 Earth movements and levelling responsible for soil erosion. San Benedetto del Tronto (Province of Ascoli Piceno)

On volcanic loose material, the soils remain young because the humus strongly stabilized by allophanic material prevents from leaching process (Desideri 1979).

Of relevant economic importance is the presence of truffles in the hill. With reference to the outstanding truffle, that is, *Tuber magnatum*, the symbiosis is established with a number of trees: Pedunculate oak, European oak, Poplar, Willow, Hazelnut and Lime tree. It seems that the favourite truffle environment presents a minimal pedogenesis or no pedogenesis at all. Truffles require soil aeration, as that existing in recent alluvial or colluvial deposits and in soils disorganised by landslides (Panini et al. 1991).

4.3.5 Soils of the Southern Italy

The majority of the hills and the plains of southern Italy belong to the meso-Mediterranean belt characterised by the Holm oak which has a latitudinal and altitudinal range very wide "the Holm oak is the most integral and orthodox expression of that *Quercetum ilicis* rightly considered by botanists and naturalists as the most evolved and mesophilous manifestation of Mediterranean vegetation" (Gambi 1986).

The forest occupies 29.7 % of the territorial surface (34.7 % is the average for Italy) and presents a maximum cover in Abruzzo and Calabria with 40 % and a minimum in Apulia (9 %). The forest soils of the hills and the low mountain slopes are Humic Umbrisols and Haplic Cambisols (Eutric or Dystric) according to the parent material.

In the Mediterranean Southern Apennines, the landscape of flysch is characterised by the presence of European oak, Black hornbeam*a*, Oriental Hornbeam (*Carpinus orientalis* Mill.) and Italian oak (*Quercus frainetto* Ten.). European oak is particularly important because ranges from *Fagetum* to *Lauretum* and can fit to several types of soil, especially to the Haplic Cambisols (Clayic). Vertisolisation has occurred after the cutting of forests of European oak on clay soils of Basilicata (Fig. 4.31). As a consequence of forest cutting and overgrazing Leptosols and Regosols are omnipresent, but the area covered by Humic Umbrisols becomes larger due to many reforestation projects.

The separation between forest and grazing land is not so sharp in Mediterranean environment owing to the presence of the *macchia*. It has to be considered that in the Mediterranean environment may be desirable to maintain a pastoral activity, even minimal, because it represents a guarantee of forage during the dry period, in addition, grazing prevents forest fires and preserves the soil resource (Talamucci 1991). The animal trampling in the forest has a

Fig. 4.31 Agricultural soil formerly European oak stand on montmorillonitic clay. (Haplic Vertisol). Bosco Pallareto (Province of Potenza)

number of positive and negative consequences on soil. The first are as follows:

- integrated soil fertility (vegetal and animal),
- mobilisation of the accumulated dead biomass,
- soil removing operated by animals and dissemination of useful grasses.

Main negative aspects are as follows:

- diminishing of water infiltration and consequent increase of run-off,
- modification of the chemical composition of the litter,
- decrease of carbon stored in the soil.

As a conclusion about the subject of the grazed forests, it can be said that with well-defined rules, the positive aspects are overcoming the negative ones; without rules, the opposite occurs.

Making a general land use assessment for the southern land (Adinolfi and Sgroi 2011), we observe that the decrease in the surfaces devoted to field crops is a little superior to that of the national average (−4.0 against −3.6 %). The surfaces covered by permanent crops (olive, vineyard and fruits) are practically unchanged. Pasture lands have increased 4.7 %, but the cattle number has decreased (−3.1 %). This fact leads to a better management of the environment, with more pasture and less animals.

Fig. 4.32 Cereal fields and badlands in the middle Basento watershed. Aliano (Province of Matera)

Twenty years ago, the suggestion for increasing range and cattle breeding has been stressed by Iannelli (1992).

The majority of the hills and many mountain slopes are terraced with the presence of Escalic Regosols and Anthrosols. The marine Pliocene hills are mainly covered by extensive cereal crops, olive groves and vineyards. The full range of soils goes from Regosols and Leptosols to Vertic or to Haplic Cambisols (Calcaric). Patches of badlands occur with Pliocene formation (Fig. 4.32). In the internal plains and on the fluvial terraces, the pedogenesis has produced, respectively, Haplic Fluvisol (Eutric), Haplic Cambisols (Eutric), Endogleyic Cambisols, Calcic Vertisols and Haplic Luvisols (Chromic).

Fallow, once largely practiced, is a reliable method to maintain the soil fertility in acceptable limits. It is associated to superficial tillage to facilitate the grass germination. Fallow in southern Italy is the simplest reply to dry climatic conditions. Cereals fit very well with a climate that is dry during the summer and humid during the winter. The problem is the reconstitution of the fertility after a number of cycles based on cereals. Farmers knew, from the Roman period, that the soil must be untilled for 2 years or more. The soils (Calcaric and Vertic Cambisols, Haplic Calcisols, Calcic Vertisols and Eutric and Calcaric Regosols) reach with the fallow a semi-permanent equilibrium.

Burning the stalks contributes to atmospheric pollution but determines a nitrogen increase because fire operates a partial soil sterilisation after which the bacteria prevail on the fungi. A more sophisticated fire use, not practiced today due to the high cost, is the Italian *debbio*. It consists in heaping and burning herbaceous turfs in a way similar to that of the charcoal pile and then distributes on the field the burned earth. The advantages are related to a better availability of nitrogen, phosphorus and potassium.

The actual return to natural conditions of the mountain environment due to the land abandonment makes a shocking contrast to the overused plains. The two problems do not annul each other but need local specific solutions (Di Gennaro et al. 2005).

Famous since the time of the Roman Empire are the Campi Flegrei at the foot slopes of the volcano Vesuvio around Naples. Here, the Andosols being very fertile have favoured intensive human settlement and agricultural land use.

In the province of Salerno and Avellino, volcanic ash has been deposited originating very deep and fertile soils: Humic Andosols on steep slopes have stands or coppices of Chestnut trees of high productivity, Haplic Andosols on gentle sloping areas are intensively cultivated. These soils present the risk of landslides and mud flows if the ash lays on consolidated rocks. This was the case of the great disaster occurred at Sarno in the province of Salerno in 1998 with 180 casualties. The background of the event was a Mesozoic relief covered by a blanket of ash which in turn had a Chestnut cover. From investigations of Terribile et al. (2000), it can be said that all the landslides in that area took place with Andosols developed on ash lying on carbonatic formations and bearing Chestnut tree stands. The Andosols, rich in allophanic material are able to retain at saturation an amount of water superior to the weight of the dry soil itself. This phenomenon, combined with the tixotropic properties, gives to the soil the capability to liberate suddenly, after a mechanical thrust, part of the water contained in the micropores and then to generate a mud flow. The weight of the trees probably contributed to the mass movement.

Steppe environment is present in southern Italy in three main zones: Salento, Tavoliere and Murge. Probably Murge in past-time sheltered forest of Pubescent oak today entirely disappeared. Murge has calcareous origin and forms a sort of plateau that traditionally has been used as a place where the heard of sheep passed the winter before the transhumance towards the Apennines. Due to the millennial overgrazing, the soil is extremely eroded, thin and skeletic: Leptic Luvisol (Chromic) "Terra rossa".[10] The actual vegetation is adapted to the extreme climatic and pedological conditions. All the botanical specimens have set up physiological mechanisms to overcome the dry periods. Well-visible botanical species are *Asphodelus ramosus* L., *Urginea maritime* L. Baker, *Ferula communis* L., *Euphorbia spinosa* L. and rare *Pyrus amigdaliformis* Vill.

In the Murge and Salento, the earth movements, the land levelling and the grinding of the rocks to produce new agricultural soil favour erosion and landslide and cause impairment of the attractiveness of a landscape once characterised by a sharp contrast of red and white colours (Costantini and Righini 2002). The involved soils are Leptic Luvisol (Chromic), Haplic Regosol (Calcaric), Haplic Leptosol (Calcaric) and Haplic Calcisols which are white.

The major part of the Tavoliere with Vertic and Calcaric Cambisols and Haplic Vertisols (Calcaric) "is today devoted to the irrigated cultivation of tomatoes, sugar beets and asparagus and non-irrigated durum wheat. Both systems, which might seem to be contradictory, are sustainable due to their specific production characteristics and efficient use of the water throughout the year". (European Soil Bureau Network 2005).

4.3.6 Soils of the Islands

Sicily

Man as a factor of pedogenesis has a particular importance in Sicily due to the long history of the island (Fierotti 1977). Therefore, the poverty of woods and land degradation occurring in several areas have a historical explanation.

Sicily has a complete set of altitudinal belts: from 3,323 m of altitude of the Etna volcano to the sea level.

Starting from the top of Etna, we notice that between 3,000 and 2,500 m of altitude in the area defined "volcanic desert" by Noirfalise (1987) *Astragalus siculus* Biv. is the only botanical species responsible for a minimum of pedogenesis. The soil association is rock and Lithic Xerorthents (Fierotti 1988), corresponding to Lithic and Leptic Regosols. Between 2,500 and 2,000 m with *Astragalus siculus* Biv. cooperate also *Genista aetnensis*(Biv.) DC. and *Juniperus oxicedrus* L.

In the altitudinal belt between 2,000 and 800 m, the volcanic formation of Etna must be treated separately from the calcareous formations of Nebrodi and Madonie and from the gneiss and michaschists of Peloritani. Andosols rich in organic matter by the influence of Beech, Chestnut and Oastrian pine var, Calabrian (*Pinus Nigra* Arnold. *Var. laricio*) are found on the slopes of Etna between 1,600 and 800 m. The geological calcareous formation of Peloritani, Nebrodi and Madonie are patchy covered by Beech with the endemic *Abies nebrodensis* Máttei (Umbrepts and Haploxeralfs). Frequent deposition of volcanic ash improves the soil depth and fertility.

Beech stands between 1,200 and 1,600 m from Etna to Madonie embrace an area that is defined by man rather than by bioclimatic situations (Hoffmann 1960). Beech rarely form pure stands being generally mixed with Pubescent oak and with a few specimens of *Abies nebrodensis*. On the Madonie, there are 5,000 ha of Flowering ash (varieties *rotundifolia* and *angustfolia*) producing manna (for details see Dazzi and Fatta Del Bosco 2009).

[10] Terra rossa is an international denomination of a soil typical of warm Mediterranean environment on calcareous rocks.

Fig. 4.33 Lithic Luvisol (Chromic). Monte Pellegrino (Province of Palermo)

In the oak belt (1,000–600 m), the Pubescent oak is accompanied by Holm oak and Cork oak. The soils are thin and eroded. A remnant wood of deciduous oak is that of Bosco della Ficuzza on Rocca Busambra. The Holm oak formation is present on the low slopes of all the Sicilian mountains. Holm oak constitutes a meso-Mediterranean belt with Cork oak, Arbutus (*Arbutus unedo* L.), Wild olive (*Olea europaea* L. *Var. oleaster*), Laurel (*Laurus nobilis* L.), Myrtle (*Myrtus communis* L.) and *Calycotome villosa* (Poiret) Link. The historical intensive exploitation has degraded this belt, and in several zones, the soil has disappeared being eroded or buried under dentritic colluvium.

The Holm oak and the Mediterranean *macchia* below stay frequently on Terra rossa, that is, Haplic Luvisol (Chromic) or Haplic Luvisol (Rhodic). This soil is present in several soil associations of the soil map of Sicily (Fierotti et al. 1988). Due to the peculiarity of Terra rossa, some of these associations call for comments. The Leptic Regosols and Haplic Luvisol (Chromic) of the association n° 2 are almost exclusive of the province of Trapani, locally are called *sciare*, and configure a mainly flat landscape arid and desolated. The actual degraded vegetation is a *gariga.*[11] If irrigated, these soils are suited for fruit trees, citrus and orchards. In this case, the land acquires a high value that justifies the use of machineries for shattering and grinding the calcarenite to create new soil.

In the association n° 7, there are rock outcrops and Leptic Luvisols (Chromic) characterising the massifs of the province of Palermo (Fig. 4.33) and Trapani. The vegetation is composed of brushwood and meagre pasture for goats. The topography is rough, and karstic phenomena are pronounced. On the high slopes of Monte Pellegrino, there is a *gariga* of *Euphorbia dendroides.*

Among the best soils of Sicily are those of the almost level area of Vittoria (association n° 29) with Haplic Luvisols (Chromic) showing good depth, texture and structure. Vineyards, green houses and olive groves are spread on the territory whose unfavourable places grow almond trees.

The Monti Sicani of Mesozoic era present areas reforested with Aleppo pine (*Pinus halepensis* Mill.) and Atlas cedar (*Cedrus atlantica* (endl.) Manetti). The first has produced hemi-mor, the second mor-moder. Both of them are very important because compensate the bases lost by leaching process (Dazzi 1996).

The gypsum–sulphur evaporitic formation in the provinces of Agrigento, Caltanissetta, Enna and Trapani goes from the sea level up to 800 m, exceptionally up to 1,200. The rugged landscape is one of the most impervious in Sicily. The steppe character of this environment is clearly expressed by the presence of *Hyparrhenia hirta* (L.) Stapf. The soils (Leptic Regosols and Vertic Cambisols) are unfertile, very low in chemicals and entirely deprived of organic matter. They can be cultivated only in places with deep soils. Several areas have been reafforested with Aleppo pine and *Eucalyptus sp*. The soil evolution under Eucalyptus (FAO 1985) is a question mark, anyhow a new landscape that controls soil erosion has been created, especially around Piazza Armerina.

The heart of Sicily (a quarter of the surface) is constituted of clay hills covered by cereals or pasture and forming, from the sea level up to 1,000 m, an unfinished soil catena[12] with Regosols on top of the hills, Haplic Cambisols or Vertic Cambisols on the slopes and Haplic Vertisols in the small alluvial valleys.

Vertisols, Chromic or Pellic, not necessarily belonging to a catena are found in many places of alluvial origin. These soils are important not only for their extent but especially for their high agronomic value, once the farmers have overcome the problem of management of these fertile but difficult soils.

[11] *Gariga* is a poor steppe vegetation with xerophylous shrubs as *Spartium*, *Cistus*, *Erica*, *Stipa* and others. In extreme climatic situation take the place *Chamaerops humilis*, *Asphodelus* and thorny *Asparagus*.

[12] A catena being a direct function of the topography minimises the role of other pedogenetic factors.

Fig. 4.34 Haplic Cambisol (Humic) in the Holm oak forest of Supramonte (Province of Nuoro)

Sardinia

The land use in Sardinia is the oldest of Italy since the *Nuragic* civilisation started 6,000 years ago. The majority of the soils is then quite far from the original pedogenesis.

Aru et al. (1990, 1991) have identified eight basic Sardinian landscapes.

Landscape on Limestone and Dolomite

Areas belonging to this landscape are the Supramonte of Orgosolo and Oliena, Monte Albo, part of Sarcidano and the area between Porto Torres and Alghero. The soils are Lithic Leptosols, Rendzic Leptosols and Haplic Luvisols (Chromic). Particularly interesting is the area of Supramonte due to the existence of islands of well-preserved Holm oak climacic forest.[13] Holm oak has a moder humus elaborated by Arthropods on the slopes (Fig. 4.34), mull worked by *Anellida* in the compluvium, and humus called *twin humus* in the intermediate situation (Susmel et al. 1976). The reason of the *twin* denomination concerns the fact that during the fall and the winter, the humus of Holm oak is dominated by *Acari* and becomes a coarse moder, but during the spring, Collembola takes over and produces a fine moder or even a mull. The final result is a package of different layers of humus. The climax of the Holm oak formation is the brown Mediterranean soil (Mancini 1955; Duchaufour 1970) characterised by a black A horizon and a brownish red Bw, corresponding to Haplic Cambisol (Humic and Eutric).

In many cases, the forest of Holm oak is far from the climax because cutting, fire and pork pasture have modified the original soil profile that often consists in a Haplic Regosols (Humic). The pastures in the Holm oak belt are mediocre. We must observe that the border lines of Holm oak, Cork oak[14] and Pubescent oak are not well defined in Sardinia because the altitude plays a secondary role with respect to the exposure and steepness (Aru and Baldaccini 1977). On colluvium at the foot slopes of limestone relieves, eventual hard calcic horizon is detectable by a *gariga* of European fan palm *Chamaerops humilis* L., like that at the base of Monte Tuttavista.

Landscapes on Metamorphic Rocks: *Schists and Shales*

These are the landscapes of Gennargentu, Barbagia Belvì, Gerrei, Sarrabus, SanTeodoro-Orune-Siniscola, and the geologically complex area of Sulcis and Iglesiente. The Gennargentu is the highest mountain of Sardinia (1,834 m), its pedogenesis on the upper slopes is reduced because the natural vegetation has been eliminated, and today, the organic matter contribution is limited to a clear steppe formation of *Astragalus sirinicus* Ten. *subsp*. *genargenteus* and to Black alder (*Alnus glutinosa* (L. Gaertner.) along the small water courses.

Going down, we face the belt of Black hornbeam with Holm oak and Yew (*Taxus bacchata* L.) then the important belt of Holm oak alone and finally, Mediterranean *macchia* with Lentisk (*Pistacia lentiscus* L.), Arbutus and Tree heath (*Erica arborea* L.). It is interesting to remember that La Marmora (1857) noticed the succession of the different vegetation belts.

Landscapes on Intrusive Rocks (*Granite and Granodiorite*)

They form an elongated and vertical belt from Santa Teresa di Gallura until Gennargentu. The soils, if not degraded are Haplic Cambisols (Humic), but in many cases, the equilibrium has been broken by fire and overgrazing, and the soils are Leptosols or Regosols. Cork oak likes silicate rock and more humidity than the Holm oak. Cork oak may be pure or mixed with Holm oak and Pubescent oak. The Cork oak represents not only a beautiful landscape but also an important income; hence, it follows that the Cork oak ecosystem must be maintained through a rational exploitation whereas grazing, fire and ploughing lead to severe soil degradation (Vacca 2000).

Landscapes on Effusive Acid Rocks (*Andesites and Rhyolites*)

[13] Holm oak is well adapted to different types of soil; nevertheless, the most suited are soils on marly sandstone and on volcanic tuffs (Umbric Andosols).

[14] Cork oak has to be considered as the warmer facies of the Holm oak formation (Arrigoni 1968).

Fig. 4.35 Nuraghe Santa Sabina, that is, a building of the pastoral Nuragic civilisation (4,000–5,000 years b.p.). The stones are of basalt and the soil is an Andosol. Silanus (Province of Nuoro)

These landscapes are spread on two huge plateaus: Campeda and Abbasanta where pasture lands and cereals are on Vertic Cambisols (Eutric) and Lithic Leptosols (Eutric). A well-known Cork oak wood is that of the Giara di Gesturi on basaltic expansion.

Landscapes of Effusive Basic Rocks (*Basalt*)

Located especially in the Nurra region with very good Haplic Cambisols (Eutric). The best stands of Cork oak would be on soils derived from basaltic rocks, but due to the high soil fertility, they have been transformed, since the antiquity, in pasture (Aru and Baldaccini 1977). As a matter of fact, concentration of *nuraghe* (settlement of the ancient pastoralist society) is located on soils derived from basaltic rocks (Fig. 4.35).

Landscapes of the Miocene Sediments (*Calcareous Rocks*, *Carbonatic Marl*, *Marl and Sandstones*)

They are well represented in Western Sardinia, especially in the areas of Arborea and Trexenta. The soils are often organised in the typical catena with Regosols on top of the hills, Cambisols on the slopes and Vertisols at the bottom land. Agriculture is the prevailing land use.

Landscapes of Ancient Alluvial Deposits

They constitute the huge plains of Campidano di Cagliari and Campidano di Oristano. The soils present a high variability depending on lithology: zones with Haplic Calcisols or Petric Calcisols alternate zones with particular soils (*gregori*) that are clay–stony and seasonally hydromorphic. They have been transformed from forest to agriculture in recent time.

Fig. 4.36 Terrace on slope superior to 100 %. The soil is Escalic Anthrosol. Parco Regionale delle Cinque Terre (Province of La Spezia)

Landscapes of Recent Alluvial Deposits

They are found as narrow belts along the water courses. The soils typology is related to the watershed lithology. Close to the bed of the water courses, Oleander (*Nerium oleander* L.) grows on Endogleyic Regosols.

Coastal Landscapes (see Sect. 4.3.7).

4.3.7 Soils of the Coastal Areas

The Italian coasts have known in their history different phases following the different steps of the human society: cultivation in impervious places, abandonment of the sandy beaches for the danger of pirates and malaria and finally, the tourism pressure of the last 50 years.

Moving from West to East the first coasts is those of Liguria that is almost rocky with cultivations of olive groves and vineyards on terraces. The soils are Regosols and Escalic Anthrosols (Fig. 4.36).

Passing to Tuscany and Latium, we see that between Viareggio and Pisa, the retreat of the coast line has determined the disappearance of the first dunes belt, and the degradation of the behind vegetation composed of Mediterranean *macchia* on Hypoluvic Arenosols. In the past, it was customary to afforest sand dunes with Domestic pine whose humus remains at the surface without integration and tends to the podzolisation. This aspect has led Mancini (1956) to observe that good forest stands have been obtained at expenses of the soil which becomes poor.

The Holm oak formation starts in a consistent way from Livorno southward on the Tyrrhenian side and from Ancona southward on the Adriatic side. It must be said that almost always the Holm oak rather than a pure formation is an element of the Mediterranea *macchia*.

In Tuscany, Latium and Campania until Naples, the coasts are mostly elongated and sandy. Many places are large enough to allow intensive and modern agriculture suffering often for the competition of urbanism and other non-agricultural uses. The soils can be sandy or clayey in relation to the distance from the sea and in relation to the transportation model of solid material from the interior of the country. Arenosols, Cambisols and Gleysols are the most common soils. The irrigated intensive agriculture extracts an excessive amount of water from wells determining intrusion of sea water into the ground water table. Soils belonging to these environments are Luvisols (Gleyic, Haplic and Vertic), Vertic Cambisols, Endosalic Gleysols and Gleyic Solonchaks.

The Tyrrhenian coastal line presents often a series of dunes preventing the water courses to reach the sea, so lagoons parallel to the coast are formed with brackish water and halophytic vegetation. Large areas have been reclaimed and are now exploited for industrial crops, cereals and orchards. In the province of Latina (Paludi Pontine), there is the biggest example of reclaimed swamps in Italy (1920–1930), now intensively cultivated. In previous partial reclamation projects, they have introduced *Eucalyptus camaldulensis* Dehnh. for reducing the excess of water.

The National Park of Circeo testifies the original vegetation that according to the places is a transitional belt Holm oak–Pubescent oak or Pubescent oak–European oak. The soils are Haplic Cambisols (Calcaric) or Haplic Luvisols (Humic, Arenic).

The coast is mountainous in the Penisola Sorrentina and in the promontory of Cilento. The Tyrrhenian coasts of Calabria are quite rough everywhere and a traditional terraced agriculture is practiced. On impervious zones, the natural vegetation is the thermo-Mediterranean belt of the *Oleo-ceratonium* which consists of Wild olive, *Pistacia lentiscus* L., Myrtle, Arbutus, *Cistus sp.*, French lavender (*Lavandula stoechas* L.) and *Calycotome spinosa* (L.) Link on acid soils; European fan palm, *Cymbopogon hirtus* (L.) Janken and *Ampelodesma mauritanicum* (Poiret) Durd et Shinz on calcareous soils. The soils are mainly Regosols and Cambisols. On the flysch and marl of the Ionian coast, the *macchia* is often degraded to *gariga* (Fig. 4.37) with

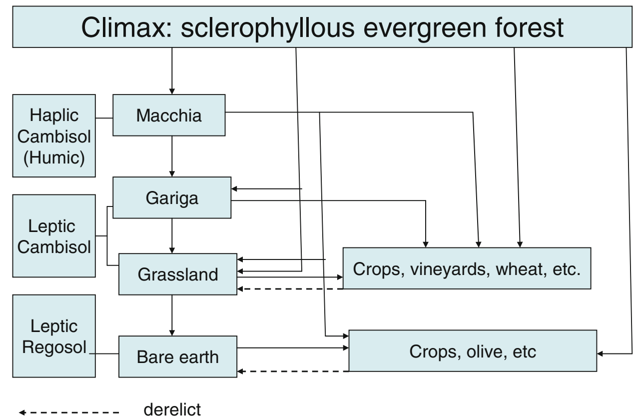

Fig. 4.37 Pattern of degradation of vegetation and soils in the Mediterranean environment (Tomaselli 1977, modif.)

Pistacia lentiscus well adapted to seasonal hydromorphic situation. The soil is Vertic or Endogleyic Cambisols.

The degradation of the original sclerophyllous forest is the most frequent case in the Pliocenic environment. The reason for this degradation is the fact that it was easy to cultivate gently sloping clay hills without rocks and stones (Bagnaresi 1979). But the erodibility of that clay is very high and often is dramatically evident in the form of badlands where the soils are Leptic Regosols (Clayic) or ground surface completely bare. If the final target is the re-establishment of the *Oleo-Ceratonion*, we must create a soil through a pioneer phase with plants resistant and suitable to this environment like *Lygeum spartum* (L.) Loefl.,*Hedysarium coronarium* L., and *Tamarix sp*. (Puglisi 1982).

Until the Sinni river, the coast alternates rocky places with low and sandy zones that become a true plain in the Metaponto area. The coast of peninsula Salentina consists in a series of abrasion terraces carved in the Murge cretaceous plateau. Sparse elements of Mediterranean *macchia* are found in the agricultural environment. The soils are Haplic Luvisols (Chromic), Haplic Cambisols (Calcaric) and Haplic Vertisols. Until Barletta, high flat rocky coast alternates low sandy beaches. The Gargano promontory has steep rocky calcareous coast with Mediterranean *macchia* and Haplic or Lithic Leptosols (Calcaric) and Haplic Regosols (Calcaric). The northern edge of the promontory of Gargano is characterised by lakes with brackish or salty water. The hydromorphic areas around the lakes have been reclaimed, and today, agriculture is practiced on Endogleyic Cambisols, Gleyic Luvisols and Haplic and Gleyic Vertisols. From the lake of Varano northward until the promontory of Conero, the true coast is a narrow belt of 150–200 m entirely modified by the tourism. The Conero has extremely narrow beaches close to escarpment stabilized by Reeds (*Arundo plinii* Turra) and Broom (*Spartium junceum* L.) (Biondi 1986) on Leptic Regosols. From Ancona to the Po delta, the coasts are narrow and sandy with only some spots of forest vegetation, like Pineta di Ravenna with Gleyic Arenosols and Haplic Cambisols (Calcaric). From Taglio di Po to Grado, the landscape presents a complex pattern. Moving from the shoreline, we meet dunes with Arenosols and Regosols, lowland with Histosols, then depressions of variable size with sheets of fresh or brackish water and with soils ranging from Histosols to Mollisols (USDA 1999), and finally, the true Holocene plain with Fluvisols and Mollisols (Bini 2000 and 2012, in this volume). From Grado to Monfalcone, the coast is similar to the previous tract of land. From Monfalcone to Trieste, the coast is steep, rocky and reforested. The soil is Leptic Luvisol (Chromic).

Passing to the coasts of Sicily, we observe that where the sea shore is dominated by mountains, the coast may be steep and rocky or level in small valleys created by alluvial material brought down by torrents. Citrus groves, orchards, vineyards and arable land are found often on terraces. The soils are Regosols, Fluvisols and Cambisols. Where the relieves are gently sloping, the influence of the sea is prevailing with formation of sand dunes and rare psammophilous vegetation. In many places, the Arenosols of the dunes are stabilized with cane fences or Mediterranean brushwood. Between Licata and Gela, the dunes harbour *macchia*, vineyards and greenhouses. Many sectors of the coast between Trabia (province of Palermo) and Menfi (province of Agrigento) belong to the calcarenitic quaternary coastal formation with Terra rossa and degraded natural vegetation. The agronomic potential is modest, but after improvements, the land becomes suitable for citrus groves, vineyards and greenhouses.

The Sardinian coasts present a high variability of forms and colours due to the different geological formation. The northern coast and part of the eastern (historical region of Gallura) consists of granite elongated in the sea forming several small harbours and promontories and configuring a *rias* landscape. Soils are Arenosols or Regosols covered by *macchia* with *Cistus spp.*, *Helychrisum italicum* (Roth) Don, *Eryngium maritimum* L., Myrtle, Wild lavender, Lentisk, Arbutus and *Juniperus phoenicea* L. whose long and superficial roots guarantee anchorage against the wind (Fig. 4.38).

In some cases, the residues of *Poseidonia oceanica* L. eradicated from the sea and brought to the beach form layers alternately covered by sand. On well-stabilized sand dunes, pedogenesis has progress developing Haplic Luvisol (Arenic) (Fig. 4.39).

Fig. 4.38 Roots of *Juniperus phoenicea* L. contributing to the sand stabilization. Sometimes, the roots are exposed to the air due to wind erosion. Cala Salinedda (Province of Olbia-Tempio)

A. Giordano

Fig. 4.39 Dune stabilized by vegetation. The soil is Haplic Luvisol (Arenic). San Teodoro (Province of Olbia-Tempio)

On Mesozoic carbonatic rocks, the coasts are abrupt (gulf of Orosei in the eastern side and Capo Caccia in the western). The soils are Lithic Leptosols (Calcaric) a subordinately Leptic Luvisols (Chromic). In the western and southern side, the coasts are rather flat, sandy, and the agricultural fields approach often the beaches. To protect these fields from the sand encroachment, important works

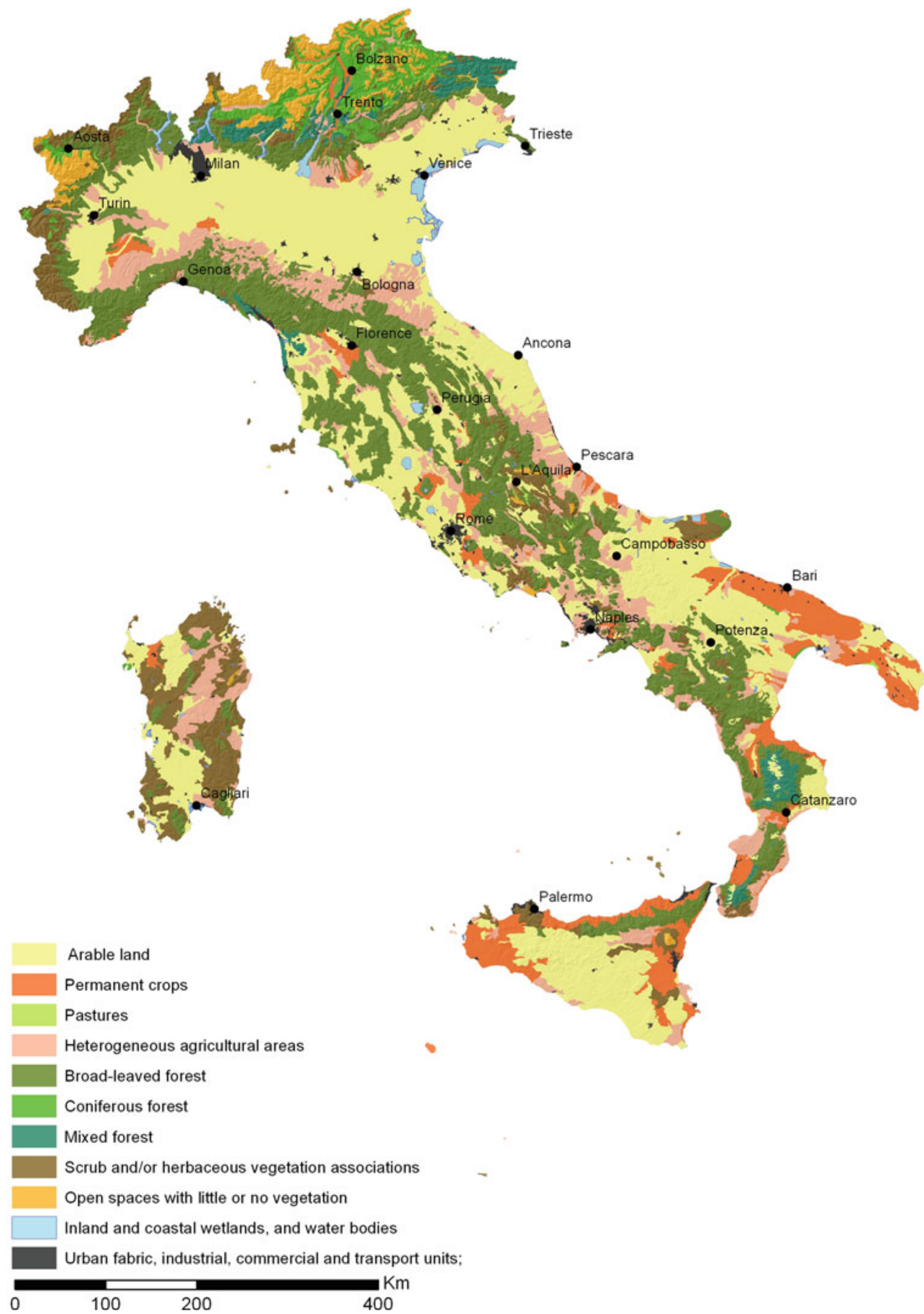

Fig. 4.40 Dominant soil cover of the soil systems of Italy (care of Costantini et al., see Chap. 6)

of sand dunes fixation have been done using Domestic pine and *Acacia cyanophylla* Lindl. (Sanfilippo 1968). The soils from Haplic Arenosols become Haplic Arenosols (Greyic). In many places of the gulf of Oristano, the soils are influenced by the ground water table (Endogleyic Arenosols and Gleyic Solonchaks).

At the end of the chapter "Vegetation and Land Use" it seems interesting to present the picture of the dominant land cover of Italy (Fig. 4.40).

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5 Time as a Soil Forming Factor and Age of Italian Soils

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5.1 Factors Influencing Soil Age in Italy

The "time" of soil formation is paced by several different clocks; each clock is set by a factor of soil formation, in turn responding to some environmental drive. The clocks work on broadly different timescales, and their effect on soil formation may unfold on scales completely different with respect to the underlying driving factor. The relative weight of the different "clocks" is defined by the general aspects of a country, intended as a setting for soil formation. In this sense, Italy displays some well-defined traits.

Geological structure, Tectonics and Geodynamics have a very prominent influence. The Mediterranean basin depicts the final stage of a continent-to-continent collision, and tectonic activity spans from the Panafrican orogeny, in Precambrian, to present-day seismicity. Mediterranean tectonics are dominated by a series of fold-and-thrust belts, with associated foreland and back-arc basins (Cavazza et al. 2004). Most of Italy is materially formed by two of the main Mediterranean fold-and-thrust belts, the Alps and the Apennines.

The Alps represents the "classic" orogen, inasmuch as basic concepts of mountain building mostly originated there. However, they are today seen as one of the most complex orogens in the world, especially with respect to the much simpler, if larger, Asian ones (Frisch et al. 2011).

The Apennines are one of the youngest mountain chains in the world, forming since Neogene through Quaternary times, in just about 23 million years. During Quaternary, Apennines experienced significant shortening (80–200 km) and up to 2.5 km of uplift, at considerable rates (up to 1 mm·y^{-1} in the Apuan Alps, Calabria and the Peloritani Mountains of NE Sicily, Cavazza et al. 2004).

This background setting is of fundamental importance to soil time in Italy. As acknowledged by modern structural geomorphology, uplift, the prime product of orogeny, and erosion are inextricably linked in a chicken-and-egg clasp. Uplift bestows on rock the potential energy for being eroded, but without erosion uplift would be impaired by the enormous weight of rock that fold-and-thrust belts can pile up in small spaces (Smith et al. 1999; Willett and Brandon 2002). Uplift is then a major factor in setting, on the broadest scale, the rate of erosion; when uplift rates are set on "high", as it is within active orogens, erosion rates tend to be the upper boundary condition of soil age.

Regional erosion rate estimates in the two main Italian mountain chains depict a clear portrait. According to Cyr and Granger (2008), erosion rates in the Northern and Central Apennines varied from 0.20 to 0.58 mm·y^{-1} from Middle Pleistocene, around 0.9 Ma, to present day. The ensemble of Northern Apennine basins draining to the Adriatic is especially well known (Bartolini et al. 1996; Bartolini 1999; Bartolini and Fontanelli 2009). Within this sub-basin, integrated sedimentation rates sharply increased sometimes between 1.3 and 0.8 My BP, from a Pliocene average of 0.23 mm·y^{-1} to a Quaternary average of 0.66 mm·y^{-1}; on the western side, Apuan Alps endured an average of 0.5 to 1.7 mm·y^{-1} throughout the Plio-Quaternary period. Holocene rates for Apennines, at 0.36–0.51 mm·y^{-1}, (Bartolini et al. 1996) do not differ significantly from the Quaternary average. Data from Southern Apennine are more sparse, and rates obtained appear to be heavily dependent on rock type. Independent studies on the southern calcareous Apennine, that is, the back-arc region, tend to agree on a range of 0.13–0.30 mm·y^{-1} within very much the same "Quaternary" as intended by N Apennine authors (Amato et al. 2003; Gioia et al. 2011). On the clayey formations of the Eastern slope, along the thrust front, different orders of magnitude are

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attained. With respect to the interval from the Last Glacial Maximum (LGM) to present, Coltorti et al. (1991) estimated 0.7–1.6 $mm \cdot y^{-1}$, but Buccolini et al. (2010), exclusively focusing hilly clayey landscapes, estimated maxima of 3.0–7.8 $mm \cdot y^{-1}$.

Present-day, catchment-level, measurements were first gathered by Bartolini et al. (1996), using suspended load gauges. The overall conclusion was that these rates are comparable to long-term Quaternary rates. Regional averages span from 0.466 $mm \cdot y^{-1}$ for Po the tributaries flowing from the Apennine to 0.528 $mm \cdot y^{-1}$ for other rivers of Emilia-Romagna and Marche.

Bartolini (1999) and Amato et al. (2003) agree that even such high rates are insufficient to maintain the Apennine in a steady state, and that the chain is still uplifting. In the Northern Apennines, this is visually evidenced by the vast outcrops, at high elevation and relief energy levels, of very erodible marly formations, such as the "Marnoso-Arenacea", (marly-arenaceous formation) and by the resulting accelerated erosion.

Similar estimates for the Alps yield lower values, underlining the higher maturity of the Alpine orogen. Long-term (Miocene to present-day) data by Einsele (2000) suggest > 0.01–0.5 $mm \cdot y^{-1}$. Higher values of 0.6–1 $mm \cdot y^{-1}$ only turn out when considering the LGM-to-present interval (Hinderer 2001; Wittman et al. 2007). Holocene data show an east–west trend; Vezzoli (2004) comes out at an average of 0.07 $mm \cdot y^{-1}$ for the Dora Baltea watershed, while Norton et al. (2011) find out 0.17–1.4 $mm \cdot y^{-1}$ for the Eastern Alps. The same trend is clearly visible in present-day data: while chain-wide estimates cluster between 0.125 $mm \cdot y^{-1}$ (Hinderer 2001) and 0.086 $mm \cdot y^{-1}$ (Bartolini and Fontanelli 2009), they are actually averaging values often lower than 0.01 $mm \cdot y^{-1}$ in the western catchments and higher than 0.5 $mm \cdot y^{-1}$ in the eastern ones.

A notable element in all long-term estimates is that they usually assume a bulk density (BD) of "soil" of 1.8 $g \cdot cm^{-3}$; this is definitely high with respect, for example, to the value of 1.4 $g \cdot cm^{-3}$ commonly used as a default average for ploughed soils. This value is itself too high for unploughed soils; as shown in Table 5.1, measured BD values of Italian forest and range soils average only 1.16 $g \cdot cm^{-3}$ in the topsoil, not attaining 1.4 $g \cdot cm^{-3}$ even at 72 cm depth. Similarly, De Vos and Cools (2011) report, from analysis of 5055 forest soils of Europe, median values growing from 1.02 to 1.35 $g \cdot cm^{-3}$ while moving down from the 0–10 to the 40–80 cm depth intervals. When the effect of the BD value on the conversion from sediment volume to land surface lowering is accounted for, one is left with the serious possibility that published, long-term erosion rates estimated from geological methods are underestimated.

Table 5.1 Soil bulk density (BD) values retrieved from the national soil database held at CNCP (forest and range soils)

Depth interval (cm, $\pm 1\sigma$)	Bulk density ($g \cdot cm^{-3}$, $\pm 1\sigma$)	N. measurements (in CNCP database)
0–26.6 (±16.4)	1.16 (±0.26)	1211
26.6–52.2 (±32.4)	1.29 (±0.28)	515
52.2–71.9 (±38.0)	1.29 (±0.28)	333

Other underestimation factors are better known and acknowledged in publications. When estimating present-day erosion rates, they refer especially to the severe practical and conceptual limitations of the measurement of river bedload. For longer-timescale, regional, estimates based on sediment volume, underestimation is brought by the efficiency of sediment transport to final stores. Such efficiency is always below 1 and can go to 0; for example, a zero efficiency is acknowledged when the catchment areas of the major alpine lakes are bodily removed from calculations. This effect tends to fade out when very long time intervals are considered, as such intermediate sediment stores as moraines, alluvial fans and valley fills are not bound to last for million years. It is, however, well present in shorter intervals, when it should bring about lower estimated rates. The significantly higher erosion rates typically estimated for such critical, and short, intervals as LGM to present should be then regarded as especially noteworthy.

The significance of these data for soil age is better understood when they are translated in the soil loss units better known to soil scientists, those defined by Wischmeier and Smith (1960, 1978). Taking 1.4 $g \cdot cm^{-3}$ as a standard soil BD value, figures in $mm \cdot y^{-1}$ are multiplied by 14 to yield the corresponding value in $t \cdot ha^{-1} \cdot y^{-1}$, as shown in Table 5.2. In this way, the Quaternary period average for Northern Apennines yields 6 $t \cdot ha^{-1} \cdot y^{-1}$, and the maximum published Adriatic basin slope waste rate, 7.8 $mm \cdot y^{-1}$ from LGM to now (Buccolini et al. 2010), corresponds to 109 $t \cdot ha^{-1} \cdot y^{-1}$. The long-term mean rate lies then well within the range of typical present-day erosion rates for ploughed soils of Europe and is much above a proposed tolerable limit of 1.4 $t \cdot ha^{-1} \cdot y^{-1}$ (Verheijen et al. 2009). Actual erosion plot data in Italy are very few; Van Rompaey et al. (2005) analysed data from reservoir siltation throughout Italy, finding out average values of 5.4 $t \cdot ha^{-1} \cdot y^{-1}$ for A-pennine catchments, 16.2 $t \cdot ha^{-1} \cdot y^{-1}$ for Sicily ones and 2.7 $t \cdot ha^{-1} \cdot y^{-1}$ for Sardinia. Further comparison with the compilation of soil erosion in agricultural and other man-disturbed soils in the Mediterranean region, compiled by Shakesby (2011), confirms that "background", long-term soil erosion is large with respect to agricultural soil loss.

These comparisons show that variations in soil loss *sensu Wischmeier*, important as they are for correct soil management, are not that meaningful for long-term soil

Table 5.2 Selected data on alpine and apenninic denudation rates

Source	Area	Time interval	Method	Erosion rate, mm·y^{-1}			Erosion rate
				Min	Max.	Mean	Mean, t·ha^{-1}
Adriatic apennine slope							
Cyr and Granger (2008)	Romagna	Present	Cosmogenic nuclides	0.28	0.58	0.43	6.02
Cyr and Granger (2008)	Romagna to Esino river	10^6 y BP	Cosmogenic nuclides	0.20	0.24	0.23	3.22
Bartolini et al. (1996)	North of Pescara	Quaternary	Sediment budget	0.41	0.46	0.45	6.30
Bartolini et al. (1996)	North of Pescara	Holocene	Sediment budget	0.36	0.51	0.43	6.02
Bartolini et al. (1996)	Po tributaries	Present	Suspended load	0.07	0.86	0.47	6.58
Bartolini et al. (1996)	Reno to Tronto catchments	Present	Suspended load	0.17	1.29	0.53	7.42
South apennine, calcareous							
Amato et al. (2003)	Ionian Lucania	0.8–0.6 My to present	Landform reconstruction	0.20	0.30	0.25	3.50
Gioia et al. (2011)	Campania-Lucania	2 My to present	Landform reconstruction	0.06	0.25	0.11	1.50
Gioia et al. (2011)	Campania-Lucania	1.2 My to present	Landform reconstruction	0.06	0.43	0.17	2.38
Gioia et al. (2011)	Campania-çucania	0.7 My to present	Landform reconstruction	0.08	0.19	0.11	1.54
Gioia et al. (2011)	Campania-Lucania	0.15 My to present	Landform reconstruction	0.24	0.48	0.36	5.04
South apennine, mixed							
Coltorti et al. (1991)	Various	LGM to present		0.70	1.60	1.15	16.10
Buccolini et al. (2010)	North of Tronto river	LGM to present	Landform reconstruction	7.80	7.80	7.80	10.920
Buccolini et al. (2010)	Northern Abruzzo	LGM to present	Landform reconstruction	2.40	3.00	2.70	37.80
Alps							
Einsele (2000)	Alps	Miocene to present	Landform reconstruction	<0.01	0.50	0.25	3.50
Wittmann et al. (2007)	Swiss Alps	LGM to present	Cosmogenic nuclides	0.27	0.90	0.58	8.12
Hinderer (2001)	Alps	LGM to present	Sediment budget	0.20	1.00	0.60	8.40
Hinderer (2001)	Alps	Present	Sediment budget	0.05	0.27	0.13	1.75
Norton et al. (2011)	Eastern Alps	Holocene	Cosmogenic nuclides	0.17	1.40	0.78	10.92
Bartolini and Fontanelli (2009)	Alps	Present	Total load	–	–	0.09	1.20
Bartolini and Fontanelli (2009)	Oglio river	Present	Suspended load	–	–	<0.01	0.11
Bartolini et al. (1996)	Cellina river	Present	Total load	–	–	0.88	12.32
Vezzoli (2004)	Dora baltea catchment	Present	Bedload	0.01	0.73	0.07	0.98

Note Conversion from mm·y^{-1} to t·ha^{-1} is based on soil bulk density of 1.4 g·cm^{-3}, irrespectively of values used by original authors

evolution and soil age, at least when applied to a tectonically active area like Italy.

Climate is the second "clock driver" of soil formation. The direct relation between climate conditions and soil formation rates is well known, at least in general terms. On the most reductionist possible basis, the clock "springs" (or batteries, for the younger reader) are water and biological activity. To further define, "water" translates into excess rainfall over evapotranspiration; this excess supplies the volume of water flowing through the soil, available for leaching soluble matter. Leaching is necessary to allow chemical reactions to proceed without being choked by their

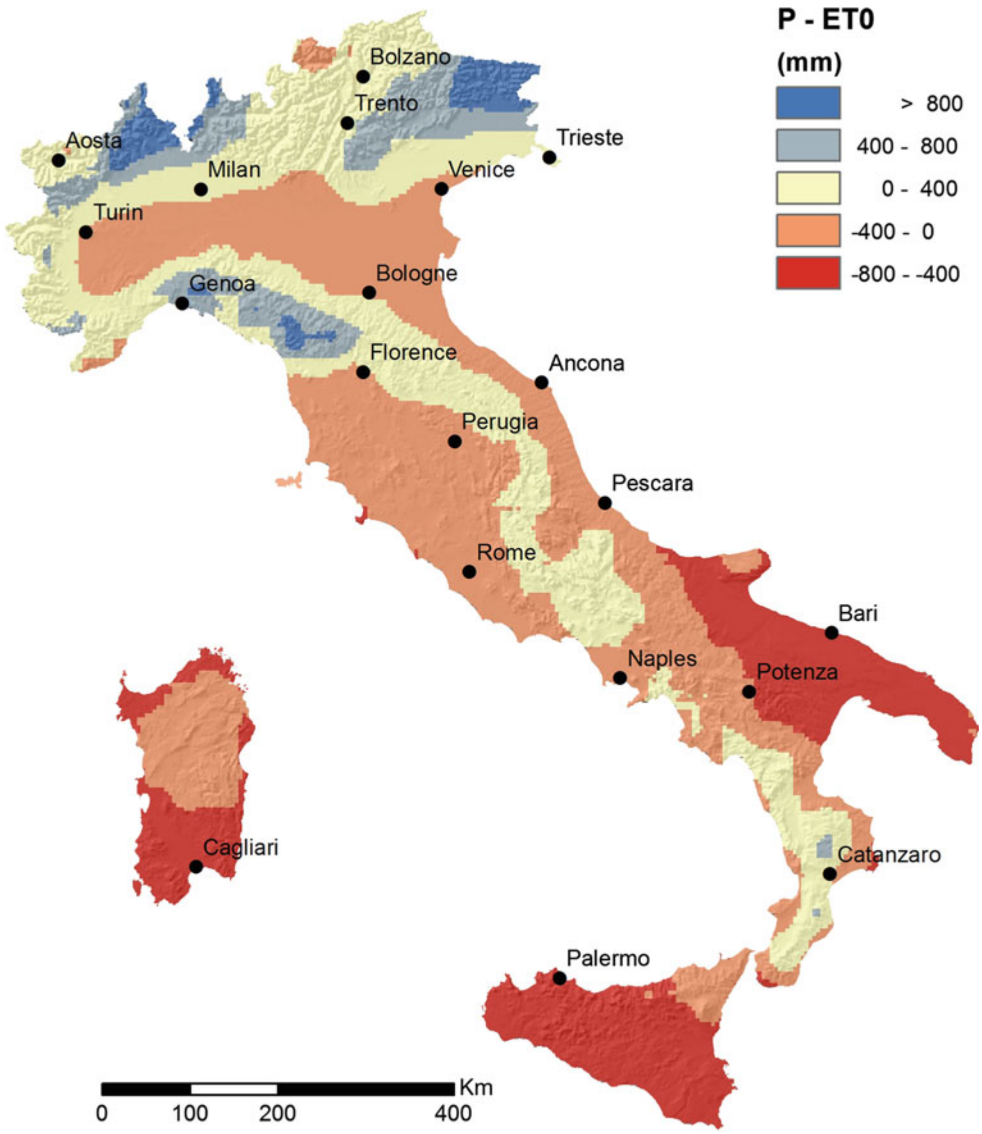

Fig. 5.1 Long-term yearly rainfall-evapotranspiration budget for Italy

own products. The main effect of "biological activity" on soil formation is a flow of protons from biota to soil; of course, this flow must be considered net over a parallel flow of buffering chemical species, also coming from biological activity. Protons, either free or biologically mediated, likely determine more than 80 % of irreversible chemical reactions involving minerals and are, then, the main engine of chemical weathering (Sletten and Ugolini 1991). Apart from active volcano slopes and fumarolic areas, soil proton inflow is largely a function of ecosystem gross primary productivity (GPP), the rate at which photosynthetic organisms produce plant biomass (Chapman and Reiss 1999). Both GPP and the functions linking GPP and net proton production are, on broad spatial and temporal scales, dependent on climate; for Italy, rainfall is the main limiting factor. A similar conceptual model was, indeed, the basis of the zonal soil concept by Dokuchaev (1967).

Figure 5.1 shows the distribution of excess precipitation over reference evapotranspiration (ET0), as mapped for Italy (see Chap. 2 for details about data and methods); the incidence of areas with a rainfall deficit is clear. Furthermore, weighing of the geomorphic stability factors greatly reduces the significance of the broad belt having an excess rainfall between 0 and 400 mm. A large share of this belt covers Alpine and Apennine areas, where generally high instability is not likely to be compensated by such a limited rainfall excess. The other large region belonging to this belt is the "high plain", along the northern edge of the Po valley. This area is obviously stable, but it is essentially made up of fluvioglacial terraces, old enough to have seen different climatic conditions. Knowledge obtained from existing survey data (Costantini et al. Chap. 6, this book) indicates that the "climate engine" is powerful enough to overcome serious geomorphic instability only in those areas having more than 400 mm yearly excess rainfall.

There is, however, more than direct climate effects; climate cannot be neglected as a factor in determining stability, or not, of geomorphic surfaces (i.e. soils). Linkages between climate and erosion modes and rates dominated concepts and ideas of physical geography for long times. The classical concept of "morpho-climatic systems", however, was never very successfully applied to Italian landforms; actually, this concept only really works with definitely cold, hot, dry or wet climates. Books and chapters on climatic geomorphology usually list glacial, periglacial, arid and tropical systems only, eventually after discussing contrasting ideas about morpho-climatic zones.

Modern ideas are somewhat different; it is indeed widely held that stationary climate–landform interactions do not give adequate account of observed erosion. Clear negative feedbacks exist in all "morpho-climatic systems", providing for the achievement of some form of equilibrium and stability, or meta-stability, of land surfaces. Of course, uplift and other crustal movements provide for the permanence of erosion, but do not explain actual erosion rates, over intermediate timescales, in any satisfactory way.

The real progress of the last decades is the acknowledgement of the role of climate change on erosion processes. Climatic transitions are much more effective at fostering erosion than any realistic working mode of stationary climatic systems. The example of the glacial/periglacial environment is most classical. Cold stadials, with extensive ice accretion, are very effective at rock shattering, and glaciers move huge masses of debris. However, glaciers are, at best, indifferent sediment carriers. Most of the debris either remains bound into and below ice or travels for just short distances, building massive low- to medium-order sediment stores. Deglaciation allows debris to move freely, and sediment stores to be partly flushed, as large amounts of water become again available for the true long-distance carriers, the rivers. Shattered mountain slopes are free to move in giant landslides to the footslopes, where rivers will, admittedly with some leisure, carry them away. Back to erosion rates, one can easily notice how rates estimated for the time span "LGM to present" are anomalously high, about an order of magnitude higher than long-term ones for the same region (Hinderer 2001; Wittman et al. 2007). Such high rates are due to the unique efficiency of the deglaciation transition in flushing sediment stores and transferring matter to the ultimate depositional areas.

The high geomorphic productivity of stadial/interstadial sequences is a good explanation for low stability of land surfaces in the Alpine landscape, but similar considerations, if less widely known, also apply to Mediterranean landscapes. Quaternary oscillations in Mediterranean climates are much better described in terms of dry/moist, rather than cold/warm (and vice versa) shifts. Dry/moist cycles may be as effective as cold/warm ones; dry spells cause the geomorphic system to approximate the working of the arid morpho-climatic system, which is very effective at producing debris but ineffective at carrying them far away. Dry/moist transitions restore transport capacity, which is actually more effective at the transition itself than in a stationary, moist climate. Two factors foster very high rate erosion at dry/wet transitions: first, vegetative cover tends to lag climate, so that early rains fall on poorly vegetated surfaces and run-off production is very large; second, large amounts of loose sediments are found in low-order stores, still with a high potential energy and ready to be carried. The process has been found effective across widely different timescales, in any climate displaying serious dry/moist cycles (Waters and Haynes 2001; Porter and Zhisheng An 2005; Boenzi et al. 2008; Carnicelli et al. 2008; Piccarreta et al. 2011).

The Quaternary was defined as "a geological period characterized by climate instability" (Anderson et al. 2007), certainly a good definition. The large increase in erosion rates with the onset of Quaternary, at least the "short" or "stratigraphic" Quaternary preferred by Italian authors, fuelled discussion about fast, climatically driven erosion being the actual enigne, and not the trailer, of the orogeny-erosion machine. At present, the debate sees consensus weighted in favour of the "classical" hypothesis, but this does not detract from the influence of erosion on rates of tectonic uplift, nor it decreases the significance of climate instability in controlling and upper-bounding soil time.

In discussing the setting of soil "clocks", we can consider organisms as covariant with climate; there of course remains to evaluate anthropic influence. If we gauge, as it is classical to do, soil "development" as the integral of all soil properties, including structure, assemblages of pedofeatures and horizon sequence, we realize how serious is the impact of mechanical soil disturbance as a rather rude way to "reset the clock". Man-made soil mechanical disturbance cannot generally rewind weathering; the only exception is selective erosion in ploughed fields, when fine earth may be considered as a weathering product. But man-made disturbance can completely upset soil organization, which is as important as composition in terms of soil functionality and "age". Existing figures on tillage erosion are very scanty, and as far as we know, there is none from Italy. What do we have (Verheijen et al. 2009) suggest that tillage erosion may be at least as important as water erosion, and even more, and that "other" man-made erosion, such as "harvest erosion" may also be serious. For how exceedingly sparse, and even potentially misleading, these data may be, effects in terms of influence on soil "age" must be serious. Tillage erosion is, clearly, a process efficiently moving soil without carrying it any great distance; in this sense, its geomorphic effect somewhat mimics the effect of arid or glacial climates, and this appears to be a general feature of the effects of agriculture on geomorphic systems. If, then, the geomorphic action of the farmer (the herder, the lumberjack, etc.) needs not be overstated, it cannot be neglected, either.

In this sense, Italy is rather unique for the time extent of anthropic influence; strong impacts from agriculture are well documented since the Bronze Age (Sadori et al. 2004; Cruise et al. 2009; Kaltenrieder et al. 2010) or, at least, since early Greek colonization, between 2,500 and 3,000 y BP (Tinner et al. 2009; Noti et al. 2009). If Italy is not the birthplace of agriculture, we can note that many older ploughed areas in the world have either been desertified and abandoned or, at least, undergone significant interruptions of intensive agriculture. None of this in Italy, where the land has been continuously under the plough for a duration, and with a sustained intensity, with which only East Asia bears comparison. Indeed, the footprint of persistent, intensive (and successful) agriculture is intimately entangled to the making of Italy as we know it today. An effective key to the reading of Italy's Mediaeval, Renaissance and Modern history are the ways in which a strong and safe food base, a dense population and the ensuing wealth were a major cause of political division, foreign influence, economical and technological progress and artistic greatness. The price, in terms of soil maturity, has not been cheap; any pedologist with survey experience in agricultural lands knows how large is the amount of disturbance left by thousands of years of sustained ploughing.

So, we can conclude that the soil "clocks" of Italy are set to a short day. The effect can be clearly judged by the statistics presented in Chap. 6 (Costantini et al., this book), where we see that Cambisols, or Inceptisols, represent more than a quarter of the soil typological units of Italy, and that Entisols (Regosols, Fluvisols, Arenosols, etc.) are the second most frequent soil order; together, the two "immature" orders of Soil Taxonomy account for more than half the soil cover of Italy.

5.2 Holocene Soil Formation in Italy

Specific soil processes and field character development in Mediterranean climate conditions were reviewed by Sauer (2010); this review suggests that a steady state in epipedon melanization might be achieved in as little as 25 years, and likely in less than 190 years. Egli et al. (2008) also support this interpretation, and depict a rapid evolution of soil organic matter; actually, they show a strong synergy between time and succession of natural vegetation, but we consider such synergy as integral to the time factor. Organic matter is seen by Egli et al. (2008) to accumulate rapidly in the very first centuries of soil formation. Vegetation succession from *maquis* to evergreen oak forest, together with rapid calcium leaching and consequent pH drop, brought about a significant shift from humic acids to fulvic acids within about 400 years in the volcanic soils of Mount Etna.

Solum thickness achieved within Holocene is reported as 120–130 cm in the Northern Po plain (Costantini and Napoli 1992), 168 cm in the Reno valley, S of Bologna (Eppes et al. 2008), >85 cm in Basilicata (Sauer et al. 2010) and 90 cm on a 4,000 years old lava on Etna (Egli et al. 2008). These data are fairly comparable with data from other Mediterranean-climate regions of the world (Sauer 2010). A soil depth of this order implies, at the very least, development of a Cambic horizon, as also described by Amorosi et al. (1996) for the Reno valley and by Sevink et al. (1982, 1984) for Southern Lazio. Eppes et al. (2008) do describe clay coatings first appearing in soils <2,000 years old in the Reno valley. These authors, however, do not even hold such coatings adequate to define Bt horizons in any soil younger than about 10,700 cal y BP, in agreement with Amorosi et al. (1996). Fully comparable interpretations are proposed for Central Tuscany (Napoli et al. 2006; Costantini et al. 2009).

Though reddening in Holocene times, up to a redness rating (RR, Torrent et al. 1983) of 7.5, was documented for much less favourable climatic areas (Schwertmann et al. 1982), data presented in Sauer (2010) suggest a generally much slower process, true reddish soils mostly not forming within Holocene times. These data are consistent and appear in line with field experience.

The above considerations concerning RR and, partially, development of an argic horizon, must be confronted with two well-documented exceptions, which also allow a more detailed discussion of the interactions between time and parent material.

The Confine soils of Emilia-Romagna (http://geo.regione.emilia-romagna.it/cartpedo/) attain an RR of 3.75 in the BC horizon and show weak evidence of clay illuviation (Fig. 5.2). They develop on a geological formation mapped as the AES7 sub-synthem (Amorosi et al. 1996, 2001); this formation centres on a Late Glacial gravel body, constrained by radiocarbon dating at between 19,000 and 8,500 ^{14}C years BP.

The soils of the proposed Bovolone series (Costantini and Napoli 1992) show a fully developed argic horizon and attain a maximum RR of 5. They develop on mostly sandy alluvial deposits belonging to the terraced Adige river alluvial fan, deposited close to the LGM (Fig. 5.3).

Development of these two soils spans, then, latest Pleistocene and Holocene; the latter presumably had a greater influence, due to more favourable conditions for soil formation. However, they both formed on highly permeable parent materials and substrata, made up of coarse gravel for the Confine and of deep sands for the Bovolone, allowing a high leaching efficiency.

Fig. 5.2 Representative Confine soil profile (gravelly clay loam phase), an Endoskeletic Cambisol (*Chromic*); *Source* Servizio Geologico, Sismico e dei Suoli, Regione Emilia-Romagna; www.suolo.it

Fig. 5.3 Representative Bovolone soil profile, a Stagnic Cutanic Luvisols (*Chromic*)

Leaching of carbonates and exchangeable bases appears to be heavily influenced by such other factors as climate, parent material and drainage; some generalization with respect to time can anyway be attempted. Soils developed on carbonate-bearing parent material appear not to become fully decarbonated in the most common soil formation times in Italy (Sevink et al. 1982, 1984; Amorosi et al. 1996; Eppes et al. 2008; Sauer et al. 2010). In the same time frame, acidification is restricted to favourable climate and parent material conditions; the clear majority of "modal age" soils having 100 % base saturation. The "time divide" examples of the Confine and Bovolone soils stand up, this time, in support of the above general considerations; these soils became completely decarbonated, but remain fully base-saturated, in a time span somewhat longer than Holocene, notwithstanding their specially favourable drainage conditions.

In the much studied Reno valley, there is agreement on Bk horizons only appearing on sediments dated to the first half of Holocene (i.e. >5,000 years old; Amorosi et al. 1996; Eppes et al. 2008). Well-defined carbonate pedofeatures are described by Sevink et al. (1982, 1984) on surfaces generically attributed to Marine Isotope Stages (MIS) 2–4, that is, aged between 10,000 and 90,000 years BP (de Wit et al. 1987), and by Eppes et al. (2008) on terraces formed around 12,500 years BP. In the drier climates of Southern Italy (Sauer et al. 2010), only limited carbonate translocation is visible within comparable timescales.

In the LGM-to-present time frame, the ratio of "active", oxalate-extractable iron oxides to total, DCB-extractable iron oxides (Feo/Fed) is likely to be a significant indicator of chemical weathering; Eppes et al. (2008) show the usefulness of this ratio, which depicts a clear separation between calcareous soils about 1,000 years old and other soils of more than 3,000 years age; similar trends are shown by Scalenghe et al. (2000). Unfortunately, this ratio has seen little further use in dated soils; the more widely used ratio of total iron oxides to total soil iron content (Fed/Fet) is of little use to differentiate within Holocene and late glacial soils as, on such short timescales, it is completely overprinted by parent material influences.

In Alpine, and high elevation/rainfall Apennine landscapes, the weight of time is much lower. The powerful "zonal" engine of areas above 400 mm yearly excess rainfall pushes soils to converge to *climax* much faster than even the limited time allowed by glaciations and erosion.

Favilli et al. (2010) describe patent podzolization in soil horizons constrained at fifteenth century, or later, age; true spodic horizons only required about 1,700 years. In the prevailing steep landscapes examined in this chapter, erosion makes itself felt in denying the persistence of any true albic horizon. Certini et al. (1998) illustrated early evidences of podzolization after as little as 50 years after conifer planting, in the marginal climate conditions of Tuscany at 950 m asl. Goslar et al. (2005) consistently measured present-day rates of peat accumulation of

5–15 mm·y^{-1} in a population of Alpine peats, including Alto Adige ones.

Development of Andosols can often be constrained quite finely. Frezzotti and Narcisi (1996) describe a widely correlated Andosol ("Pedomarker B") draping the carbonate massifs of the Central-Southern Apennine and discuss hard evidence of it having formed between about 12,000 and 4,500 ^{14}C years BP. Though the chapter is not exhaustive in describing the soil, this is actually comparable to the one described by Cecchini et al. (2002) in much the same area and landscape. This soil is actually closer to true andic nature than discussed in the original chapter, as later BD measurements (unpublished) always yielded values <0.9 g·cm^{-3}. Similarly, (Scarciglia et al. 2006) hint that 16 ky minimum were required for partial Andosol development in the Sila uplands of Calabria, influenced by anthropic disturbance and frequent forest fires.

In the more Mediterranean, if somewhat *sui generis*, landscape represented by the Etna slopes, Egli et al. (2007, 2008) found that basaltic lava developed into a Humic Leptosol in 125 years and into a Humic Regosol in a few centuries. The Vitric Andosol development stage was attained in a few thousand years and appears as a sort of soil development plateau, many parameters remaining then constant across more than 100,000 years of soil age. Further evolution shifts to different timescales: a true Andosol was described on a lava flow dated at 115,000 year BP, but absence of intermediate time points does not negate the possibility of andic characters developing in shorter times.

5.3 Dated Palaeosols of Italy

However, older soils are by no means unknown in our country. By a classical natural paradox, much the same forces and processes driving intensive and effective erosion have, among their secondary effects, the building and conservation of significant, if lesser, old land surfaces, thus making Italy a place as good as any for palaeopedological research.

Long-term erosional dynamics, presiding to the dismantling of major orogens, are typically complex and display pulsating time components. We have already reviewed the effects of climatic cycles; to these we can add the effects of the tectonic urge, which is not constant in time, neither in the endogen primary drivers nor in the geomorphic response. The causal chain running from plate collision to soil erosion has several links, and elasticity is built in most of them. Tectonic push may accumulate in the terrain for hundred of thousands of years, to be then released in a very few thousand ones, when local thresholds are crossed (Bull 1990). Climatically and tectonically driven erosional pulses are clearly visible in the ways sediment, either primary or recycled from low to order stores, is moved to such intermediate stores as alluvial terraces, alluvial fans, moraines, outwash landforms, etc. In the intrinsic nature of pulsating erosion, these landforms are then dismantled primarily by dissection, so that the normal trend is for their treads to shrink progressively without being heavily disturbed. Such surfaces are naturally common, if not always very extensive, in tectonically active areas like Italy.

A kind of old, palaeosol-bearing, geomorphic surface more unique to Italy is represented by the so-called "palaeo-surfaces" ("*paleosuperfici*"), scattered across the Apennine. These are defined as "uplifted summit areas of low relief" (Bartolini 1999) or "hanging remnants of ancient landscapes" (Amato et al. 2003). They are interpreted as fragments of ancient, relatively mature, landforms developed by long-term planation processes which shaped the palaeo-Apennines from early Miocene emersion to the start of rapid uplift in Middle Pleistocene. Bartolini (1999, 2003) proposes that rapid acceleration of Apennine uplift should have started between 1.0 and 0.8 My BP, implying that palaeo-surfaces should have developed up to this time. Amato et al. (2003) define two orders of such surfaces in Southern Apennine; they propose, for the older surface, a Santernian to Emilian (1.8–1.15 My) age and a Sicilian to Middle Pleistocene (1.15–0.9 My) age for the younger surface. At present, Apennine palaeo-surfaces are little exploited by palaeopedological studies. Indeed, they are not terrace treads in the classical sense, but rather complete systems of ridge-and-depression landscapes, with a much lower relief energy than the surrounding and lower-lying slopes, so that their value as palaeosol repositories is uncertain. A pioneer study by Bartolini et al. (1984) identified deep weathering saprolites, suggestive of long-term stability and warm-moist climate conditions occurred before the uplift and not easily found in Italy.

The issue of the oldest palaeosols to be found in Italy has two other notable hotspots. The first one came from Cremaschi (1987). This monumental study is, unfortunately, partially unusable today, as later revisions of archaeological stratigraphical concepts made most of its underlying chronology obsolete. One part that definitely stands, however, is the one concerning the oldest interval of the succession. This is found on glaciofluvial, and possibly fluvial, sediments on the Alpine side of the Po plain, and was dated by palaeomagnetical techniques to the Matuyama chron, that is to >0.7 My BP. The palaeosols in this interval stand out for a series of characters associated with advanced pedogesis, such as iron segregation, micropedal structure, non-birefringent matrix and so on. Terhorst and Ottner (2003) studied two outcrops of stacked palaeosols they intended as directly correlated with Cremaschi (1987) outcrops, and found that the deeper portions were distinguished from overlying, younger soils by the presence of true neoformation kaolinite and by high values, up to 50 $g \cdot kg^{-1}$, of Fed. Another documented occurrence of soils in this range of development comes from Central Italy (Costantini and Damiani 2004; Napoli et al. 2006; Costantini et al. 2006). These chapters report the occurrence of plinthite in alluvial fans associated with the uplift of a Central Tuscany range. During subsequent etchplanation of this range, a Cromerian fauna became fossilized in doline infillings, thus locating the genesis of the older soils on the fans at before MIS 13, consistent with the ages proposed by the other authors.

These evidences point out the maximum levels of soil formation attained within geological and climatic settings not too far removed from present times; they should be viewed with appropriate caution in terms of the analysis of relations between time and soil properties. The dates here reviewed were arrived at by intrinsically low-resolution methods, with conceptual uncertainties, and the characters of these soil-forming episodes imply that they lasted longer than the uncertainties in dating. The general timescale proposed by Amato et al. (2003) for the palaeo-surfaces would, however, fit consistently. Formation of the soils and weathering profiles described by Bartolini et al. (1984); Cremaschi (1987); Terhorst and Ottner (2003); Napoli et al. (2006) and Costantini et al. (2006) in a time span between the Santernian and Emilian stages in Lower Pleistocene (Santernian, about 1.6–1.7 to 1.3 My; Emilian, 1.3–1.2 My) is in no way in contrast with existing knowledge on the genesis of similar soils and pedofeatures.

In between the two extremes of Lower Pleistocene and Holocene, there is in Italy a wealth of more or less preserved palaeosols. Their chronology is often uncertain, as dating methods between the upper boundary of ^{14}C, at about 50,000 years, and the Matuyama–Brunhes inversion at about 780,000 years are of recent development and subject to ambiguities. It is a special pity that, for example, such methods as OSL and U/Th series disequilibria measurement were not available to support the investigations reported by Cremaschi (1987).

After the Matuyama/Brunhes inversion, the next firm point in Cremaschi's stratigraphy is the base of the well known Ghiardo loess; this base is actually an archaeological surface, which was dated at 60–70,000 years BP (Martini et al. 2001). As the soils on the Ghiardo loess have a fully developed argic horizon and are completely decarbonated, this gives us a clue to the time needed for a fine-textured (silty loam) soil of Italy to achieve these development stages. Other published data do not disagree; the soils on the H terrace of Ajmone Marsan et al. (1988), circumstantially placed at 10–50 ky BP, are quite comparable; similar soils described by Eppes et al. (2008) are generically considered as "older than 20,000 years".

Comparison with the T1 soil of Sauer et al. (2010) outlines the weight of different depositional histories; this soil is definitely similar to the Ghiardo loess soil in its upper part but shows significant carbonate accumulation in the lower part. In this outcrop, the loess column is approximately twice as thick as in typical Ghiardo loess outcrops. This implies a larger amount of primary, loess-borne, carbonates which could not be fully leached, also due to the drier climate. An analogous influence of sedimentary history is shown by the Valsorda loess (Ferraro 2009). This loess was dated as aggrading from about 36 to about 18.7 ky BP, but later burial and limited thickness did not allow anything more than the development of a Cambic horizon.

Formation of fragipans and albeluvic tonguing is documented by Costantini et al. (2009), with a significant age scatter between 18.8 and 72.6 ky BP, implying both uncertainties in OSL dating and the possibility that fragipan formation, too, is more influenced by sedimentation history than by simple elapsed time. Similarly, Ajmone Marsan et al. (1988) and Scalenghe et al. (2000) describe fragipans appearing on different terraces within a long chronosequence, going back to Upper Pleistocene and possibly to even older times.

Higher levels of development are attained by Italian soils of ages spanning the Eemian interglacial (MIS 5) and back through Upper and Middle Pleistocene, but the timing of their appearance is as yet poorly constrained, due to a somewhat lesser number of outcrops and loose dating. Observed development levels include acidification to Alisol (Sauer et al. 2010; Costantini et al. 2009) or Ultisol (Sanesi 1965; Mazzanti and Sanesi 1986) levels and development of nitic, ferric or even petroferric horizons (Sevink et al. 1982, 1984; Costantini et al. 2009) (Table 5.3).

5.4 Conclusions

Within the time span since the LGM, the soil most likely to form on the ubiquitous, fine-textured and calcareous parent materials of Italy is a partially decarbonated, fully base-saturated Cambisol. Clay illuviation horizons are likely to have formed only in specially favourable conditions. Such results compare very closely to the analysis of soil pedodiversity in Italy presented elsewhere in this book.

Due to the complex geological and climatic history of our country, the time factor is a major contribution to the extent and nature of pedodiversity in the soils of Italy.

This kind of time-related complexity represents, undoubtedly, an additional burden for the development of soil–landscape relation modelling, in both its conventional and high-tech forms, and strongly recommends a sound geological base in the formation of soil surveyors and scientists.

Table 5.3 Hard dates for duration of pedogenetic processes in Italy

Source	Area	Soil-forming process	Dating	Dating method
Sauer (2010)	Lucania, Spain	Melanization	25–190 y BP	^{14}C
Certini et al. (1998)	Tuscan Apennines	Incipient podzolization	50 y BP	Records
Egli et al. (2008)	Etna Mt., Sicily	Melanization, humic leptosol	125–438 y BP	Lava stratigraphy
Egli et al. (2008)	Etna Mt., Sicily	HA to FA shift	438 y BP	Lava stratigraphy
Favilli et al. (2010)	Trentino	Bs horizon	550 y BP	Charcoal ^{14}C
Favilli et al. (2010)	Trentino	Spodic horizon	1,700 y BP	Charcoal ^{14}C
Egli et al. (2008)	Etna Mt., Sicily	Vitric andosol	4,000 y BP	Lava stratigraphy
Eppes et al. (2008)	Reno valley, N Apennines	Soil thickness 168 cm	≈5,000 y BP	^{14}C
Costantini et al. (2009)	Central Tuscany	Cambic horizon	≈5,700 y BP	IRSL-OSL
Amorosi et al. (1996)	Reno valley, N Apennines	Cambic horizon	<8,440 y BP	^{14}C
Costantini and Napoli (1992)	Northern po plain	Soil thickness 120–130 cm	Holocene	Stratigraphy
Sevink et al. (1984)	Southern Lazio	Cambic horizon	Holocene	Stratigraphy
Napoli et al. (2006)	Central Tuscany	Cambic horizon	Holocene	Stratigraphy
Costantini and Napoli (1992)	Adige river plain	RR 5, argic hor., decarbonation	Holocene	Stratigraphy
Amorosi et al. (2001)	Emilia Apennine foothills	RR 3.75, decarbonation	8.5< and <19 ky BP	Stratigraphy
Eppes et al. (2008)	Reno valley, N Apennines	Calcic horizon	9.5< and <12.7 ky BP	^{14}C
Frezzotti and Narcisi (1996)	Abruzzo	Andic Umbrisol	12 ky BP	Tephrostratigraphy
Sauer et al. (2010)	Ionian Lucania	Soil thickness >85 cm	<16 ky BP	Stratigraphy
Ferraro (2009)	Garda Lake area	Cambic horizon	33 until 18 ky BP°	14C, OSL, IRSL
Amorosi et al. (1996)	Reno valley, N Apennines	Calcic horizon	<19.6 ky BP	^{14}C
Scarciglia et al. (2006)	Sila Mts., Calabria	Andic Umbrisol	≥16 ky BP	Tephrostratigraphy
Sevink et al. (1984)	Southern Lazio	Calcic horizon	MIS 2	Stratigraphy
Ajmone Marsan et al. (1988)	Piemonte high plain	Argic horizon, full loess decarbonation	10–50 ky BP	Stratigraphy
Sauer et al. (2010)	Ionian Lucania	Argic and calcic horizon	55–16 ky BP[a]	OSL
Eppes et al. (2008)	Reno valley, N Apennines	Argic horizon, full decarbonation	>20 ky BP	^{14}C
Cremaschi (1987)	Emilia Apennine foothills	Argic horizon, full loess decarbonation	60–70 ky BP	TL
Cremaschi (1987)	Alpine foothills	Ferralic properties	>0.7 My BP	Palaeo-magnetism
Terhorst and Ottner (2003)	Alpine foothills	Kaolinite neoformation, fed 50 $g \cdot kg^{-1}$	>0.7 My BP	Cremaschi 1987
Costantini et al. (2006)	Central Tuscany	Plinthite	> MIS 13	Stratigraphy
Bartolini et al. (1984)	Tuscan Apennine	Deeply weathered saprolite	>1.0 My BP	Stratigraphy

[a] accretionary soil
° buried soil

On the other hand, the variety of soil–time relationships existing in the soils of Italy contributes to make them an integral, and by no means lesser, part of our environmental heritage. The foremost fact that, in most of Italy, soil formation never stopped in the last millions of years, while at the same time undergoing constant, and often major, changes in soil forming factors makes Italian soils a huge, and mostly as yet untapped, palaeo- and archaeo-environmental record. Limited exploitation is no doubt a function of methodological difficulties, but there are clear signs that progresses in investigation methods and technologies are overcoming such difficulties. It is then possible to foresee that, in the next very few decades, the study of soil–time relations in Italy will make great strides and will be able to bring a significant contribution to palaeo-environmental studies. This will, in turn, contribute to some significant improvements in geological and geomorphological mapping, and last, but not least, to an improved ability to examine, represent and use soil spatial distribution.

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6 Pedodiversity

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6.1 Systematic Pedology and the Soil Information System of Italy

This chapter is aimed at representing the pedodiversity of Italy. Pedodiversity can be generally defined as the variation of soil properties (usually characterized by soil classes) within an area (Ibáñez et al. 1995; McBratney 1995; McBratney and Minasny 2007). Therefore, the evaluation of pedodiversity is strongly dependent on geographic as well as on taxonomic generalization. In both cases, the available amount of knowledge and data affect the outcome dramatically. In fact, it is known that pedodiversity increases along with the detail and the amount of information, indicating considerable soil endemism, a key consideration in conservation and preservation planning (Guo et al. 2003). Pedodiversity of a country or region is not only a basis knowledge of a fundamental resource, but it can also orientate the density of observation in planning a soil survey, or provide a first estimation of uncertainty in digital soil mapping.

A major step forward in the detailed knowledge of Italian pedodiversity has been reached in the last decades, with the launch of systematic soil survey programmes at regional level, as well as with the start of a soil mapping programme at national scale (see Chap. 1 of this book). The following paragraphs will give an overview on the available soil information at the national level, the diversity of soil genetic types, their geographic distribution, and the statistical variability of their properties.

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The systematic pedology of Italy has been traditionally related to the activity of soil mapping (see Chap. 1). The works of Paolo Principi (1943) and Fiorenzo Mancini and collaborators (1966) are the milestones of the pedological knowledge of Italy at the country level. In their works, the soil information of Italy was related to the soilscapes that were appreciable at the scale 1:1,000,000, and to an original classification system, which was correlated to the other national systems of Europe. In the following years, the attempt to work out a national soil classification system was abandoned, and Italian soil scientists adopted the American Soil Taxonomy (Soil Survey Staff 2006), the international (FAO—Unesco 1974; FAO/ISRIC/ISSS 1998) and, more rarely, the French systems (Douchafour 1970; Baize and Girard 1998) to classify soil profiles.

Soil mapping proceeded at different scales for applied and research purposes (Magaldi et al. 1992; Costantini et al. 1999). In the late eighties, a major soil survey programme was initiated, aimed at producing soil maps and databases at 1:250,000 scale for most Italian regions, as well as at setting an Italian National Centre for Soil Mapping (Centro Nazionale di Cartografia Pedologica, CNCP, http://abp.entecra.it/soilmaps/en/home.html), which created a national soil information system.

The soil information system of Italy is now constituted of a set of hierarchic geodatabases showing soilscapes at different reference scales (Table 6.1). Among them, the soil region is aimed at describing soil geography at the European level (Finke et al. 1998; Righini et al. 2001; Costantini et al. 2007), sub-regions, systems, and sub-systems point to the national and regional dimensions, while soil units and elements are mainly of local interest.

At present, the available soil databases for the whole of Italy are those of the soil regions, sub-regions, and soil systems, while soil sub-systems databases are available in several administrative regions. Soil sub-regions are created to generalize soil information from the more detailed scale. Databases of soil units and elements still cover a limited portion of Italy.

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Table 6.1 Hierarchy of soilscapes and databases of Italy

Soilscape	Reference scale	Reference polygon size (ha)
Soil region	1:5,000,000	10^5–10^6
Soil sub-region	1:1,000,000	10^3–10^5
Soil system	1:500,000	10^3–10^4
Soil sub-system	1:250,000	10^2–10^3
Soil unit	1:50,000	10^1–10^2
Soil element	1:10,000–25,000	10^{-1}–10^1

Thus, the soil regions, sub-regions, and soil systems are the available databases[1] for national soil information. The soil information was collected and harmonized from different sources, with the collaboration of the Ministry of Agricultural, Food and Forestry Policies, the soil bureaus of the Italian Regional Administrations, as well as by the soil chairs of some Universities. A specific software was created, able to store and correlate data on soil profiles and typological units coming from different sources (ISIS-Italian Soil Information System).

Soil typologies were called Soil Typological Units (STUs) and groups of units (STU groups). The STU group describes the geographic outlines of a set of STUs, while a STU shows genetic and functional characters of a set of soil profiles (Figs. 6.1 and 6.2). Every STU group is composed of one or more STUs. A STU clusters the soil observations, stored either in national or regional databases, which have similar classification, organization, and characters of functional horizons. The functional horizon is a soil layer created by grouping genetic horizons, on the basis of a set of functional properties that influence soil management and land use, in particular, soil capability classification (Costantini 2009).

Every STU has both a *benchmark* profile and a *derived* profile. The benchmark profile is a georeferenced soil, chosen among the most typical of the STU (Fig. 6.3), whereas the derived profile is made up elaborating all the observations allocated to the STU. The degree of soil "typicity" is evaluated by means of algorithms, weighting the mathematical distance from the mean values of all soil properties belonging to the STU (Costantini 2007). In a report of a derived soil profile, the automatically calculated modal qualifiers of the nonparametric attributes, as well as the mean, standard deviation, and number of data of the parametric attributes, including analytical values of functional horizons, are shown.

The code of a STU group is formed from the soil region number and the WRB code, adding a progressive number for each STU (for instance, 61.3RGca1).

[1] The DBs are maintained by the Research centre for Agrobiology and Pedology of the Agriculture Research Council (CRA-ABP). Releases are downloadable from http://abp.entecra.it/soilmaps/en/home.html.

The geography of the soil region database was created by taking into consideration the climate and lithology factors of pedogenesis, and allocating main soils to soil mapping units. A more sophisticated methodology was created for the soil systems and the other more detailed databases. In particular, the geography of the soil systems database, called "land systems", was delineated at the reference scale 1:500,000, by combining layers that refer to the action of the soil-forming factors. Land systems were thus composed of homogeneous areas with regard to relief, lithology, drainage network, and land cover. The Digital Elevation Model of Italy at 250 m, reclassified with SOTER (FAO 1995), the geological map of Italy at scale 1:500,000 (Servizio Geologico d'Italia 1978), and the Corine-Land Cover database (Cumer 1994) were the thematic maps used for the delineation activity. The thematic layers were interpreted by overlapping in a GIS environment and checked on Landsat TM5 satellite images. Besides the aforementioned databases, available for the whole of Italy, some regional soil databases at the reference scale, provided by the regional soil services, were also used.

All the land system attributes had original legends, which were created in function of the generalization needed for the reference scale of the map. Up to seven land components (LCs) were recognized in each polygon of a land system, matching the information provided by the existing national thematic maps. A "land component" was a specific combination of morphological class, lithology, and land cover in the soil system. The linkage between geography and soil was then created by allocating to a LC one or more STU. LCs were not delineated, but their incidence in the polygon was quantified using the aforementioned thematic layers.

The geography of the soil sub-systems and the other databases was produced with a similar methodology, but at a higher detail level and using less generalized legends. Also in the case of sub-system, a LC could have one or more STUs, as exemplified in Fig. 6.4.

For Example, SSS1 has two polygons; in the first one, POLY_SSS1, there are two LCs, namely LC1 and LC2, which cover 90 and 10 % of the polygon, respectively, as estimated by remote sensing or field estimation. The field soil survey allocates to LC1 two soil typological units, 62RGca1 and 62CMca1, for a 20 and 80 %, respectively, while LC2 is entirely dominated by on STU, the 62RGca1.

6.2 Soil Regions of Italy

The soil region database is the first informative level for the soil map of Italy and, at the same time, is the tool for soil correlation at the continental level. Soil regions are a regionally restricted part of the soil cover characterized by a typical climate and parent material association; they were

STU group *Calcic Vertisols of 62.2* **62.2VRcc1**

Soil region: 62.2 Hills of Sicily on Tertiary clayey flysch, limestone, sandstone and gypsum, and coastal plains on Tertiary clayey flysch, limestone, calcareous sandstone and gypsiferous rocks in sloping land. Mediterranean sub-tropical climate.

Soil systems pedolandscapes (Land Components)

Soils on marine clay sediments; alluvial deposits, alluvial lacustrine deposits; in eroded deeply dissected terraces and karstic plateau, medium and high hills with medium and low gradient, with subdentritic drainage pattern, low and medium hills with medium gradient and subparallel drainage pattern; with row crops and vineyards.

STU:

62.2VRcc1.1 fine (Hyposodic)

Class. ST: Chromic Calcixererts fine, mixed, thermic

Class. WRB: Calcic Vertisols (Hyposodic)

Land capability: III class

Limiting cond: Rooting depht

62.2VRcc1.2 fine (Stony phase)

Class. ST: Chromic Calcixererts fine, mixed, thermic

Class. WRB: Calcic Grumic Vertisols

Land capability: IV class

Limiting cond: Stoniness

62.2VRcc1.3 fine (Gleyic phase)

Class. ST: Typic Calcixererts fine, mixed, thermic

Class. WRB: Calcic Gleyic Vertisols (Hyposodic)

Land capability: III class

Limiting cond: Soil chemical fertility

Fig. 6.1 Report of a soil typological unit group (STU group), as automatically created by the national soil database

STU **Calcic Vertisols of 62.2, fine (Hyposodic)**

Code 62.2VRcc1.1 Benchmark sTSCP9

Soil region 62.2 Hills of Sicily on Tertiary clayey flysch, limestone, sandstone and gypsum, and coastal plains on Tertiary clayey flysch, limestone, calcareous sandstone and gypsiferous rocks in sloping land. Mediterranean sub-tropical climate.

Soilscape Soils on fluvial sediments; dominant land form: linear slope; main land use: row crops.

World Reference Base
Hyposodic Calcic Vertisols

Soil Taxonomy
Chromic Calcixererts fine, mixed, thermic

Land capability
III class Suitable for cultivation of row crops with severe soil limitations.

Limiting conditions
Rooting depth

FUNCTIONAL HORIZONS

CODE	DESCRIPTION	Lower Depht cm	d. st.	n
1	Ap	44	24	69
2	Assk, Bssk, Bk	115	38	86
3	Ck, Ckm, BC, C, Cy	165	42	49

Total number of profiles: 47

Site description: mean, standard deviation, or frequency, and number of sites considered.

	mean	st. d.	n		fq	n
Elevation (m.s.l.)				**Surface runoff**		
medium hills (200-400)	225	145	47	medium	12	42
Slope (%)				**Internal drainage**		
gently sloping (6-13)	7	9	47	moderately well drained	38	47
Stones (%)				**Erosion**		
few (0.4-1)	1	2	36	absent	21	37
Rocks (%)				**Crusting risk**		
absent	0	0	38	low	40	40
Rock depth (cm)				**Compaction risk**		
not compiled	-	-	0	very high	17	40
Rooting depth (cm)				**Root restriction**		
moderately deep (50-100)	52	17	47	shrinkage-swelling	47	47
Water table upper limits (cm)				**Water table type**		
not determined	-	-	0	absent	31	16
Soil moisture regime and aridity index (day/yr)				**Climatic interference**		
Dry-xeric	122	9	47	weak	46	47

Analysis: mean, standard deviation and number of analysed horizons[1].

Hor	Tex. Cl.	Sand (dag kg^{-1})		Clay			Coarse fragments (dm^2 m^{-2})			pH (1:2.5 H_2O)			Bulk Density (g cm^{-3})			F.C. (cm m^{-1})		W.P.			Organic Carbon (dag kg^{-1})		
		mean	st.d.	mean	st.d.	n.	mean	st.d.	n.	mean	st.d.	n.	mean	st.d.	n.	mean	st.d.	mean	st.d.	n.	mean	st.d.	n.
1	C	23.8	11.0	43.2	8.2	63	2.75	3.33	60	8.1	0.3	63	1.19	0.13	24	38.6	5.21	24.4	5.07	63	0.96	0.31	63
2	C	21.3	13.1	56.4	9.1	79	2.19	5.57	74	8.2	0.3	79	1.18	0.10	21	40.6	6.05	26.5	5.74	79	0.69	0.34	78
3	C	26.8	21.2	40.7	15.6	29	3.76	16.98	48	8.1	0.3	29	1.23	0.12	12	37.3	9.68	23.6	8.82	29	0.35	0.30	28

Hor	CEC (cmol(+) kg^{-1})			Salinity (dS m^{-1})			ESP (%)			$CaCO_3$ total (dag kg^{-1})			CaCO3 active (dag kg^{-1})			Base saturation (%)			Permeability Class			COLE (m m^{-1})		
	mean	st.d.	n.	mean	st.d.	n.	mean	st.d.	n.	mean	st.d.	n.	mean	st.d.	n.	mean	st.d.	n.	mean	st.d.	n.	mean	st.d.	n.
1	33.5	18.9	62	0.53	0.38	61	3.56	2.87	47	14.7	11.5	63	5.75	4.76	61	100	0.0	47	3	1	62	0.10	0.05	2
2	33.5	21.7	74	1.10	1.06	74	7.49	5.46	60	15.7	11.1	80	6.69	4.67	73	100	0.0	60	5	1	78	0.11	0.04	4
3	29.5	13.5	26	1.23	0.77	29	13.32	11.1	15	18.9	14.4	29	5.56	5.37	27	100	0.0	16	4	1	33	0.10	0.02	2

[1] **Hor**: code of the functional horizon. **Tex. Cl.**: texture class, **C** = clay. **F.C.** and **W.P.:** Field Capacity and Wilting Point, soil water content at 33 kPa and 1500 kPa respectively. **Permeability Class:** field estimation of hydraulic conductivity (μm s^{-1}): 1 = very high (>100); 2 = high (10-100); 3 = moderately high (1-10); 4 = moderately low (0.1-1); 5 = low (0.01-0.1); 6 = very low (<0.01). **COLE:** coefficient of linear extensibility.

Fig. 6.2 Report of a derived profile of a soil typological unit (STU), as automatically created by the national soil database

SOIL SITE sTSC P 9

UTS - STS: 62.2VRcc1 1 **Correlation:** benchmark
Soil region: 62.2
Land system: 482CCAM434120
Land subsystem: FTXXAFXX
Land Unit: FTOELNPRVAAFXX20
Elevation: 11 m s.l.m.
Slope: 2 % **Aspect:** °
Rocks: absent
Land use: ; main land use: row crops in permanently irrigated land
Land form hm: fluvial terrace between mountain ridges
Land element dm: tread
Substratum: alluvial sediments; clay
Parent material: colluvium; clay

Survey date: 09/07/2004
Surveyer: Enrico Quaglino
Coordinates: utm-wgs84 33 **N:** 4156982 **E:** 323637 **LAT:** 37.54 **LON:** 13.00
Site: Campisi
Municipality: Sciacca
Province: Agrigento
Stones: small few (0.4-1%)
medium absent
large few (0.4-1%)

Characters and qualities: Water table type: absent, erosion: water: sheet erosion moderate, runoff: medium, internal drainage: somewhat poorly drained, rooting depth: shallow 25-50 cm; root restriction: shrinkage-expansion movements, available water capacity: high 150-200 mm, depuration capacity: high
Class. USDA: 9°ed. (2003)Chromic Calcixererts fine, mixed, thermic
Class. WRB: Calcic Vertisols (Hyposodic)
Notes: Posizione leggermente più alta rispetto al fondovalle. Evidenti fessure in superficie.

HORIZONS

Ap 20 cm moist color: 2,5Y 4/4, described on broken face, no coarse fragments; estimated texture: silty clay loam; structure: subangular blocky fine, weak; consistence: very resistant; weakly adhesive; weakly plastic; hydraulic conductivity: moderately low; pores: very fine (<0.5 mm) few (0.1-0.5%) and fine (0.5-1 mm) few (0.1-0.5%); cracks: wide (6-10 mm) scarce <10 (n/dmq), no concentrations, no faces; roots: fine (1-2 mm) few (1-10), biological activity: absent;effervescence: effervescence: violent; boundary: clear smooth

Bkss1 57 cm moist color: 2,5Y 5/4, described on broken face; main redox features: 2,5Y 5/1, common (2-15%) fine (<5 mm), distinctness: faint, on faces of aggregates poor in Fe; secondary redox features: 10YR 4/6, few (2-5%) fine (<5 mm), distinctness: distinct, on faces of aggregates rich in Fe, no coarse fragments; estimated texture: silty clay; structure: subangular blocky medium, weak; consistence: very resistant; weakly adhesive; weakly plastic; hydraulic conductivity: low; pores: very fine (<0.5 mm) few (0.1-0.5%); concretions of calcium carbonate very small (3-5 mm) common (2-20%) and masses of calcium carbonate very small (3-5 mm) few (<2%); pressure faces and slickensides few(<10%); roots: fine (1-2 mm) few (1-10), biological activity: absent;effervescence: effervescence: violent; boundary: clear smooth

Bkss2 90 cm moist color: 2,5Y 5/4, described on broken face; main redox features: 2,5Y 5/1, common (2-15%) fine (<5 mm), distinctness: faint, on faces of aggregates poor in Fe; secondary redox features: 10YR 4/6, common (2-15%) fine (<5 mm), distinctness: distinct, on faces of aggregates rich in Fe, no coarse fragments; estimated texture: silty clay; structure: angular blocky fine, weak; consistence: resistant; weakly adhesive; weakly plastic; hydraulic conductivity: low; pores: very fine (<0.5 mm) few (0.1-0.5%); concretions of calcium carbonate very small (3-5 mm) common (2-20%) and masses of calcium carbonate very small (3-5 mm) few (<2%); pressure faces and slickensides few(<10%), biological activity: absent;effervescence: effervescence: violent; boundary: gradual smooth

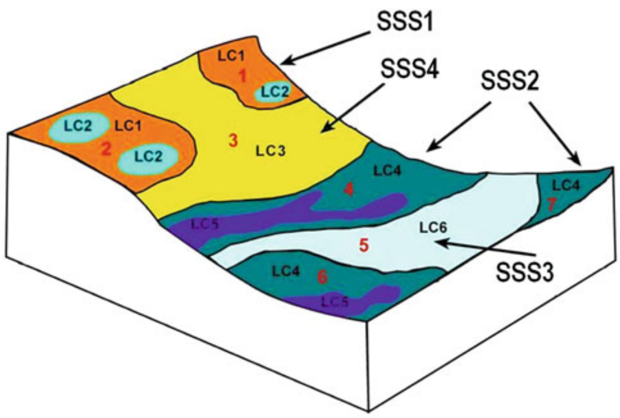
Ck moist color: 2,5Y 5/4, described on surface of small aggregate; main redox features: 2,5Y 5/1, common (2-15%) medium (5-15 mm), distinctness: faint, on faces of aggregates poor in Fe; secondary redox features: 10YR 4/6, common (2-15%) fine (<5 mm), distinctness: distinct, on faces of aggregates rich in Fe, no coarse fragments; estimated texture: silty clay; structure: angular blocky fine, weak; consistence: extremely resistant; weakly adhesive; weakly plastic; hydraulic conductivity: moderately low; pores: very fine (<0.5 mm) very few (<0.1%); concretions of calcium carbonate small (6-20 mm) common (2-20%) and masses of calcium carbonate very small (3-5 mm) common (2-20%), no faces, biological activity: absent;effervescence: effervescence: violent; boundary: unknown

CHEMICAL AND PHYSICAL ANALYSIS

Horiz.	Depth cm		Sand dag/kg						Silt dag/kg			Clay	CaCO3 dag/kg		O.C.	O.M.	pH		
			v. coarse	coarse	med.	fine	v. fine	total	coarse	fine	total	dag/kg	total	active	dag/kg	dag/kg	H2O	CaCl2	KCl
Ap	0	20	0.5	0.8	1.5	3.7	6.0	12.5	12.4	28.5	40.9	46.6	31.4	13.2	0.48	0.82	8.5	n.d.	n.d.
Bkss1	20	57	0.7	0.9	1.4	3.7	6.4	13.1	13.8	28.6	42.4	44.5	33.3	14	0.47	0.81	8.4	n.d.	n.d.
Bkss2	57	90	0.8	1.0	1.7	4.2	6.7	14.4	13.2	27.7	40.9	44.7	32.7	13.9	0.44	0.75	8.2	n.d.	n.d.

Horiz.	Depth cm		Exchange complex cmol(+)/kg								BS	Total	ESP	N tot	P ass	K ass	F.C.	W.P.	AWC	B.D.	ECe	C/N
			Ca	Mg	Ca+Mg	Na	K	H	Al	CEC	%	Acid.	%	g/kg	mg/kg	mg/kg	g/g	g/g	mm/m	g/cm3	dS/m	
Ap	0	20	14.5	8.0		2.29	0.63	0	0	25.4	100	0	9.0	n.d.	n.d.	n.d.	42.5	26.7	157.6	1.26	1.56	n.d.
Bkss1	20	57	13.9	7.8		2.54	0.63	0	0	24.8	100	0	10.2	n.d.	n.d.	n.d.	41.3	25.3	159.4	1.26	2.24	n.d.
Bssk2	57	90	12.6	7.3		3.77	0.67	0	0	24.4	100	0	15.2	n.d.	n.d.	n.d.	41.2	25.4	157.5	1.25	4.60	n.d.

Fig. 6.3 Report of a benchmark profile of a soil typological unit (STU), as automatically created by the national soil database



SSS	POLY_SSS	LC_SSS	LC_PERC	STU	STU_PERC
SSS1	1	LC1	90	62RGca1	20
SSS1	1	LC1	90	62CMca1	80
SSS1	1	LC2	10	62RGca1	100
SSS1	2	LC1	70	62RGca2	40
SSS1	2	LC1	70	62LVcc1	60
SSS1	2	LC2	30	62RGca1	80
SSS1	2	LC2	30	62CMca2	20
SSS4	3	LC3	100	62LVcc2	60
SSS4	3	LC3	100	62RGca1	40
SSS2	4	LC4	60	62CMfv1	80
SSS2	4	LC4	60	62FVca1	20
SSS2	4	LC5	40	62LVca1	40
SSS2	4	LC5	40	62CMca3	60
SSS3	5	LC6	100	62FVca1	100
SSS2	6	LC4	80	62CMfv1	70
SSS2	6	LC4	80	62FVca1	30
SSS2	6	LC5	20	62LVca1	60
SSS2	6	LC5	20	62CMca3	40
SSS2	7	LC4	100	62CMfv1	60
SSS2	7	LC4	100	62FVca1	40

Fig. 6.4 The linkage between soil and geography in a soil sub-systems database (modified from Lambert et al. 2002). A polygon (POLY_SSS) of a sub-system (SSS) is constituted by one or more land component (LC_SSS), having a percentage of coverage. In a LC_SSS, there are one or more soil typological units (STU), in a percentage (STU_PERC)

delineated according to the criteria of the Manual of Procedures version 1.0 for the georeferenced soil database of Europe (European Commission 1999). The geography of the Italian soil regions is reported in Fig. 6.5, while Fig. 6.6 shows the legend of the map units as well as some basic statistics.

Figure 6.7 depicts the size of the soil region in function of a broad geographic and topographic distinction in plains, mountains, and hills. The figure highlights that hilly lands are the most lithologically and climatically variable environments, in terms of the two main soil-forming factors. This finding seems to contradict Ibáñez et al. (1998), who reported that, at a global scale, the highest pedodiversity is in mountainous areas. In Italy instead, the soil regions located on hills are as a rule smaller than those placed on mountains or plains, if we not consider the tail of the graph. Actually, some soil regions cover a small part of the map only because they marginally fall in Italy, but are widespread in European neighbouring countries (soil regions 34.2, 37.3, 16.5, 67.2, 35.4).

6.3 Soil Systems of Italy

The soil system database currently stores information of 3,357 polygons, 2,182 soil systems, and 8,906 LCs, which are linked to 1,413 STUs. To obtain a map of the Italian soil systems, the frequency of each STU in a delineated soil system was calculated and a maximum of three dominant STUs retained. The resulting map shows the distribution of 820 STUs (Fig. 6.8). Therefore, not all the STUs of the national database could be reported in the map. Nevertheless, the map allows to appreciate the great soil variability of Italy. In the map, the most common kind of soils are Haplic Cambisols (Calcaric), followed by Haplic Regosols (Calcaric), Haplic Cambisols (Eutric), Haplic Calcisols, Vertic Cambisols, Cutanic Luvisols, Leptic Phaeozems, Haplic Luvisols (Chromic), Haplic Cambisols (Dystric), and Fluvic Cambisols.

A more generalized map, reporting only dominant soils expressed as Reference Soil Group of WRB (RSG), shows the presence of 22 out 35 main soil types (Fig. 6.9). The map demonstrates that Cambisols are the most widespread RSG of Italy, followed by Luvisols.

Similarly, Fig. 6.10 depicts the distribution of dominant soil orders of Soil Taxonomy. Also in this case, Inceptisols, that is soils at intermediate stage of evolution, are the most frequent. Ten out of the twelve soil orders are represented; however, it must be stressed that some orders are shown in the map to a very limited extent, for example, Aridisols in Sardinia, while Gelisols, which are probably extensive on the Alps, are not mapped, because of the lack of data (Tables 6.2 and 6.3).

6.4 Typological Diversity of the Soils of Italy

The national soil database currently stores 44,770 observations, 28,004 of them are classified with WRB and 23,280 according to Soil Taxonomy. There are 1,177 national STU groups and 1,413 STUs. A total of 28,489 profiles were attributed to STUs, but only 6,909 which had been qualified as "typical" or "characteristics" were used to calculate STU mean and modal properties.

Fig. 6.5 Map of the soil regions of Italy

It is interesting to compare the density of STUs in Italy with that of Soil Taxonomy series in the USA. In Italy (300,475 km^2—water bodies excluded), there is an average of a STU every 213.4 km^2, while in the USA (9,826,630 km^2), where about 14,000 soil series are recognized, the density is one for 7,019 km^2. Therefore, typological density in Italy is about 3.3 times than that of the USA. This might reflect the different pedodiversity of the two countries.

A vast majority of the reference soil groups of WRB (25 out of 32), as well as soil orders of Soil Taxonomy (10 out of 12) are represented in the Italian STUs. No STU has been created for Albeluvisols, Anthrosols, Cryosols, Durisols, Ferralsols, Plinthosols, and Technosols, and Oxisols and Gelisols of Soil Taxonomy (Figs. 6.11 and 6.12).

The distribution of STUs in the different reference soil groups of WRB shows a clear skewness and a lognormal distribution, as found by other authors for American soil series (Guo et al. 2003). Actually, there is a significant concentration of STUs into a single main soil type, followed by a long tail of other RSGs. In particular, more than a fourth of STUs belongs to Cambisols (36.5 % to Inceptisols). Even if we privilege WRB, which is more sensitive to pedodiversity than Soil Taxonomy, more than a half of STUs belongs to only four reference soil groups (Cambisols, Luvisols, Regosols, Phaeozems), and 88 % to nine RSGs

	CODEX	NAME	SOILS	AREA (km^2)	AREA (%)
	Soil regions of the Italian alluvial and coastal plains, and associated low hills			**68623**	**22.7**
	18.8	Po plain and moraine hills of Piedmont and Lombardy	Cambisol - Luvisol - Fluvisol, - Calcisol, Vertisol - Gleysol - Arenosol - Histosol	49001	16.2
	60.7	Coastal plains of central Italy and included hills	Cambisol - Luvisol - Fluvisol	4985	1.7
	62.1	Capitanata and plains of Metaponto, Taranto and Brindisi	Cambisol - Vertisol - Luvisol - Fluvisols	6922	2.3
	64.4	Versilia and internal plains of Tuscany, Umbria and Latium	Cambisol - Fluvisol - Luvisols - Vertisols	5223	1.7
	76.1	Campidano and plains of Sulcis and central Sardinia	Luvisol - Fluvisol - Cambisol – Gleysols -Solonchaks	2492	0.8
	Soil regions of the Italian hills			**100347**	**33.2**
	18.7	Langhe, Monferrato and “hills of the Po” on Tertiary marine deposits	Cambisol - Luvisols - Fluvisols	3963	1.3
	35.4	Hills of Friuli on calcareous sedimentary rocks	Leptosol - Cambisol - Regosols - Luvisols	468	0.2
	56.1	Hills of central and southern Italy on effusive volcanic rocks	Cambisol - Andosol - Regosols	8702	2.9
	59.1	Hills of Sardinia on basic rocks	Cambisol - Leptolsol –Vertisols - ArenosolFluvisol	2434	0.8
	59.7	Hills and mountains on limestone covered by volcanic ashes of southern Italy, and included alluvial and coastal plains	Cambisol - Leptosol - Luvisols	15226	5.0
	59.8	Hills of Sardinia on basalt and trachyte	Cambisol - Leptolsol - Vertisols	5261	1.7
	59.9	Hills and mountains on limestone and igneous rocks of Sicily	Cambisol - Leptosol - Andosols	3398	1.1
	61.3	Hills of central and southern Italy on Pliocene and Pleistocene	Cambisol - Regosol - Vertisols	16292	5.4
	62.2	Hills of Sicily on Tertiary clayey flysch, limestone, sandstone and gypsum, and coastal plains	Cambisol - Luvisol - Vertisol - Leptosols - Regosols	12089	4.0
	62.3	Hills of Calabria and Sicily on Tertiary calcareous rocks and sediments, with included alluvial and coastal plains	Cambisol - Vertisol - Luvisol	15021	5.0
	67.2	Carso	Leptosol - Cambisol - Luvisols,	400	0.1
	72.2	Hills of Murge and Salento	Luvisol - Regosol - Cambisol	10082	3.3
	72.3	Hills of Gargano	Luvisol - Cambisol	1524	0.5

Fig. 6.6 Map legend of the soil regions of Italy

	78.1	Hills of Emilia-Romagna and Marche on Tertiary flysch deposits	Regosol - Cambisol - Calcisols	5487	1.8
	Soil regions of the Alps			**51914**	**17.2**
	16.5	Eastern and central Alps on calcareous sedimentary rocks	Leptosol	1100	0.4
	34.2	Western Alps on calcareous sedimentary rocks	Leptosol	1333	0.4
	34.3	Eastern and central Alps on calcareous sedimentary rocks	Leptosol - Cambisols	18267	6.0
	35.6	Western Alps on metamorphic rocks	Leptsol - Cambisol	2442	0.8
	37.1	Western and central Alps on igneous and metamorphic rocks	Leptosol - Podzols - Cambisols	25661	8.5
	37.3	Western Alps on metamorphic rocks	Leptosol – Cambisol - Podzols	3111	1.0
	Soil regions of the Apennines			**66000**	**21.9**
	16.4	Apennine relieves on limestone and intra-mountain plains	Cambisol - Leptosol - Luvisols	15287	5.1
	35.7	Highest part of northern Apennine	Cambisol - Leptosol - Podzols	3668	1.2
	60.4	Anti-Apennines chains of Tuscany	Cambisol - Luvisol - Leptosols	6373	2.1
	61.1	Apennine and anti-Apennines relieves on sedimentary rocks of central and southern	Cambisol - Regosol - Luvisols	16456	5.4
	66.5	Apennine of Calabria and Sicily on igneous and metamorphic rocks	Cambisol - Leptosol	7352	2.4
	78.2	Northern and central Apennine	Regosols - Cambisols	16864	5.6
	Soil regions of the Etna and Sardinian mountains			**15113**	**5.0**
	59.2	Mountains and hills of Sardinia, on acid crystalline rocks	Cambisol - Leptolsol - Luvisols	7323	2.4
	66.4	Mountains of Etna	Leptosol - Cambisol - Regosols - Andosols	1242	0.4
	67.4	Mountains and hills of Sardinia on metamorphic rocks	Leptosol - Cambisol - Luvisols,	6548	2.2

Fig. 6.6 continued

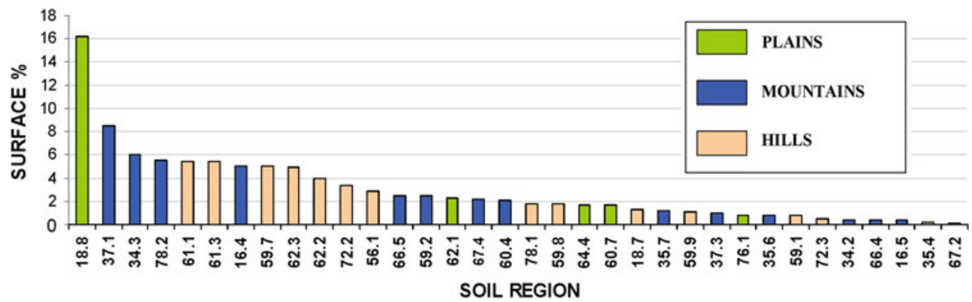


Fig. 6.7 Surface distribution of the Italian soil regions and prevalent landform

(the former plus Calcisols, Vertisols, Fluvisols, Leptosols, and Andosols), while the remaining 16 RSGs are represented in 12 % of STUs.

A similar trend is depicted by profile numerosity of RSGs and orders of Soil Taxonomy (Figs. 6.13 and 6.14). However, it is worthwhile to stress that a larger number of main soil types are represented by soil profiles than by STUs. In particular, there are profiles classified as Albeluvisol, Anthrosol, Cryosol, Plinthosol, and Technosol of WRB, and Gelisols of Soil Taxonomy, which are not correlated to a STU. Consequently, Ferralsol (Oxisols) and Durisol are the only main kind of soils that have not yet been found in Italy.

Actually, many soil profiles stored in the national database are not allocated to a soil typological unit. In many cases, they are profiles that represent small traits of land, only reproducible at a detailed or very detailed scale.

It is also interesting to report the detail level of classification for STUs and profiles. There was a marked change in the detail of classification using either the 1998 or the 2007 versions of the WRB system. Using the 1998 version, there were 838 STUs having only one qualifier; 461 had two, and 110 three qualifiers; whereas among the 27,873 profiles, 7,972 did not have qualifiers,[2] 14,428 had one, 4,190 two, 1,198 three, and 85 four or more qualifiers. Thus, most of both STUs and profiles could be properly classified using only RSG and one qualifier. According to the 2007 version instead, which better distinguished qualifiers into prefixes and suffixes, the outcome was much more articulated, as reported in Table 6.4. The most striking change was the passage of the qualifiers Calcaric, Eutric, and Dystric to the suffix positions, substituted by the qualifier Haplic as prefix. In this way, the number of STUs and profiles with one prefix only decreased, on the advantage of the number of STUs and profiles defined by the RSG, plus a prefix and a suffix.

Figure 6.15 reports the presence of WRB qualifiers in the classified soil profiles. Only the WRB qualifiers used to classify at least 100 soil profiles are reported. 138 out of the 180 WRB qualifiers foreseen by WRB are used (about three quarters of the global pedodiversity). The qualifiers that so far have not been found are the following: Acroxic, Anthrotoxic, Arzic, Carbic, Ecotoxic, Endoduric, Geric, Gibbsic, Glacic, Hydragric, Hydrophobic, Hyperalbic, Hyperalic, Hyperduric, Hyperochric, Hypersalic, Hyperthionic, Irragric, Lamellic, Lignic, Linic, Ornithic, Ortsteinic, Petroduric, Petrogleyic, Petrogypsic, Petrosalic, Placic, Posic, Puffic, Reductaquic, Rustic, Solodic, Sombric, Sulphatic, Takyric, Vermic, Vetic, Voronic, Xanthic, Yermic, Zootoxic.

However, likewise RSGs, the distribution of qualifiers shows an evident concentration in relatively few cases, followed by a long tail. In fact, only 33 qualifiers are present in at least 100 profiles, while almost a double, 66 qualifiers, have been found in less than 10 profiles.

Although the most common qualifiers, that is, Calcaric, Haplic, Skeletic, Eutric, are all related to the nature of parent material and to incipient pedogenesis, a second group, namely Chromic, Calcic, Stagnic, and Luvic, indicates specific soil-forming mechanisms. If we consider the large number of studied profiles, we can conclude that the most common pedogenetic processes evidenced by WRB qualifiers in Italy are the following:

1. release of iron from parent material and synthesis of iron oxides, having pigmentation power and giving reddish soil colours;
2. carbonate dissolution and accumulation of secondary calcium carbonate, in the form of either soft powdery lime or hard nodules;
3. iron and manganese reduction and oxidation, related to the presence of a seasonal perched water table, to give soil mottled colours with reducing features, preferentially concentrated on pores and ped surfaces;
4. clay content differentiation along the profile, caused by different process, but mainly by clay translocation in depth, from superficial leached soil horizons.

On the top of that, particle flocculation and cementation, and the formation of aggregates and structures of different shape and size, is a characteristic process that goes along with the described mechanisms of soil formation.

As mentioned before, in addition to the most common qualifier, a long array of others are used to classify soil profiles, which bears witness to the great deal of

[2] In most cases, this was a consequence of an incomplete translation from Soil Taxonomy to WRB classification.

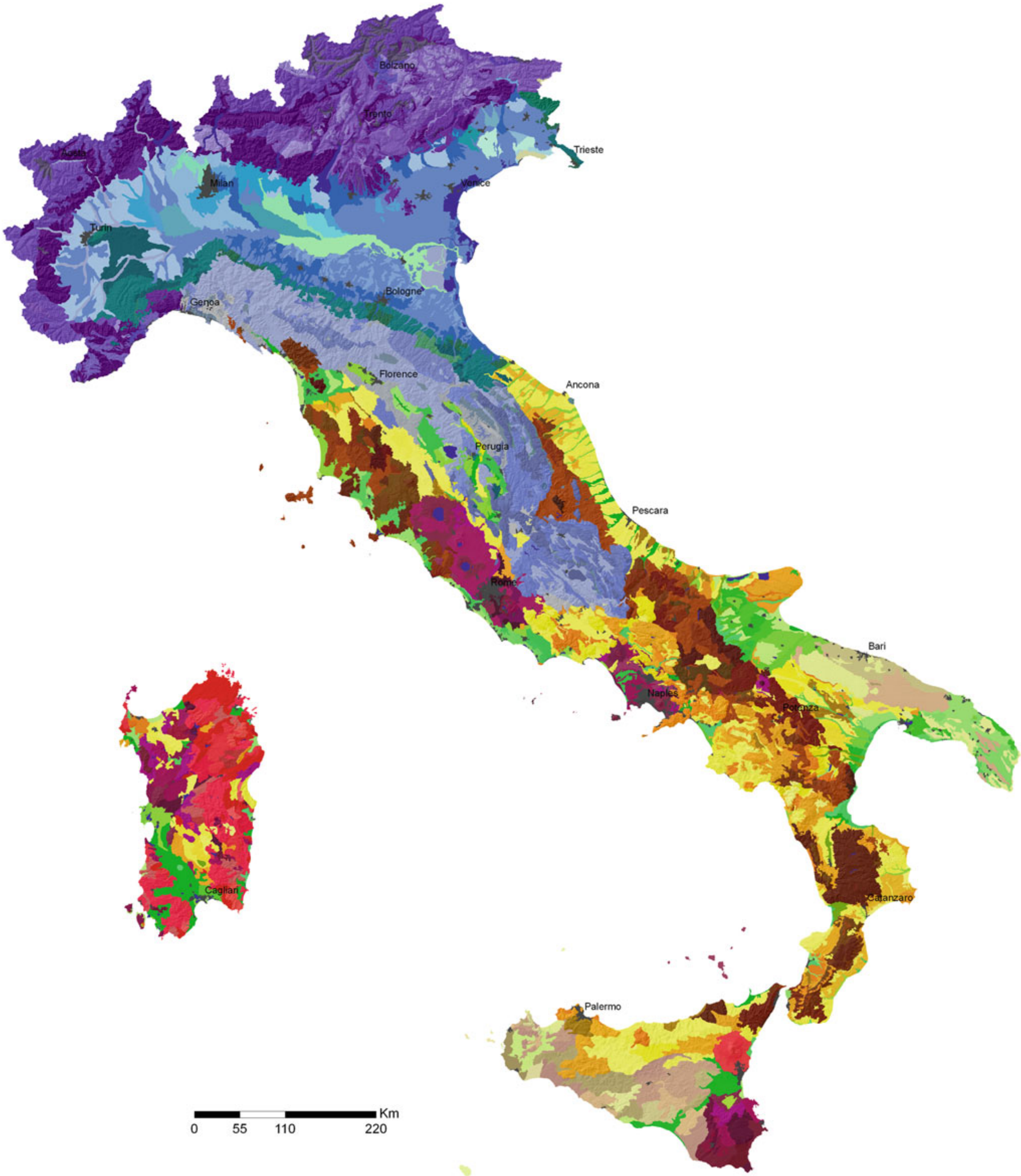


Fig. 6.8 Map of the soil systems of Italy

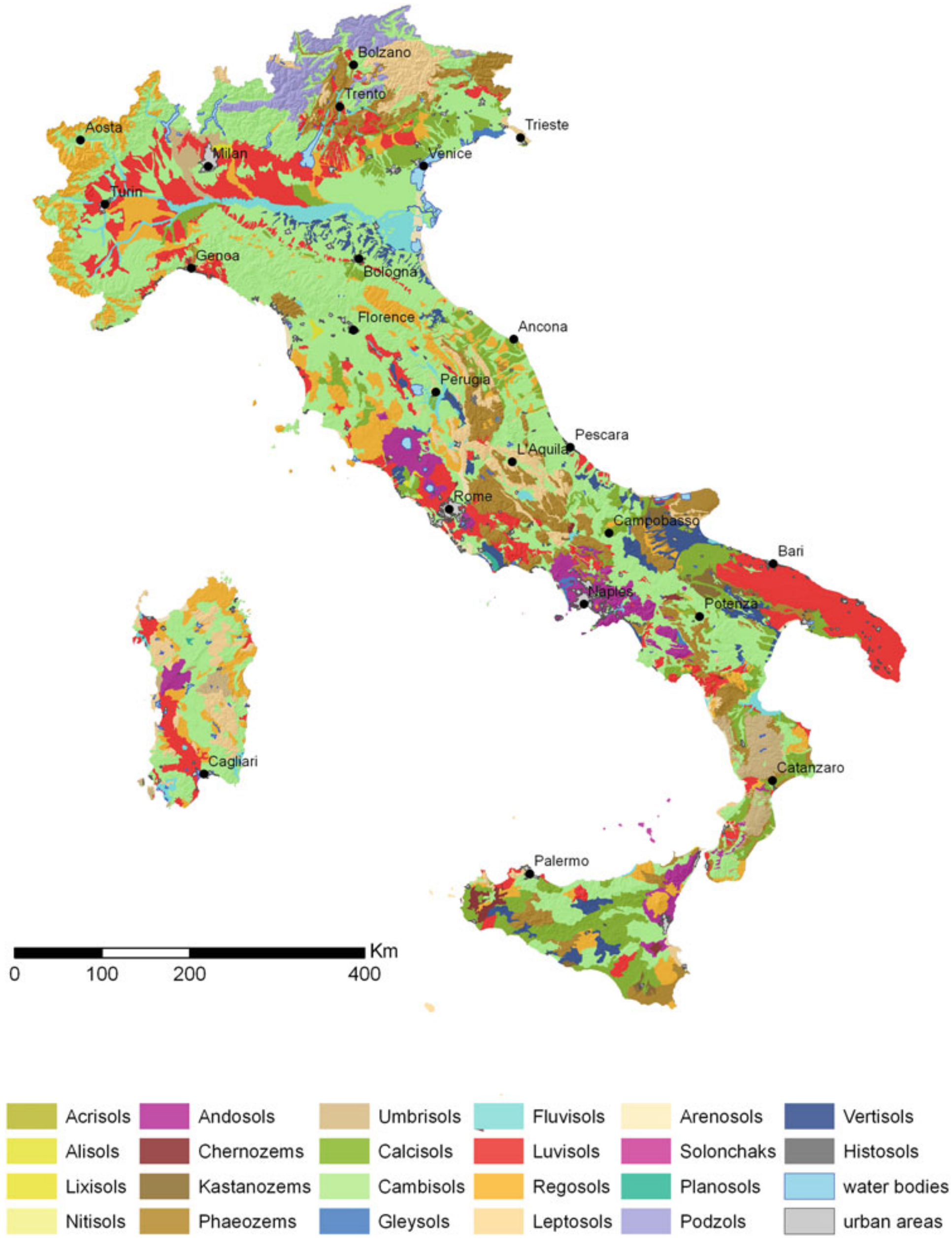


Fig. 6.9 Map of the dominant reference soil groups of the WRB, derived from the soil systems database of Italy

pedogenetic mechanisms acting in Italy, and gives reason for the high heterogeneity of soil types.

Soil classification at a more detail confirms the utmost endemic nature of STUs (Fig. 6.16). On a total number of 556 different WRB taxa, 352 have a unique correspondence with a single STU. On the other hand, there are 7 genetic types, that is Haplic Cambisols (Calcaric), Haplic Calcisols, Haplic Cambisols (Eutric), Haplic Regosols (Calcaric), Haplic Fluvisols (Calcaric), Haplic Vertisols (Eutric), and Haplic Cambisols (Dystric), having from 63 to 17 STUs, which means that these taxa are very variable, in dependence of the presence of other qualifiers and characteristics.

The reported figure draws also attention to the decline in pedodiversity due to soil erosion. The most striking example is given by Haplic Cambisols (Calcaric) and Haplic Regosols (Calcaric), both in most cases formed from calcareous partially consolidated parent material of pre-Quaternary age and widespread on hilly land. The number of STUs belonging to the Regosols can be reasonably put in relationship with the loss of the Cambic horizon, as a consequence of accelerated soil erosion. Actually, the massive erosion caused by recent human activities in these kinds of soils, as well as the risk of loss of pedodiversity, has been reported by many authors in different parts of Italy (a.o., Bazzoffi et al. 2006;

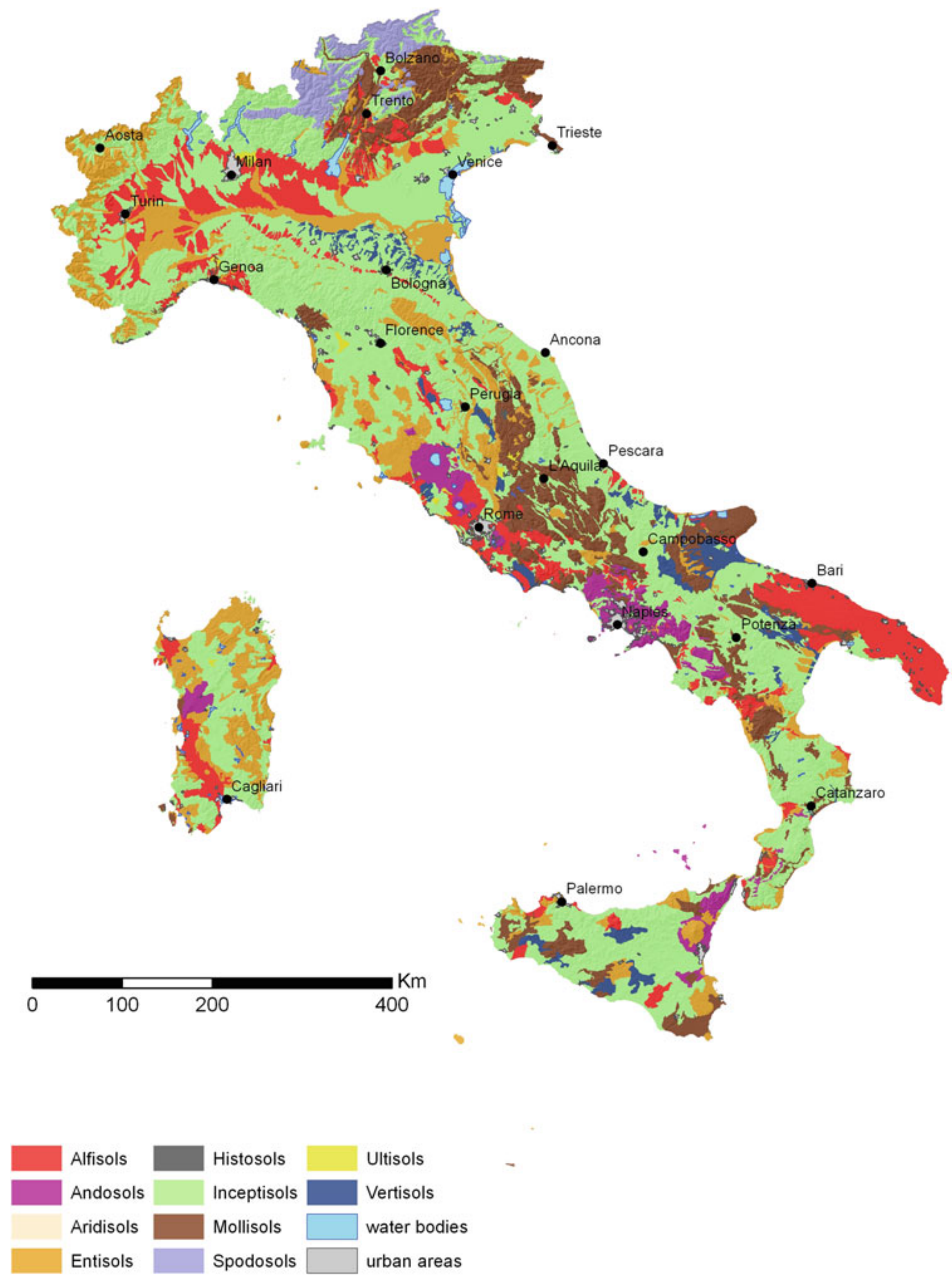


Fig. 6.10 Map of the dominant orders of Soil Taxonomy, derived from the soil systems database of Italy

Capolongo et al. 2008; Costantini and Barbetti 2008; Lo Papa et al. 2011).

6.5 Distribution and Characteristics of Major and Typical Soil Taxa

The spatial distribution of dominant soil classes at different generalization levels is reported in the previous paragraphs. However, soil distribution can be also treated likewise biological species (Ibáñez et al. 1995, 2006), that is, in terms of areas within which specific soil taxon can be found, not only as dominant soil, but as presence. This provides a broader and more exhaustive way to depict the occurrence and density of soil natural bodies. At the same time, it makes easier the linkage between taxa distribution and their characteristics, as well as the relationship between pedogenesis and soil-forming factors.

To give a national overview, we had to select both the taxonomical and geographic generalization. With regard to the taxon, we decided to use as reference the RSG with the first prefix and suffix. This level had resulted as the most

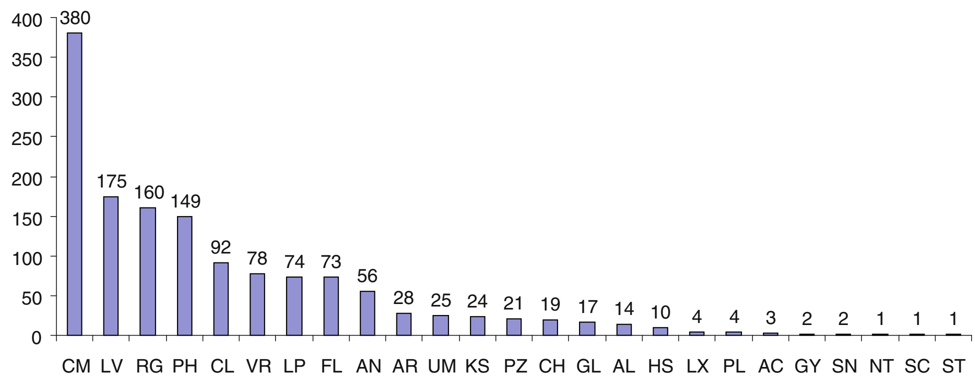


Fig. 6.11 Number of soil typological units belonging to the different reference soil groups of WRB. *CM* Cambisols, *LV* Luvisols, *RG* Regosols, *PH* Phaeozems, *CL* Calcisols, *VR* Vertisols, *FL* Fluvisols, *LP* Leptosols, *AN* Andosols, *AR* Arenosols, *UM* Umbrisols, *KS* Kastanozems, *PZ* Podzols, *CH* Chernozems, *GL* Gleysols, *AC* Acrisols, *HS* Histosols, *LX* Lixisols, *PL* Planosols, *AL* Alisols, *GY* Gypsisols, *SN* Solonetzs, *NT* Nitisols, *SC* Solonchaks, *ST* Stagnosols

Table 6.2 Coverage of dominant reference soil group of WRB (urban areas and water bodies excluded)

RSG	km^2	%
Cambisols	115,107	39.006
Luvisols	37,901	12.844
Regosols	29,874	10.123
Pheozems	24,750	8.387
Calcisols	24,106	8.169
Leptosols	16,528	5.601
Andosols	9,704	3.289
Vertisols	7,925	2.686
Podzols	7,500	2.542
Fluvisols	7,276	2.466
Umbrisols	7,224	2.448
Arenosols	2,412	0.817
Kastanozems	2,030	0.688
Chernozems	1,126	0.382
Gleysols	625	0.212
Alisols	509	0.172
Planosols	201	0.068
Histosols	195	0.066
Acrisols	51	0.017
Solonchaks	33	0.011
Nitisols	11	0.004
Lixisols	11	0.004
Total	295,097	100.000

Table 6.3 Coverage of dominant orders of Soil Taxonomy (urban areas and water bodies excluded)

ORDER	km^2	%
Inceptisols	146,228	49.552
Entisols	48,508	16.438
Alfisols	38,416	13.018
Mollisols	35,711	12.101
Andosols	9,704	3.289
Vertisols	8,059	2.731
Spodosols	7,500	2.542
Ultisols	741	0.251
Histosols	195	0.066
Aridisols	33	0.011
Total	295,097	100.000

commonly used to distinguish STUs; moreover, it was a fair compromise between detail of information and numerosity of profiles in each STU. Then, this taxonomic level could provide information about the expression of rather detailed

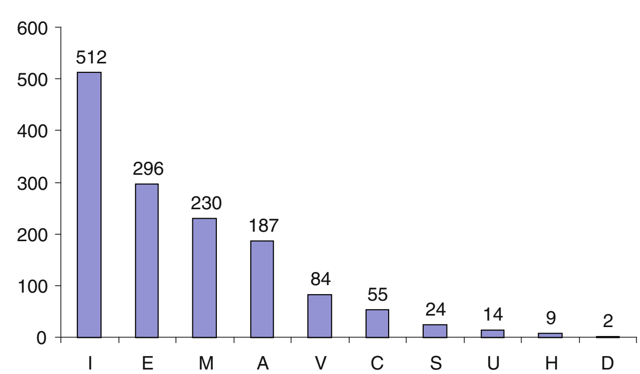


Fig. 6.12 Number of soil typological units belonging to the different orders of Soil Taxonomy. *I* Inceptisols, *E* Entisols, *M* Mollisols, *A* Alfisols, *V* Vertisols, *C* Andosols, *S* Spodosols, *U* Ultisols, *H* Histosols, *D* Aridisols

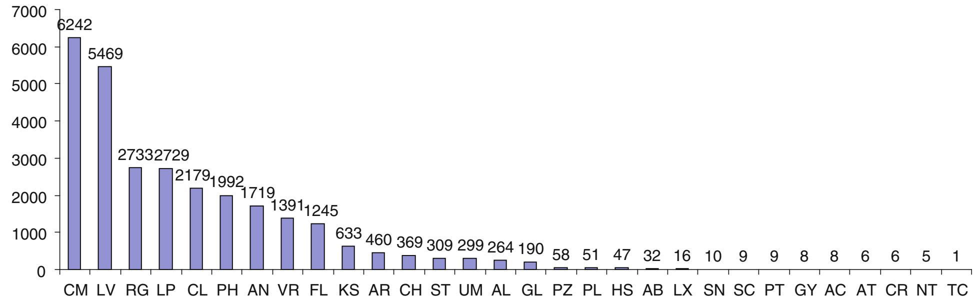


Fig. 6.13 Number of soil profiles belonging to the different reference soil groups of WRB. *AN* Anthrosols, *CR* Cryosols, *PT* Plinthosols, *SC* Solonchacks, *TC* Technosols

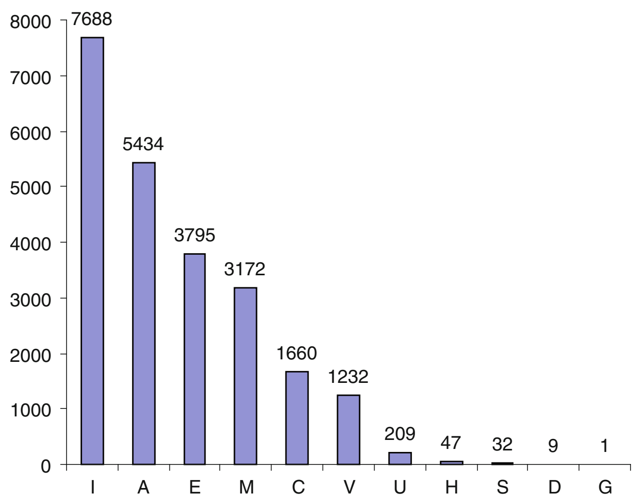


Fig. 6.14 Number of soil profiles belonging to the different orders of Soil Taxonomy

Table 6.4 Detail of WRB classification (reference soil groups RSG and qualifiers) used for soil typological units and profiles

Detail of classification	STUs (n)	Profiles (n)
RSG only	0	7,562
1 prefix and 0 suffices	453	7,761
1 prefix and 1 suffix	592	9,787
1 prefix and 2 suffices	235	1,851
1 prefix and 3 suffices	31	144
2 prefixes and 0 suffices	86	485
2 prefixes and 1 suffix	4	259
2 prefixes and 2 suffices	5	53
2 prefixes and 3 suffices	1	7
3 prefixes and 0 suffices	0	76
3 prefixes and 1 suffix	1	13
3 prefixes and 2 suffices	5	4
3 prefixes and 3 suffices	0	2
Total	1,413	28,004

soil-forming processes, acting in wide areas. The elaboration of a report of a taxon took into account all profiles of the STUs belonging to that taxon.[3] Analogously, climatic statistics were worked out using the values attributed to the sites of the considered profiles.[4]

The representation of soil distribution on map was more complicated, because of the skewed nature of the distribution of Italian soil types, which is reflected in their extent. We put together polygons of soil systems where profiles of the STUs belonging to the same taxon were present, or where a published soil map testified the presence of the named taxon. When the information could not be generalized at the scale of soil systems, we merged all polygons of soil sub-systems where profiles (or published maps) of the STUs belonging to the same RSG were present.

An estimate of the geographic dispersion of the taxon was obtained averaging the local density of profiles, calculated as the ratio between the number of soil profiles belonging to the taxon and size of the delineation.

[3] In reading the report of the derived profile, it must be paid attention to the number of cases. For instance, the presence of an E horizon in the Haplic Luvisols (Chromic) has been recorded in a relatively small proportion of sites (Fig. 6.23). This can be due to the different land use of the soils belonging to this taxon, since under agriculture the E horizon is seldom preserved. Similarly, in the description of site characteristics, it should be considered the number of sites that were described and stored for the specific characteristic or quality. For instance, in the mentioned taxon, the presence of the water table was only recorded in 25 cases, but in all of them it was absent, therefore we can assume that water table is usually absent. Also mean analytical values of a horizon may come from different amounts of cases, in dependence of the presence of the horizon as well as of the effective analysis of the sample. The Cr horizon of the example, in particular, shows a marked increase of the sand content; however, only two sites were analysed, both belonging to Haplic Luvisols (Chromic) formed on calcarenites. Therefore, the textural value of Cr is representative only of this kind of Haplic Luvisols (Chromic).

[4] see Chap. 2 for details about the climatic information.

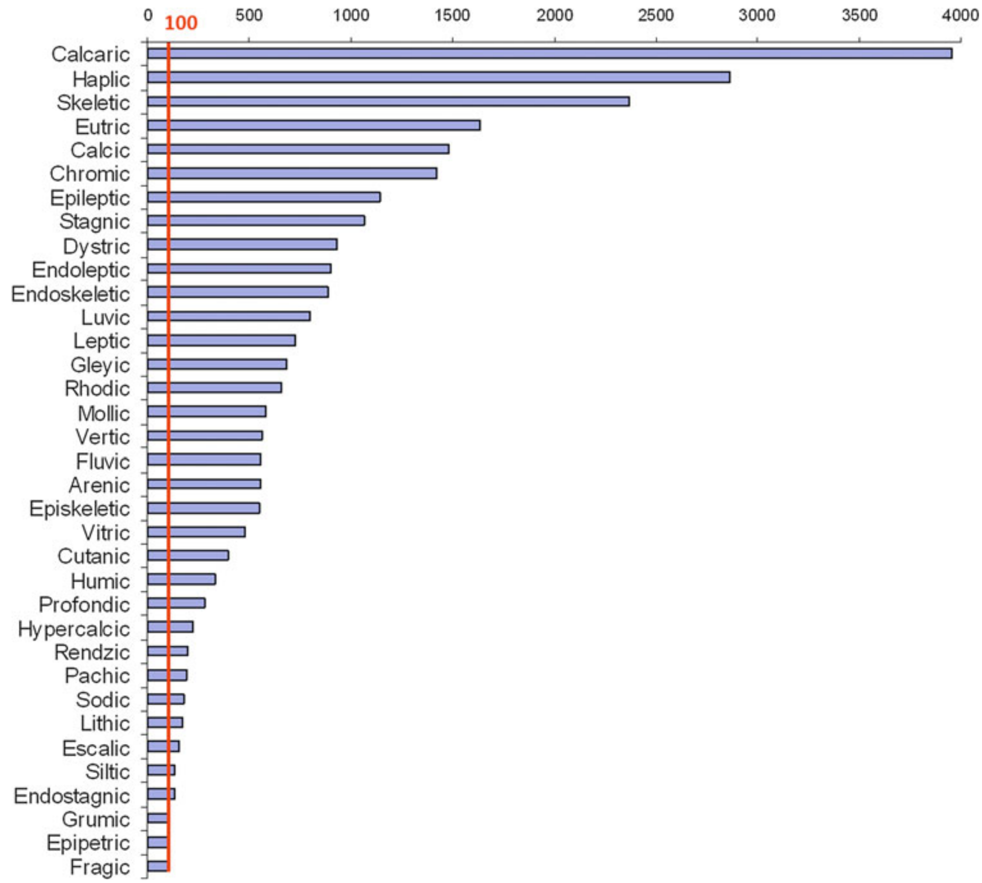


Fig. 6.15 Number of soil profiles and WRB qualifiers

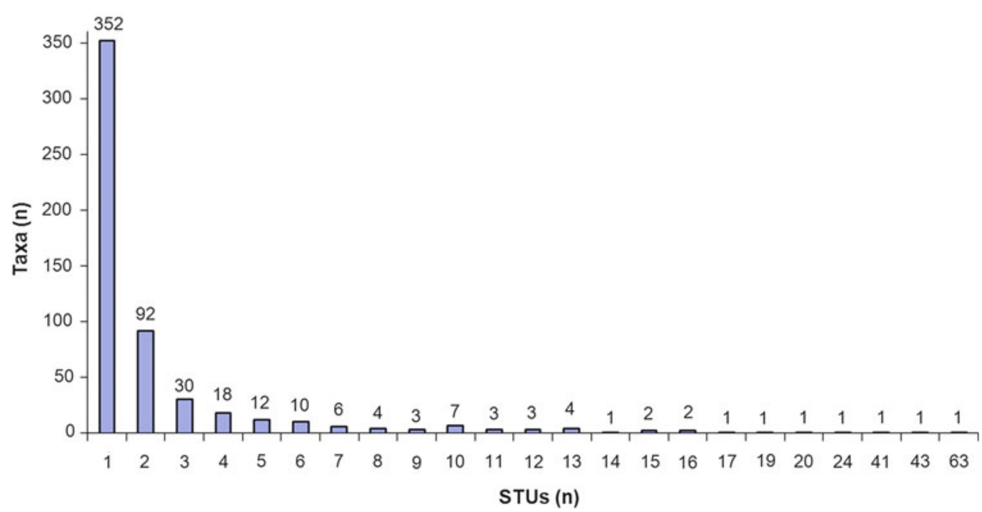


Fig. 6.16 Frequency of STUs per soil taxa

6.5.1 Haplic Cambisols (Calcaric)

Haplic Cambisols (Calcaric) is the most common soil taxon of Italy. Soil belonging to this taxon are present in around 82,024 km^2 and forms 63 STUs. They represent the main feature of the soilscape in many hilly lands, but they are also present on plains (Fig. 6.17). They formed from calcareous sediments, mainly of marine origin, under different types of climate (Table 6.5). On average, their climate is rather warmer and with a more pronounced deficit than the mean climatic and pedoclimatic Italian conditions (see Chap. 2 for the mean country values). According to the Soil Taxonomy, they have a xeric, marginally to ustic, soil moisture regime and a thermic, close to mesic, soil temperature regime.

The derived profile (see Sect. 6.1) of 798 Haplic Cambisols (Calcaric), corresponding to Typic Haplustepts of

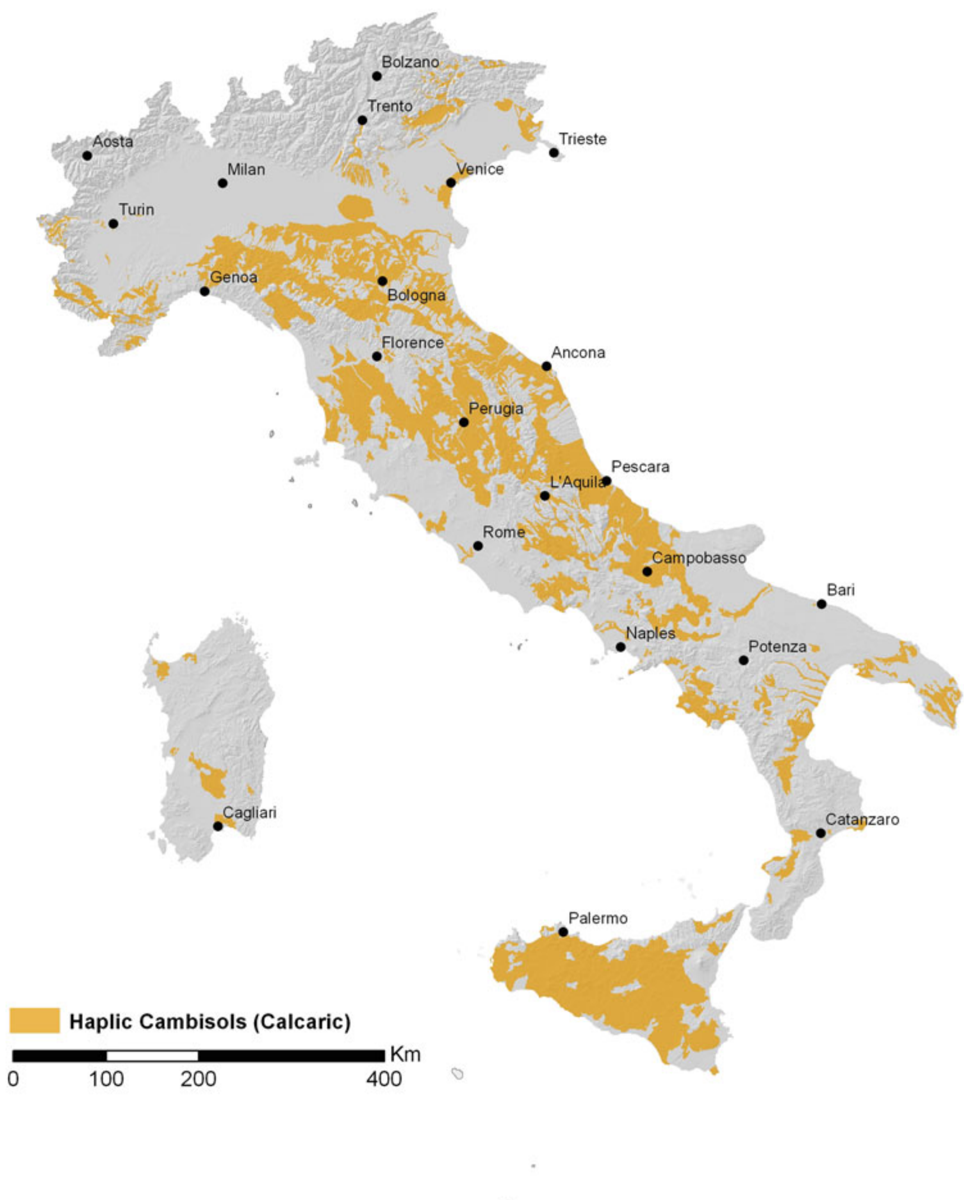


Fig. 6.17 Geographic distribution of Calcaric Cambisols (*density of profiles* 1.62 per 100 km^2)

Table 6.5 Average long-term climatic data of Calcaric Cambisols

Variable	Unit	Average	Standard deviation	Number of data
Mean annual temperature	(°C)	14.1	2.02	774
Potential evapotranspiration	(mm)	1,039	102.6	774
Total annual rainfall	(mm)	840	189	774
Aridity index	–	0.83	0.25	774
Climatic aggressivity (F FAO)	–	79.4	14.0	774
Continentality	(°C)	15.0	0.5	774
Seasonality	(mm %)	10.12	0.03	774

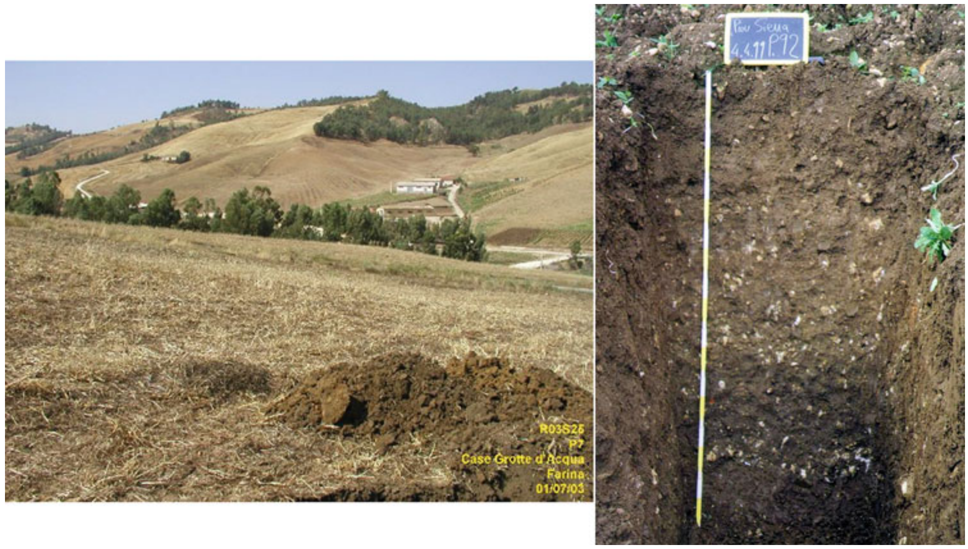


Fig. 6.18 Typical landscape (Sicily, photo courtesy of Assessorato Agricoltura of Regione Siciliana) and profile (Tuscany, photo Francesco Lizio Bruno) of Calcaric Cambisols

Soil Taxonomy, lays on moderate slopes, is clay loam and rather deep, it is cultivated with different kind of crops, especially cereals, with some management difficulties and conservation problems (Figs. 6.18 and 6.19)[5]. The limitations are related to the presence of some stoniness, the moderate available water capacity, and the rather low soil organic carbon (SOC) content of the uppermost horizon, which is one of the main causes of its high risks of crusting and compaction, slow infiltration, sensitivity to run-off and water erosion. Internal drainage though is rather good, as well as permeability of all the horizons, as a consequence of the moderate aggregation and porosity, which is about 50 % of the horizon volume, according to bulk density. Laboratory-measured field capacity and wilting point indicate around 10–11 % in weight of available water in the surface and sub-surface horizons. Active lime content is moderate and may be a problem only for sensitive species. Groundwater is generally absent, only in few cases is deep, however, this soil class has very high purifying capacity of pollutants.

Notwithstanding the rather low average SOC concentration, the carbon sink capacity of the modal Italian soil is not at all negligible. Actually, it corresponds to a density of 6.15 kg m^2, with a SD of 0.97 kg m^2, in the first functional horizon (0–35 cm), and 11.27 kg m^2 (SD 1.77 kg m^2) in the first meter. These outcomes are comparable to the estimated world average of soils under crops for the 0–40 cm and 0–1 m depths, that is, 7.17 and 11.2 kg m^2 (SD 7.7 kg m^2) (Jobbagy and Jackson 2000). Also the organic matter stratification, which is assumed to be an indicator of soil quality (Franzluebbers 2002), points to a fair soil fertility of the taxon and to a rather high sink potential capacity. In fact, the ratios between the carbon density of the first and the following functional horizons are 1.49 and to 2.86, respectively with the B and C horizon.

Woodlands on this soil type are limited at present, but actually on increase, since the management problems are an obstacle for many of the intensive modern agricultural systems. Hence, the land-use change of this taxon, which is currently afoot, can lead to the formation of a mollic horizon and to modify the classification into Haplic Phaeozems, which are actually fairly well intermingled in the same soilscape.

[5] *SD* = standard deviation, *n* = sample, *N* = population; *Available water capacity* mean estimated value on horizons up to the potential rooting depth (Saxton and Rawls, 2006). *Crusting risk* function of silt and organic matter content (Costantini et al. 2007). *Compaction risk* function of clay, silt, organic matter content (Vignozzi et al. 2007; Costantini et al. 2007). *Hydrologic group* function of clay, sand, silt, bulk density (when not determined, estimated according to Pellegrini et al. (2007) BD [$(clay)^2$; (sand); $(organic\ matter\ content)^{-2}$]), potential rooting depth and water table depth. (United States Department of Agriculture 2007). *Purifying capacity* function of coarse fragments, cation-exchange capacity, potential rooting depth, pH (Region Emilia Romagna 1995). *Low*. *Depth* = Lower depth (cm); *Tex. Cl.* = texture class: *C* = clay, *CL* = clay loam, *FSL* = fine sandy loam, *L* = loam, *LS* = loamy sand, *S* = sand, *SC* = sandy clay, *SCL* = sandy clay loam, *SIC* = silty clay, *SICL* = silty clay loam, *SI* = silt, *SIL* = silt loam, *SL* = sandy loam; *Permeability* mean hydraulic conductivity from field estimation class mean values; *COLE* coefficient of linear extensibility; *Field Capacity and Wilting Point* soil water content at 33 kPa and 1,500 kPa (pressure plate apparatus); *CEC* = Cation-Exchange Capacity; *ESP* = Exchangeable Sodium Percentage; *Salinity* electrical conductivity of a soil water 1:2.5 solution (approximately 1/4 of saturated paste). *Extractable Fe oxalate* oxalate extractable iron, *Extractable Fe pyr*. pyrophosphate extractable iron, *Extractable Fe total*: total extractable iron, *Extractable Fe pyr.—ox*. difference of pyrophosphate extractable iron and oxalate extractable iron, *Extractable Al oxalate* oxalate extractable aluminium, *Extractable Al total* total extractable aluminium, *Al + 0.5Fe oxalate* sum of oxalate extractable aluminium and half of oxalate extractable iron; *oxalate extractable Si* oxalate extractable silica, *pH NaF* sodium fluoride pH, *P ads*. phosphate retention.

Haplic Cambisols (Calcaric)

Soil Taxonomy
Typic Haplustepts

Main geologies
alternating pelitic-arenitic, arenitic-marly and arenitic-pelitic rocks; limestone.

Main morphologies
linear slope, slope dissected by small valleys, valley floor.

Main land uses
row crops, eterogeneous croplands, broadleaved woodlands.

FUNCTIONAL HORIZONS

description	lower depth (cm)	SD	N
Ap, A	35	17	937
Bw, BC	78	33	952
C, Cr, CB	109	61	679

Total number of observations: 798

Site description: mean and standard deviation, mode and frequency, and number of sites considered.

	mean	SD	N
Elevation (m a.s.l.)			
medium hills (200-400)	349	249	790
Slope (%)			
strongly sloping (13-20)	14	15	793
Stones (%)			
frequent (4-15)	5	16	673
Rocks (%)			
few (0-2)	1	4	607
Rock depth (cm)			
deep (100-150)	112	51	116
Potential rooting depth (cm)			
deep (100-150)	121	61	507
Water table depth (cm)			
deep (100-150)	128	42	8
Available water capacity (mm m^{-1})			
moderate (100-150)	128	55	687
Soil moisture regime and aridity index (dry d y^{-1})			
xeric (80-115)	82	25	669
Soil temperature regime and value (°C at 50 cm)			
mesic (8-15)	14	2	524

	mean	SD	N
Crusting risk			
high (> 0.60)	0.63	0.1	361
Compaction risk			
high (1.71 - 1.80)	1.77	0.2	367
Internal drainage			
well to moderately well drained	3.3	1	470
Surface runoff		n	N
medium		108	387
Hydrologic group			
slow infiltration (C)		231	511
Root restriction			
no restrictions and no impediments		165	496
Purifying capacity			
very high		109	232

Analyses: Mean, standard deviation and number of samples

Low. depth (cm)	Tex. Cl.	Sand (dag kg^{-1}) mean	Sand SD	Clay (dag kg^{-1}) mean	Clay SD	N	Coarse fragments (dm^2 m^{-2}) mean	SD	N	Bulk Density (g cm^{-3}) mean	SD	N	Permeability (µm s^{-1}) mean	SD	N	COLE (m m^{-1}) mean	SD	N	Field capacity (dag kg^{-1}) mean	SD	N	Wilting point (dag kg^{-1}) mean	SD	N
35	CL	30.0	19.0	29.6	12.7	760	8	12.1	537	1.3	0.2	94	29.45	44.3	448	0.04	0.03	45	21.6	4.8	32	10.3	3.0	32
78	CL	29.6	19.6	30.1	13.1	709	11	18.0	582	1.4	0.2	46	19.73	35.6	526	0.04	0.03	19	19.8	3.8	9	9.1	2.1	9
109	L	34.5	25.6	26.5	16.1	346	12	24.3	501	1.4	0.2	17	24.79	48.7	367			0			0			0

Low. depth (cm)	pH (1:2.5 H_2O) mean	SD	N	Organic Carbon (dag kg^{-1}) mean	SD	N	CEC (cmol(+) kg^{-1}) mean	SD	N	Base saturation (%) mean	SD	N	ESP (%) mean	SD	N	$CaCO_3$ total (dag kg^{-1}) mean	SD	N	$CaCO_3$ active mean	SD	N	Salinity (1:2.5 dS m^{-1}) mean	SD	N
35	8.0	0.4	759	1.48	1.58	725	21.5	11.1	356	96	15.4	282	2.5	4.3	242	18.4	14.9	730	5.3	4.1	265	0.27	0.5	180
78	8.1	0.4	702	0.77	0.66	659	19.6	9.4	359	96	15.5	275	3.3	5.5	234	20.2	15.5	703	6.1	4.7	279	0.41	0.9	177
109	8.2	0.6	330	0.38	0.68	248	18.1	12.6	150	97	12.6	115	4.7	6.5	97	26.0	19.5	331	6.9	4.6	109	0.69	1.3	58

Fig. 6.19 Derived profile of Haplic Cambisols (Calcaric)

We can speculate that the current larger dissemination of Haplic Cambisols (Calcaric) over Haplic Phaeozems in Italy is due to the role played by man activity. Several clues let us state that for many Haplic Cambisols pedogenesis probably started not before the medium Holocene, when the diffusion of agriculture rejuvenated the profile of more developed soils formed below forest stands (see Chap. 5 and, for instance, Eppes et al. 2008; Costantini et al. 2011). In the Cambisols of colluvial and fluvial origin, in particular, is rather common to find human artefacts of historical time. Therefore, pedogenesis of calcareous incoherent or pseudo-coherent sediments during Holocene in Italy seems to be able to develop aggregates and change colour of the parent material, but not to leach most of the carbonates. Thus Haplic Cambisols (Calcaric) could represent a major fingerprint of the long-lasting human exploitation of land in Italy (Fig. 6.20).

6.5.2 Haplic Luvisols (Chromic) and "Terra Rossa"

Luvisols are the second most represented class of soils in Italy, and Haplic Luvisols (Chromic) (IUSS/ISRIC/FAO 2006; Chromic Luvisols in FAO/ISRIC/ISSS 1998) are among the most important of them and, at the same time, the main contributors of Terra Rossa on karst (Fig. 6.21).

Terra Rossa, or red Mediterranean soil, is a common name used to indicate soils formed in a Mediterranean type of climate, red in colour, well structured, with a high percentage of iron oxides strongly associated with clay minerals, which developed on limestone and carbonate sediments. In the map, only Terra Rossa on karst areas is reported, that means Terra Rossa on calcareous rocks (mainly limestone, travertine, calcarenite, and chalk) where karst landforms developed. Actually, Chromic Luvisols, and other Terra Rossa like soils are also present on alluvial and other deposits, but Terra Rossa on karst is a particularly important soilscape, which outlines a characteristic ecosystem, for the most part agricultural, typifying the Mediterranean landscape. Chromic Cambisols and Phaeozems, Rhodic, and Calcic Luvisols also make part of the ecosystem. Terra Rossa distribution area covers some 35,699 km^2, and form more than 50 STUs.

Although Terra Rossa is rather widespread all over Italy, its climate is statistically warmer and dryer than the average, and the xeric and thermic moisture and temperature regimes dominate (Table 6.6). When not limited in depth, Terra Rossa is very fertile and cultivated with different Mediterranean crops, with a significant presence of tree crops (olive tree groves, vineyards, citrus trees, and orchards) traditionally mixed with row crops and vegetables. The presence of shallow rock, abundant stoniness, or some rockiness is marked by the land-use meadow and forest, or by the Mediterranean macchia. Rock fragments collected from the soil are traditionally used to build walls around the fields (Fig. 6.22).

To represent the modal Terra Rossa, we chose a set of 65 profiles classified as Haplic Luvisols (Chromic) located on karst environment (Fig. 6.23). We included in the term karst landform also the weak pronounced dolines and the fluvial-karst network developed on calcarenite. The modal profile, which is classified as Typic Haploxeralfs following Soil Taxonomy, lays on gentle slopes, is fine textured, deep, well structured and drained, without accelerated erosion, and with a high risk of crusting and compaction, when cultivated. This class of soils has been found subject to hardsetting in Sicily, probably as a result of the combination between the drying effects of the hot and dry climate, the presence of free iron, and the low soil organic matter content. The formation of a plough pan at about 15–20 cm is common in cultivated lands. The moderate purifying capacity of Terra Rossa, the rather high permeability of the horizons and underlying rock, makes the soil ecosystem of Terra Rossa sensitive to pollution.

The genesis of Terra Rossa has been extensively studied in Italy. In particular, it has been demonstrated that the driving forces of Terra Rossa formation are the Mediterranean climate and the good permeability and supply of bases provided by the underlying rock or sediment, which favour haematite genesis and particles aggregation (Colombo and

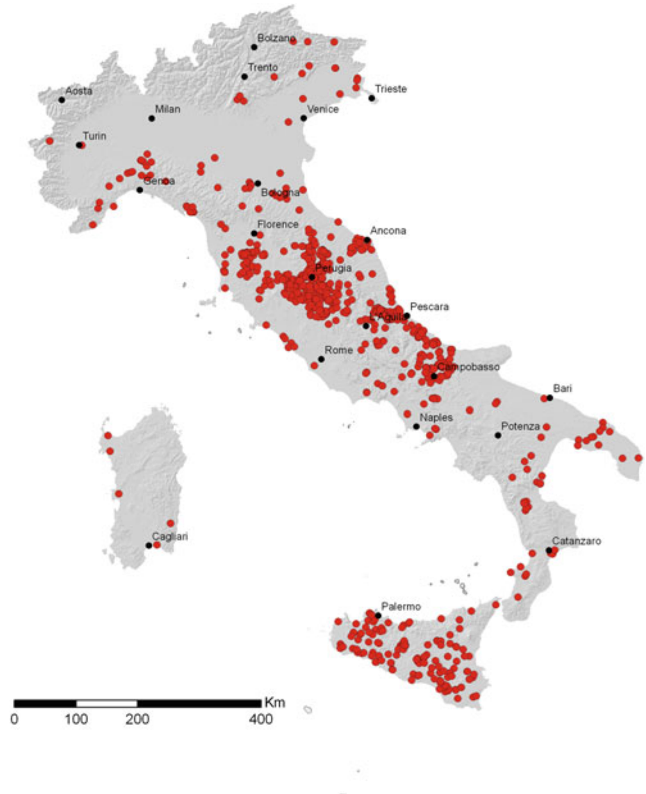


Fig. 6.20 Location of the elaborated profiles of Haplic Cambisols (Calcaric)

Torrent 1991). The underlying rock, however, may contribute only partially, or not at all, to the soil parent material. Although some authors have assumed an origin of Terra Rossa from the residual material of limestone dissolution (Bronger and Bruhn-Lobin 1997), many others stress the importance of aeolian depositions, as the amount of the limestone insoluble residue is often low and cannot produce the actual thickness of many Terra Rossa profiles (Boero and Schwertmann 1989; Boero et al. 1992). Aeolian deposition can be composed of Sahara dust (Frumkin and Stein 2004), loess (Durn et al. 1999), or volcanic ashes (Jackson et al. 1982). However, Terra Rossa can be lithologically discontinuous and polycyclic, reflecting contrasting formation processes and products of pedogenesis in the same profile (Bini and Mondini 1992; Mirabella et al. 1992; Bini and Gaballo 2006; Laubenstein and Magaldi 2008). Actually, the stratigraphy of Terra Rossa often reveals a process of colluvial layering of the profile. The rather loose material which is deposited on the surface, or comes from the dissolution of limestone, can be slowly eroded and re-deposited by the action of water and wind even on gentle slopes, like those of dolines (Costantini et al. 1992; Priori et al. 2008).

The time of Terra Rossa formation is also discussed controversially. Many authors consider these soils the products of intense weathering for a long time under sub-tropical

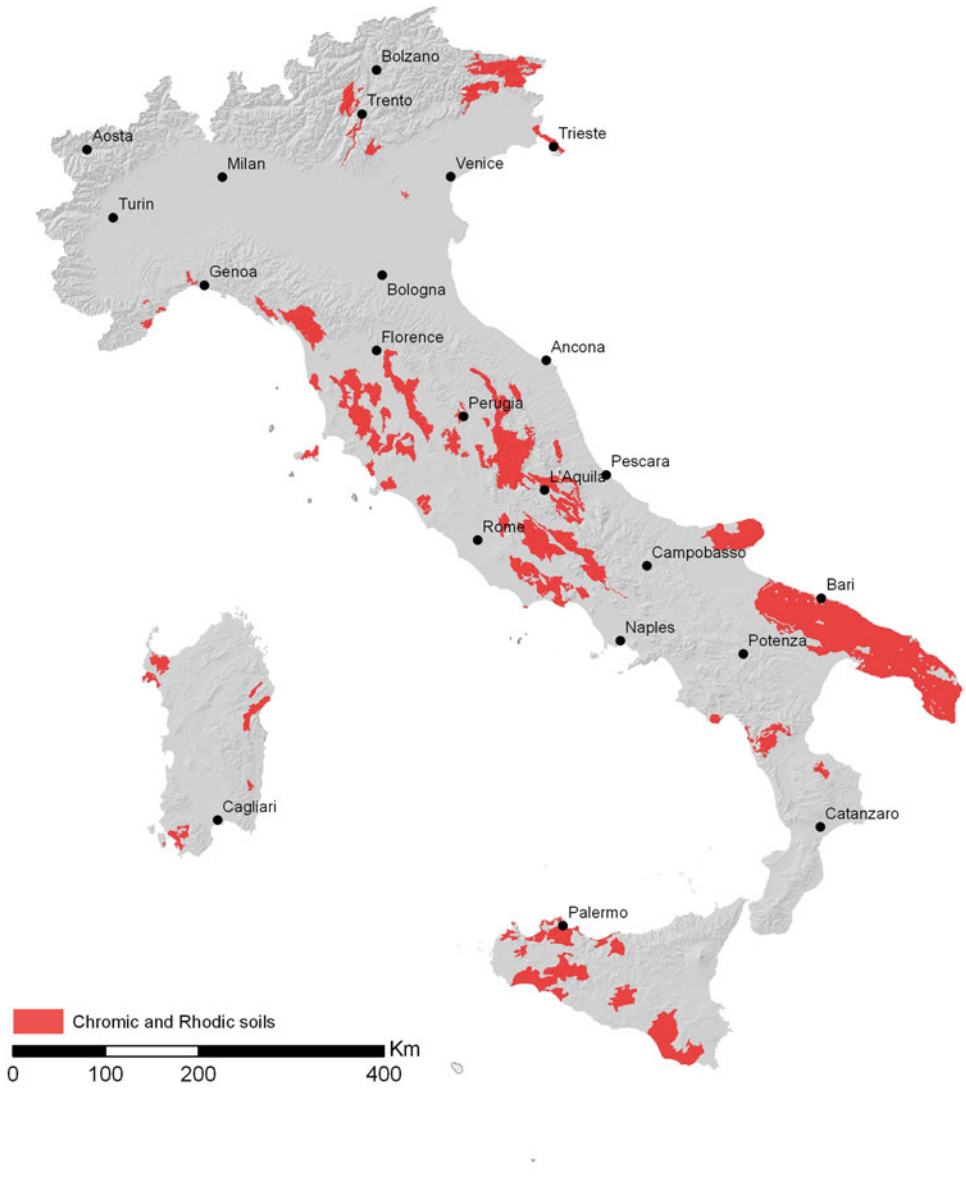


Fig. 6.21 Geographic distribution of Terra Rossa (mainly Chromic and Rhodic Luvisols and Cambisols) on karst (*density of profiles* 5.38 per 100 km^2)

Table 6.6 Average long-term climatic data of Chromic Luvisols

Variable	Unit	Average	Standard deviation	Number of data
Mean annual temperature	(°C)	14.8	2.60	64
Potential evapotranspiration	(mm)	1,101	112.6	64
Total annual rainfall	(mm)	772	243	64
Aridity index	–	0.73	0.34	64
Climatic aggressivity (F FAO)	–	75.9	16.9	64
Continentality	(°C)	14.5	0.5	64
Seasonality index	(mm %)	11.2	0.03	64

Fig. 6.22 Typical landscape (Apulia) and profile (Sicily) of Chromic Luvisols

conditions, warmer and moister than Holocene (Kubiëna 1953; Fedoroff 1997), but Bini and Garlato (1999) described Terra Rossa profiles of different ages, including Holocene. Further information on genesis and distribution of Terra Rossa are reported in Chap. 3 of this book (Fig. 6.24).

6.5.3 Haplic Calcisols

Calcisols are another major soil class of Italy and Haplic Calcisols (Typic Calcixerepts following Soil Taxonomy) are the most abundant of them. The frequent occurrence of calcareous parent materials and the characteristics of Mediterranean climate make plentiful the presence of soils with accumulation of calcium carbonate, and no accumulation of more soluble salts, especially in central and southern Italy (Fig. 6.25). They are extensively cultivated with both annual and perennial crops, and their geographic distribution covers about 57,707 km^2.

Climatic traits of Haplic Calcisols are characterized by higher mean temperature and evapotranspiration than average Italian conditions, lower precipitations and a value of the aridity index corresponding to the dry sub-humid class (Table 6.7). Modal soil temperature is higher and number of dry days larger than Italian average.

They are particularly widespread on hilly lands, where they are associated with Calcaric Cambisols, taking the relatively more stable morphological positions. In northern Italy instead, the diffusion of Calcisols within the Po plain has to be attributed to the presence of fluvial sediments rich in calcareous materials, coming from the Apennines and the central and eastern Alps, especially the Dolomites. In the Po plain, Calcisols have been particularly found in depressions and slackwater flooding areas, where carbonate soil enrichment mainly occurs as a consequence of precipitation from calcareous water, sub-surface flow, and carbonate-rich groundwater rise. This is also the case of the locally well-known petrocalcic horizons, which reform rather quickly (few years) after deep ploughing or soil ripping and constitute an important limitation to cultivation, especially of tree species (Fig. 6.26). Rapid formation of petrocalcic horizon, particularly caused by the use of highly calcareous irrigation water, has been also reported in the Apulia region.

The derived profile of 1,159 Haplic Calcisols is clay loam, poor in organic carbon, sensitive to compaction and surface crusting (Fig. 6.27). Permeability is usually limited in depth, so that they can show some hydroximorphic features. Lime and active lime contents can be a limitation, especially for tree cultivation, that needs to be properly managed, in particular, through the choice of rootstock and fertilization. They have very high purifying capacity.

The depth to the first calcic horizon is on average 73 cm, with a standard deviation of 27 cm. The correlation between depth of the calcic horizon and climatic indices is weak or absent, as also found by other authors in the USA (Royer 1999). Yet the seasonality index is highly negatively correlated, although with a low correlation index ($r = 0.2128$, $P < 0.01$), which means that the calcic horizon tends to be shallower where the difference in rainfall between the months of the year are more pronounced.

In spite of being largely widespread, and possessing ecological and economic importance, Calcisols and the genesis of calcic and petrocalcic horizons in Italy have been little investigated. Remarkable exception are made by the work of Carnicelli (1989), who studied the formation of petrocalcic horizons in different regions, pointing to their possible twofold pedogenetic and hydrogeological origin, and by that of Eppes et al. (2008), who studied a soil chronosequence on Late Pleistocene and Holocene deposits, providing meaningful information about the timing and processes of landscape response to external forcing, such as climate or anthropogenic change (Fig. 6.28).

Haplic Luvisols (Chromic)

Soil Taxonomy
Typic Haploxeralfs

Main geologies
limestone; calcarenite.

Main morphologies
marine terrace, linear slope, karst depression.

Main land uses
row crops, olive groves, broadleaved woodlands.

FUNCTIONAL HORIZONS

description	lower depth (cm)	SD	N
A, Ap	26	15	72
E, EB	27	22	13
Bt	83	36	114
BC, C, Cr	97	30	29

Total number of observations: 65

Site description: mean and standard deviation, mode and frequency, and number of sites considered.

	mean	SD	N
Elevation (m a.s.l.)			
medium hills (200-400)	311	320	64
Slope (%)			
gently sloping (6-13)	10	19	64
Stones (%)			
frequent (4-15)	8	12	60
Rocks (%)			
common (2-10)	3	4	45
Rock depth (cm)			
deep (100-150)	150	26	10
Potential rooting depth (cm)			
deep (100-150)	118	47	51
Water table upper limit (cm)			
very deep (>150)	250		1
Available water capacity (mm m^{-1})			
moderate (100-150)	119	31	32
Soil moisture regime and aridity index (dry d y^{-1})			
xeric (80-115)	98	36	33
Soil temperature regime and value (°C at 50 cm)			
thermic (15-22)	15	3	30

	mean	SD	N
Crusting risk			
high (> 0.60)	0.61	0.2	22
Compaction risk			
high (1.71 - 1.80)	1.71	0.4	22
Internal drainage			
well to moderately well drained	3.3	1	40
Surface runoff		n	N
medium		16	35
Hydrologic group			
moderate infiltration (B)		14	25
Root restriction			
compaction or paralithic contact		16	43
Purifying capacity			
moderate		8	18

Analyses: Mean, standard deviation and number of samples

Low. depth (cm)	Tex. Cl.	Sand (dag kg^{-1}) mean	Sand SD	Clay (dag kg^{-1}) mean	Clay SD	N	Coarse fragments (dm^2 m^{-2}) mean	SD	N	Bulk Density (g cm^{-3}) mean	SD	N	Permeability (μm s^{-1}) mean	SD	N	COLE (m m^{-1}) mean	SD	N
26	CL	38.7	20.2	27.2	15.0	34	4	8.4	54	1.5	0.2	7	24.4	31.9	44	0.08	0.04	3
27	L	35.7	14.6	26.8	19.0	7	5	7.3	11			0	14.9	21.2	10			0
83	CL	34.0	17.8	38.9	15.6	55	6	10.9	84	1.4	0.1	7	17.8	27.6	77	0.04		1
97	FSL	58.3	26.5	23.6	18.2	6	13	25.2	26			0	41.9	50.4	9			0

Low. depth (cm)	pH (1:2.5 H_2O) mean	SD	N	Organic Carbon (dag kg^{-1}) mean	SD	N	CEC (cmol(+) kg^{-1}) mean	SD	N	Base saturation (%) mean	SD	N	ESP (%) mean	SD	N	$CaCO_3$ total (dag kg^{-1}) mean	SD	N	$CaCO_3$ active mean	SD	N	Salinity (1:2.5 dS m^{-1}) mean	SD	N
26	6.6	1.3	36	1.93	2.59	35	25.5	21.0	29	82	23.6	29	3.8	6.2	25	1.6	5.6	31	0.8	2.2	17	0.11	0.0	15
27	5.9	1.1	7	1.00	0.59	3	9.7	3.3	2	42	2.0	2	9.9	5.1	2	0.0	0.0	4			0			0
83	6.7	1.2	56	0.50	0.52	49	23.0	17.4	49	79	24.0	48	3.4	3.8	44	0.5	1.0	48	0.2	0.6	25	0.09	0.1	20
97	6.3	1.3	6	0.28	0.13	5	10.3	4.1	5	67	36.1	5	5.5	2.0	4	0.4	0.7	6	0.0	0.0	2	0.09		1

Fig. 6.23 Derived profile of a typical Terra Rossa, Haplic Luvisols (Chromic) on karst

6.5.4 Saline and Sodic Soils

Salinity and sodicity are commonly believed to affect only marginally Italy (Tóth et al. 2008), and to be concentrated along some coastlines and in Sicily (Dazzi 2006). Although studies on Italian salt-affected soils are rather numerous, given their environmental and agronomic interest, they are mainly concentrated on the issues of irrigation and agricultural management (a.o. Crescimanno et al. 2009; Dazzi et al. 2002; Licciardello et al. 2011).

A problem in the study of saline soils in the field is determined by the dependency of salinity values on the

Fig. 6.24 Location of the elaborated profiles of Haplic Luvisols (Chromic)

weather (Raimondi 2009) and local soil variability (Castrignanò et al. 2008; Raimondi et al. 2010), as well as on the quality of irrigation water (Tedeschi and Menenti 2002). Salinity values, especially in topsoil, may change according to the amount of seasonal rainfall, soil site characteristics, quantity and management of irrigation water, all factors that are particularly variable just in the areas where many salt-affected soils are concentrated. However, studies on gypsiferous soils (a.o. Dazzi and Monteleone 2002; Dazzi et al. 2005) and on soils with parent materials rich in sodium (a.o. Busoni et al. 1995) have demonstrated that the presence of soils with a Salic or Sodic horizon could be more extensive than previously estimated for Italy, and in particular, much larger than that of Solonchak and Solonetz. In addition to the scientific results, regional soil surveys have reported the presence of saline and sodic soils in different regions and also in northern Italy (see this Chap. 8 and, among others, http://geo.regione.emilia-romagna.it/cartpedo; www.cartografia.regione.lombardia.it/geoportale).

Actually, the WRB soil classification system considers many kinds of salt-affected soils, besides Solonchaks, Solonetz, and Gypsisols. In particular, the Sodic qualifier

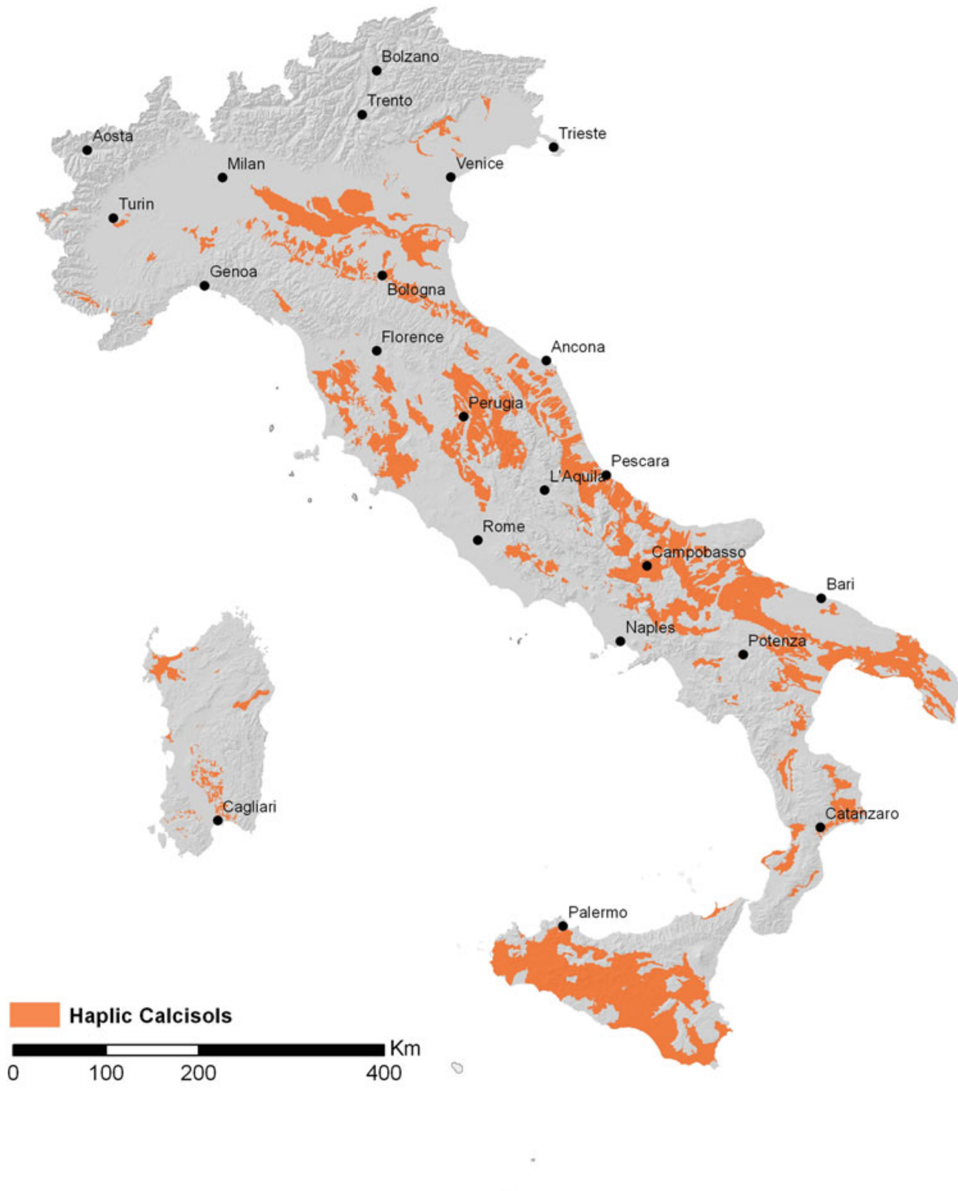


Fig. 6.25 Geographic distribution of Haplic Calcisols (*density of profiles* 2.36 per 100 km^2)

Table 6.7 Average long-term climatic data of Haplic Calcisols

Variable	Unit	Average	Standard deviation	Number of data
Mean annual temperature	(°C)	15.3	1.60	1128
Potential evapotranspiration	(mm)	1,114	113.9	1131
Total annual rainfall	(mm)	689	163	1131
Aridity index	–	0.64	0.21	1131
Climatic aggressivity (F FAO)	–	66.1	15.0	1131
Continentality	(°C)	15.0	0.68	1131
Seasonality index	(mm %)	10.1	0.03	1131

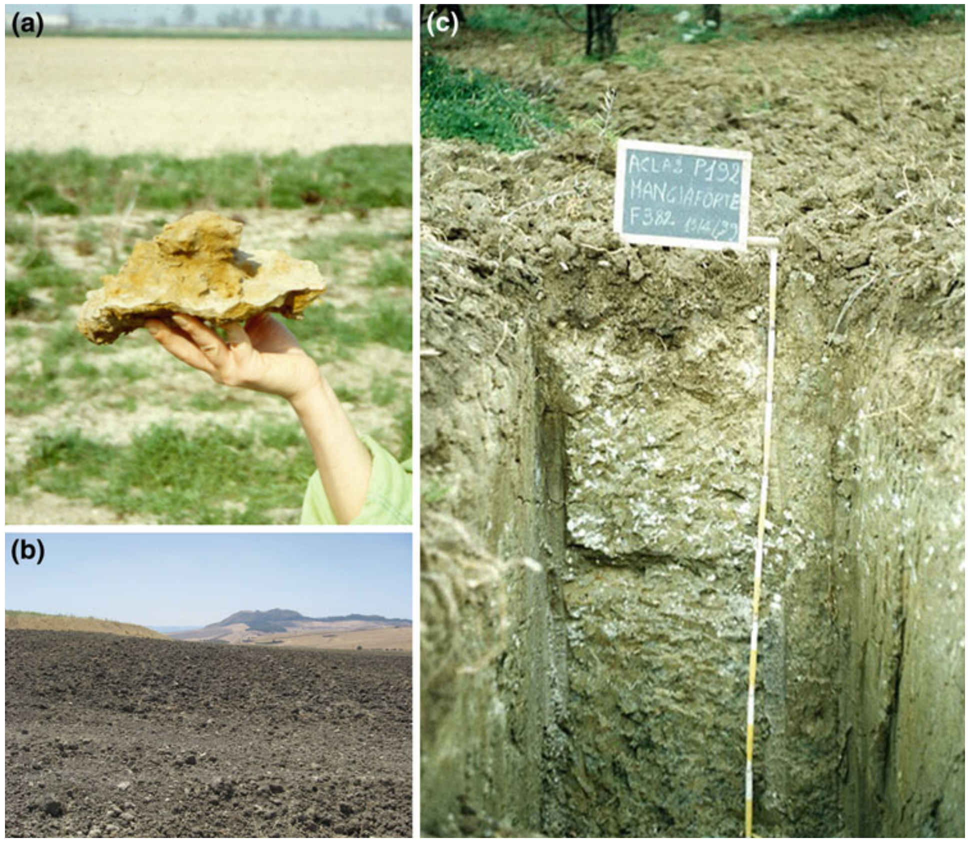


Fig. 6.26 **a** Fragment of petrocalcic horizon from a Calcisol in the Po plain (Veneto), **b** typical landscape (Sicily), **c** profile (Apulia) of Haplic Calcisols (photo courtesy of Regione Puglia)

applies on soils that have 15 % or more exchangeable Na plus Mg on the exchange complex within 50 cm of the soil surface throughout. The Hyposodic qualifier lets eligible soils that have 6 % or more exchangeable Na on the exchange complex in a layer, 20 cm or more thick, within 100 cm of the soil surface. Salic soils must have a salic horizon[6] starting within 100 cm of the soil surface and Hyposalic ones an ECe of 4 dS m^{-1} or more at 25 °C in some layer within 100 cm of the soil surface.

Some hundreds profiles and about twenty STUs stored in the national database have at least one of the Sodic, Hyposodic, Salic, Hyposalic, and Gypsic qualifiers; they belong to Vertisols, Cambisols, Regosols, Calcisols, and in a few cases to other soil classes.

The distribution area of all kinds of salt-affected soils is 31,968 km^2 (Fig. 6.29). The occurrence of sodic soils is much more widespread than that of saline soils. Although they are often rather intermingled, the area with all types of sodium-affected soils (Solonetz, and soils with Sodic and Hyposodic qualifiers) sums up 25,558 km^2 and prevails on that of all saline soils (Solonchaks, Gypsisols, and soils with Gypsic, Salic, and Hyposalic qualifiers), which is 14,605 km^2.

Saline and sodic soils mostly form from the same fine marine or fluvial and lacustrine sediments, in many cases far from the sea, on plains but especially on hilly environments. Their occurrence is not only related to the geology and morphological position, but also to the climate. Actually, climatic values and indices, calculated on the sites where they have been surveyed, show higher temperature and evapotranspiration values than Italian average, significant lower rainfall, and more aridity (Table 6.8).

It is to be highlighted that many sodic soils, especially in central and northern Italy, are only Hyposodic in depth. This means that most herbaceous crops are not much affected by sodium. Nevertheless, in the plains of northern Italy, the Sodic layer may not permit water to drain, leading to waterlogging at the surface. But it is on the slopes and clayey substrata of central and southern Italy that the occurrence of sodic and Hyposodic soils causes particularly harsh problems. In fact, the presence of a high sodium percentage on the cation-exchange complex lets the clay particles lose their tendency to stick together when wet. Soils become impermeable in depth to both water and roots, and geomorphologically unstable. Sub-surface water, in particular, flows over the Sodic soil horizon and is lost in

[6] A salic horizon must have: (1) averaged over its depth at some time of the year, an electrical conductivity of the saturation extract (ECe) of 15 dS m^{-1} or more at 25 °C, or an ECe of 8 dS m^{-1} or more at 25 °C if the pH (H_2O) of the saturation extract is 8.5 or more; and (2) averaged over its depth at some time of the year, a product of thickness (in centimetres) and ECe (in dS m^{-1}) of 450 or more; and (3) a thickness of 15 cm or more.

Haplic Calcisols

Soil Taxonomy
Typic Calcixerepts

Main geologies
calcarenite; alluvial, lacustrine or fluvial sediments; marine clay.

Main morphologies
marine terrace, linear slope, fluvial terrace in plain.

Main land uses
row crops, vineyards, heterogeneous croplands.

FUNCTIONAL HORIZONS

description	lower depth (cm)	SD	N
Ap, A	37	19	1434
Bw, B	73	27	580
Bk	95	34	675
Ck, C	115	42	1076
Cr	118	40	89

Total number of observations: 1159

Site description: mean and standard deviation, mode and frequency, and number of sites considered.

	mean	SD	N
Elevation (m a.s.l.)			
medium hills (200-400)	210	186	1149
Slope (%)			
gently sloping (6-13)	7	12	1152
Stones (%)			
frequent (4-15)	5	18	1004
Rocks (%)			
few (0-2)	1	3	436
Rock depth (cm)			
deep (100-150)	103	52	148
Potential rooting depth (cm)			
deep (100-150)	143	57	942
Water table upper limit (cm)			
deep (100-150)	127	73	18
Available water capacity (mm m^{-1})			
moderate (100-150)	139	64	568
Soil moisture regime and aridity index (dry d y^{-1})			
xeric (80-115)	93	26	550
Soil temperature regime and value (°C at 50 cm)			
mesic (8-15)	15	2	462

	mean	SD	N
Crusting risk			
high (> 0.60)	0.64	0.1	419
Compaction risk			
high (1.71 - 1.80)	1.80	0.1	421
Internal drainage			
well to moderately well drained	3.1	1	669
Surface runoff		n	N
medium		251	552
Hydrologic group			
slow infiltration (C)		210	483
Root restriction			
no restrictions and no impediments		241	547
Purifying capacity			
very high		130	269

Analyses: Mean, standard deviation and number of samples

Low. depth (cm)	Tex. Cl.	Sand (dag kg^{-1}) mean	SD	Clay (dag kg^{-1}) mean	SD	N	Coarse fragments (dm^2 m^{-2}) mean	SD	N	Bulk Density (g cm^{-3}) mean	SD	N	Permeability (µm s^{-1}) mean	SD	N	COLE (m m^{-1}) mean	SD	N	Field capacity (dag kg^{-1}) mean	SD	N	Wilting point (dag kg^{-1}) mean	SD	N
37	CL	30.2	18.3	29.9	12.5	688	4	9.1	1100	1.3	0.2	88	23.1	35.2	616	0.17	0.56	36	22.6	3.2	16	10.8	2.9	16
73	CL	30.8	20.4	29.5	13.9	307	5	13.0	442	1.3	0.2	41	19.5	34.4	252	0.07	0.03	6	25.4		1	13.7		1
95	CL	25.7	17.0	30.4	13.0	328	2	7.7	587	1.4	0.2	41	19.5	34.8	384	0.07	0.02	28	24.7	4.0	5	12.0	2.2	5
115	L	34.5	24.9	24.3	14.5	419	4	14.4	937	1.4	0.2	25	27.5	47.3	499	0.07	0.02	12	22.1	1.8	2	10.0	3.0	2
118	LS	54.5	20.6	18.6	10.1	12	5	18.9	84			0	10.5	29.9	34			0			0			0

Low. depth (cm)	pH (1:2.5 H_2O) mean	SD	N	Organic Carbon (dag kg^{-1}) mean	SD	N	CEC (cmol(+) kg^{-1}) mean	SD	N	Base saturation (%) mean	SD	N	ESP (%) mean	SD	N	$CaCO_3$ total (dag kg^{-1}) mean	SD	N	$CaCO_3$ active mean	SD	N	Salinity (1:2.5 dS m^{-1}) mean	SD	N
37	8.1	0.4	705	1.23	1.06	689	19.9	8.0	441	100	0.7	362	2.1	2.4	313	21.7	14.2	680	6.5	4.6	309	0.27	0.3	250
73	8.1	0.4	304	0.70	0.47	281	18.6	8.2	188	100	1.1	150	2.3	4.0	136	23.8	16.6	291	6.5	5.3	118	0.23	0.3	86
95	8.2	0.6	320	0.43	0.47	318	18.9	12.1	224	100	0.1	187	3.6	5.2	180	29.4	15.9	306	8.7	5.2	224	0.39	0.6	164
115	8.3	0.5	410	0.27	0.29	355	15.3	9.6	221	100	0.2	205	4.2	6.7	171	34.9	16.5	394	8.2	5.5	153	0.51	0.7	111
118	8.1	0.6	12	0.31	0.25	12	20.8	3.1	4	100	0.0	4	1.3	0.4	2	32.4	13.5	10	9.1	4.2	3	0.09	0.0	2

Fig. 6.27 Derived profile of a Haplic Calcisols

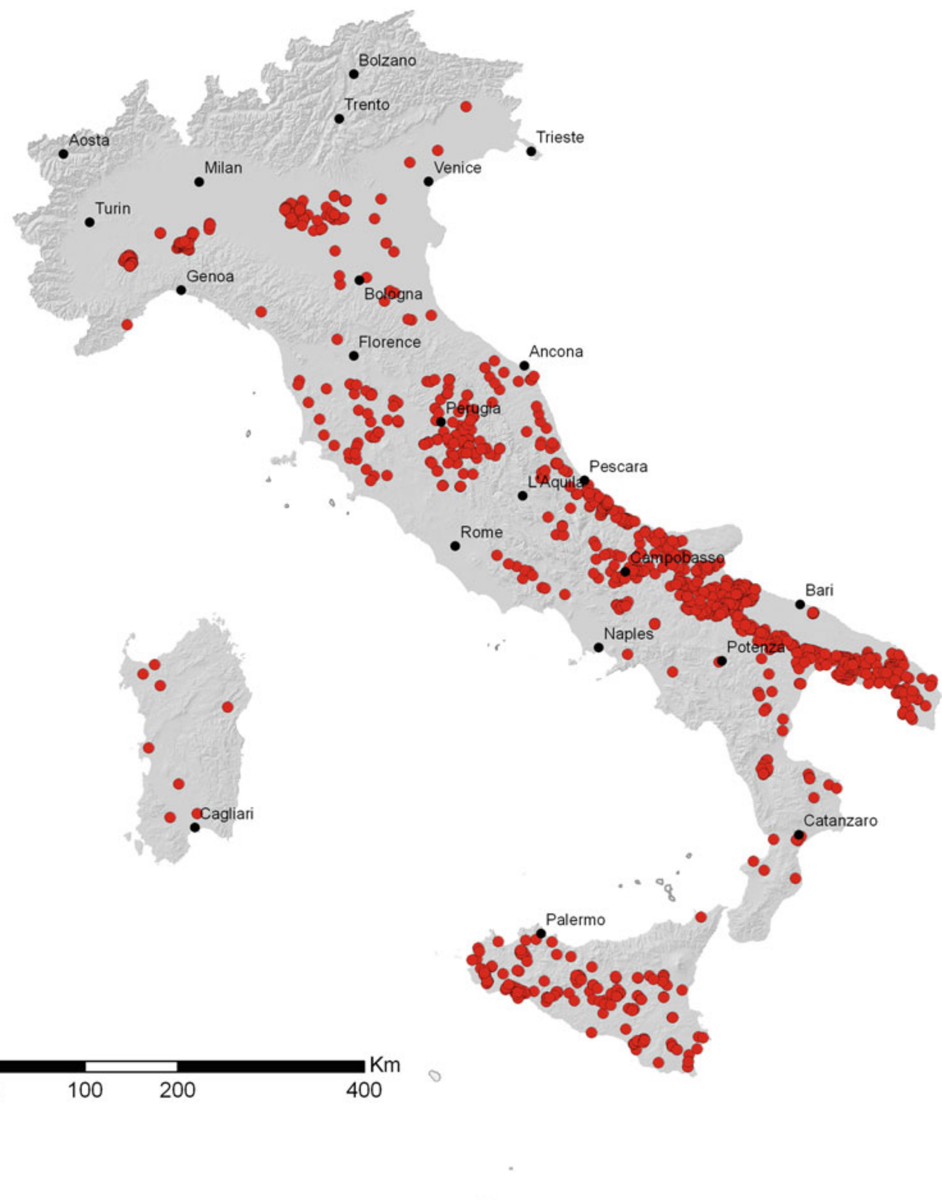


Fig. 6.28 Location of the elaborated profiles of Haplic Calcisols

lateral drainage, so that it may create tunnels, leaving cavities that eventually collapse to form gullies.

One of the main soil types affected by salinity and sodicity lays on the rolling hills formed by marine sediments and is classified Haplic Regosols (Calcaric, Hyposalic, Sodic) or Typic Xerorthent according to Soil Taxonomy (Figs. 6.30, 6.31, 6.32). These soilscapes are affected by a great variety of erosive phenomena, in some cases producing typical landscapes and important ecological environments, like those with different kinds of badlands ("biancane" and "calanchi", Alexander 1982; Calzolari and Ungaro 1998; Chiarucci et al. 1995). The limited thickness of the "solum" and the very low permeability of the C horizons and substratum are the main constraint of the soil type, favouring run-off and water erosion.

In these environments, it is also rather frequent to find saline and Sodic Regosols that form as a consequences of excessive bulldozing and earth movements. It is the activity carried out to prepare the fields for the plantation of tree cops, namely deep ploughing and slope reshaping, which may cause the outcrop of the salt-affected layers, and the failure of the cultivation (Fig. 6.33).

In spite of the overall negative effect of an excess of salts on many crops, it has been demonstrated that a moderate salinity of the deeper soil horizons of the profile can enhance the oenological outcome of some vine cultivars

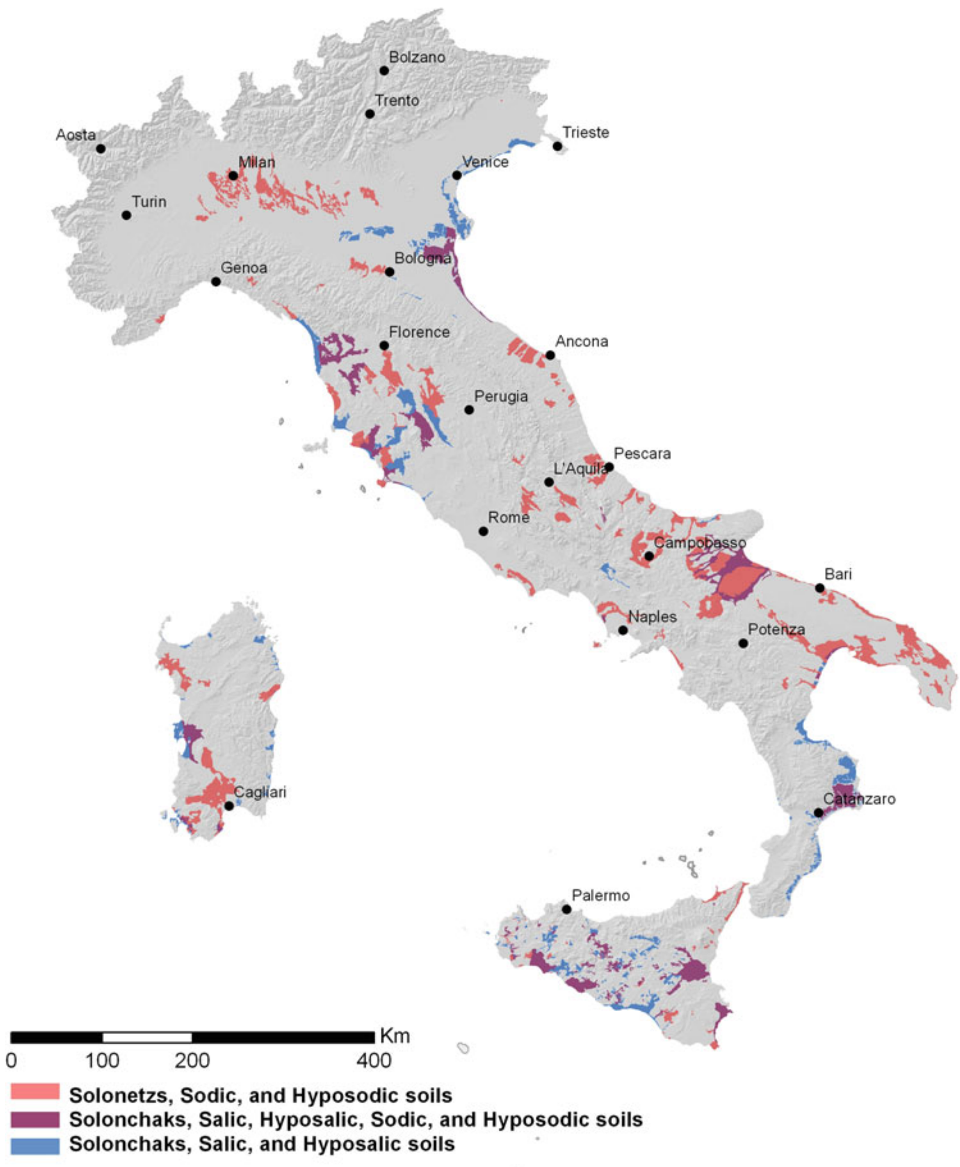


Fig. 6.29 Geographic distribution of different kinds of salt-affected soils. Areas with Salic and sodic soils of Sicily and Emilia-Romagna include Gypsisols and Gypsic soils. Density of profiles: (1) Solonetz, sodic, and hyposodic soils: 3.04 per 100 km^2; (2) Solonchaks, salic, and hyposalic soils: 3.48 per 100 km^2

Table 6.8 Average long-term climatic data of Haplic Regosols (Calcaric, Hyposalic, Sodic)

Variable	Unit	Average	Standard deviation	Number of data
Mean annual temperature	(°C)	15.8	1.46	39
Potential evapotranspiration	(mm)	1,163	90.4	39
Total annual rainfall	(mm)	653	150	39
Aridity index	–	0.57	0.17	39
Climatic aggressivity (F FAO)	–	69.4	12.5	39
Continentality	(°C)	14.6	0.4	39
Seasonality index	(mm %)	13.0	0.02	39

(Costantini et al. 2010; Scacco et al. 2010). In particular, a moderate salinity in the subsoil causes a limited physiological water stress during the phase of berry ripening, which limits the grape yield and improves the quality of the must. This can be crucial for vine varieties that tend to an excess of vegetation, when are cultivated on soils that have a large available water capacity, and too much water supply during the driest part of the growing season.

6.5.5 Phaeozems, Kastanozems and Chernozems

Highly base saturated soils with a mollic horizon are still common in Italy, in spite of the intensity and diffusion of soil erosion (see Chaps. 2, 8 and 9). They are present, as a

Fig. 6.30 Typical landscape and profile of a saline and sodic Regosol (Tuscany)

whole, in an area of 115,392 km^2 (Figs. 6.34, 6.35, 6.36, 6.37). The occurrence of Phaeozems, that is, soils with accumulation of organic matter, high base status, and any kind of mollic horizon (76,747 km^2) results more ubiquitous and widespread than Chernozems (black mollic horizon) (21,498 km^2) and Kastanozems (brown mollic horizon) (19,286 km^2), which are both more frequently found in southern Italy. Climatic conditions of these taxa are all dryer and warmer than the Italian average, and significantly more evapotranspirative and arid (Table 6.9). Although are not any significant difference in temperature and rainfall between the taxa, Chernozems show a certain less continental and more seasonal climate than Kastanozems, due to their more pronounced summer deficit, characteristic of the so-called Mediterranean steppe (Marignani et al. 2008).

These soil classes are particularly ecologically relevant, as they dominate pedogenesis on hard rocks, like limestone (Lorè et al. 2002), lava (Barbera et al. 2008), and serpentine (Bonifacio et al. 1997), but especially as they can support the vegetation type which is the closest to the climax of the area (Dazzi and Monteleone 2007; Zanini et al. 1995, see also Chap. 4). These characteristics were utilized by some authors to mark climatic changes during geological times (Ferraro et al. 2004).

Luvic Phaeozems are the most common type of Phaeozems, likewise Calcic Chernozems and Calcic Kastanozems for their reference soil group (Figs. 6.38, 6.41 and 6.44). A common relevant feature of the three taxa is the relatively high organic carbon content of the topsoil, but also of the subsoil, reaching values of 0.5 % in weight until 1 m and more, which confirms the great potentiality for carbon sequestration of this kind of soils. Actually, the SOC density of Luvic Phaeozem, Calcic Chernozems, and Calcic Kastanozems modal profiles is, respectively, 12.69, 12.76, and 12.14 kg m^2 in the first meter, and reaches 17.18, 12.90, and 13.69 kg m^2, in the whole profile. The organic matter stratification between the first two functional horizons is larger in Luvic Phaeozems than in the other two taxa, that is, 1.90 versus 1.78 and 1.28, which could be related to their moister pedoclimate.

As a matter of fact, the derived profiles of these taxa have many common characteristics and qualities. Nevertheless, the average depth to calcic horizon is only apparently similar in Calcic Chernozems and Calcic Kastanozems, but it is actually shallower in Chernozems, as the presence of a cambic horizon is less frequent than in Calcic Kastanozems (Figs. 6.39, 6.40, 6.42, 6.43, 6.45).

6.5.6 Umbrisols

Although Umbrisols rarely dominate soilscapes at the national scale (see Table 6.3), the presence of Umbrisols in the Italian soil systems is rather large, encompassing 32,055 km^2 (Fig. 6.46). Their distribution is relatively well

Haplic Regosols (Calcaric, Hyposalic, Sodic)

Soil Taxonomy
Typic Xerorthents

Main geologies
marine clay and silty-clay sediments.

Main morphologies
slope dissected by small valleys, linear slope, convex slope or summit.

Main land uses
row crops, heterogeneous croplands, broadleaved woodlands.

FUNCTIONAL HORIZONS

description	lower depth (cm)	SD	N
A	35	16	74
C	97	36	56
Cr	122	28	3

Total number of observations: 39

Site description: mean and standard deviation, mode and frequency, and number of sites considered.

	mean	SD	N
Elevation (m a.s.l.)			
medium hills (200-400)	312	129	39
Slope (%)			
strongly sloping (13-20)	17	11	39
Stones (%)			
frequent (4-15)	6	25	35
Rocks (%)			
few (0-2)	2	8	36
Rock depth (cm)			
			0
Potential rooting depth (cm)			
moderately deep (50-100)	72	46	37
Water table upper limit (cm)			
absent			0
Available water capacity (mm m^{-1})			
low (50-100)	96	52	39
Soil moisture regime and aridity index (dry d y^{-1})			
xeric (80-115)	110	23	39
Soil temperature regime and value (°C at 50 cm)			
thermic (15-22)	16	2	29

	mean	SD	N
Crusting risk			
high (> 0.60)	0.65	0.1	34
Compaction risk			
high (1.71 - 1.80)	1.77	0.1	34
Internal drainage			
well to moderately well drained	3.9	2	38
Surface runoff		n	N
medium		12	33
Hydrologic group			
very slow infiltration (D)		20	34
Root restriction			
compaction or paralithic contact		13	36
Purifying capacity			
low		11	28

Analyses: Mean, standard deviation and number of samples

Low. depth (cm)	Tex. Cl.	Sand (dag kg^{-1}) mean	Sand SD	Clay mean	Clay SD	N	Coarse fragments (dm^2 m^{-2}) mean	SD	N	Bulk Density (g cm^{-3}) mean	SD	N	Permeability (µm s^{-1}) mean	SD	N	COLE (m m^{-1}) mean	SD	N	Field capacity (dag kg^{-1}) mean	SD	N	Wilting point (dag kg^{-1}) mean	SD	N
35	SIC	14.7	15.6	40.2	17.1	73	4	7.4	67	1.4	0.2	34	17.00	29.7	50	0.06	0.03	32	31.7	7.0	24	16.8	3.4	24
97	SIC	11.0	12.7	40.0	15.7	44	3	8.8	53	1.5	0.2	16	10.51	29.4	38	0.05	0.02	17	21.7	4.9	6	11.4	1.7	6
122	SIC	4.7	4.5	43.5	2.7	2	0	0.0	2			0	0.55	0.0	2			0			0			0

Low. depth (cm)	pH (1:2.5 H_2O) mean	SD	N	Organic Carbon (dag kg^{-1}) mean	SD	N	CEC (cmol(+) kg^{-1}) mean	SD	N	Base saturation (%) mean	SD	N	ESP (%) mean	SD	N	$CaCO_3$ total (dag kg^{-1}) mean	SD	N	$CaCO_3$ active mean	SD	N	Salinity (1:2.5 dS m^{-1}) mean	SD	N
35	8.0	0.3	70	1.16	0.96	73	22.0	8.3	55	100	0.0	47	8.1	12.8	45	17.1	10.6	73	6.3	3.9	70	1.68	1.6	73
97	8.1	0.4	43	0.50	0.32	42	22.4	6.6	23	100	0.1	18	27.1	23.6	18	17.1	13.2	43	5.0	2.9	41	2.55	1.3	42
122	8.1	0.0	2	0.40	0.14	2			0			0			0	9.6	10.4	2	5.1	5.7	2	2.03	0.6	2

Fig. 6.31 Derived profile of Haplic Regosols (Calcaric, Hyposalic, Sodic)

constrained by the factors of pedogenesis; thus, their ecological and pedological values are remarkably high. Cambic Umbrisols (Humic) are the most common type of Umbrisols in Italy. They are more frequently found on linear slopes on granite, sandstone, and schist, and formed under coniferous and broad-leaved forest stands, and permanent grassland and pastures. Climate is definitely colder and more rainy than Italian average (Table 6.10). The derived profile of 53 Cambic Umbrisols (Humic) is loam, deep, with good physical characteristics, good permeability, low crusting risk, and very low compaction risk, but only moderate purifying capacity (Fig. 6.48).

In spite of their relevance, there are few published research works on Italian Umbrisols. Bini and De Siena (1995) documented the presence of Umbrisols formed on the central Italy ophiolite belt. Sanesi and Certini (2005)

Fig. 6.32 Location of the elaborated profiles of Haplic Regosols (Calcaric, Hyposalic, Sodic)

studied the genesis of umbric epipedon on sandstone, in high forests of Abies alba, Fagus sylvatica, and Castanea sativa of the northern Apennines. They demonstrated that the mean residence time of the bulk OM amounts was about a century in the A1 horizon (lower depth 5–10 cm), versus half a millennium in the A2 (lower depth 20–28 cm). Cecchini et al. (2003) collected through fall and soil solutions under a Fagus sylvatica stand in central Italy, to study dynamic and neutralization of acid solutions leaving the organic horizons. Costantini (1993) found that organic carbon density in Pachic Umbrisols formed under a Calabrian Pine afforestation in the Sila mountain (southern Apennines) reached 5.83 % in the first 10 cm, and 3.89 % in the first 60–80 cm. Considering that OC before tree plantation was less than 1 %, the OC accumulation in 27 years was more than 30 kg m^{-2} (Figs. 6.47, 6.49).

6.5.7 Vertisols

Vertisols are another ubiquitous class of soil in Italy (Fig. 6.50). The presence of soils influenced by alternating

Fig. 6.33 Consequences of excessive earth movements before the plantation of a vineyard (Tuscany). Salt efflorescences and death vines in the foreground, leopard-like spots of Sodic soils in the background vineyard

wet–dry conditions and rich in swelling clays has been ascertained in 32,226 km^2. They develop from fine sediments of different origin, preferably on plain or gently sloping positions. The morphology can be relatively steeper in the southern regions and especially in Sicily, where the Mediterranean climate enhances its sub-tropical traits (Fig. 6.51).

Vertisol formation is climate dependent and the distribution of Vertisol sub-classes itself is somewhat related to climate. In the case of Haplic and Calcic Vertisols, for instance, the soils belonging to the class Calcic are placed in significantly hotter and dryer environments than Haplic (Table 6.11).

The characteristics of a benchmark Calcic Vertisol are reported in Figs. 6.2 and 6.3, whereas properties of modal Italian Haplic Vertisols (Calcaric) are in Fig. 6.52. The most striking differentiating properties of Haplic Vertisols (Calcaric), which might reflect the climatic environment different from Calcic Vertisol, are the deeper depth of the calcic horizon and the lower lime content in the horizons.

A remarkable characteristic of most of Italian Vertisol is the rather large organic carbon sink capacity, until depths deeper than one metre, in spite of the limited concentration in the topsoil. In the case of the derived profile of 362 Haplic Vertisols (Calcaric), the carbon stock is of about 14.45 kg m^2 up to 140 cm and 11.67 kg m^2 in the first meter, but with a rather low stratification index (1.29) between the first two functional horizons.

The dynamic of organic matter in Italian Vertisols, the humus forms and microbiological activity, have been particularly studied by Dell'Abate et al. (2002) and by Marinari et al. (2010). Other specific studies on Vertisols were conducted on the genesis of fractal dimension of porosity (Moreau et al. 1999), mineralogy (Righi et al. 1999; Vingiani et al. 2004), and structure formation (Ristori et al. 1992). Management issues have been also treated, like the effects of irrigation system (Crescimanno et al. 2007) and reclamation activities (Ermice et al. 2002) on the genesis and properties of soils with vertic characteristics.

6.5.8 Andosols

The distribution area of Italian Andosols is currently under debate, as some authors claim that Andosols and soil with andic properties are much more widespread than the territories where volcanic sediments outcrop (Iamarino and Terribile 2008). Actually, the number of soil profiles that have been hitherto classified as Andosols, and stored in the national database, is quite large (1,719, see Fig. 6.13) but they are all related to the volcanic depositions of central and southern Italy (Fig. 6.54). The estimated geographic distribution of soils dominated by Fe/Al chemistry with allophanes, or Al-humus complexes, sums up 15,559 km^2 (Fig. 6.53).

The types of climate where they have been found are all Mediterranean, but preferably of the sub-oceanic or mountainous sub-types, with rather high precipitation amount and very high rainfall intensity (Table 6.12). Actually, the climatic setting of Andosols, which are located just where precipitations are particularly concentrated, makes them particularly susceptible to water erosion and landslide.

The international publication of studies on soils formed on volcanic deposits in Italy was initiated by Lulli and collaborators in the early eighties (Lulli and Bidini 1980; Lulli et al. 1988). After having focussed on soil catenae, Italian researchers turned their interest to the mineralogy and genesis of andic properties (Violante and Wilson 1983; Quantin et al. 1988; Vacca et al. 2003). More recently, the interaction between organic matter dynamic, vegetation, and pedogenesis has received much attention (Certini et al. 2001; Barbera et al. 2008; Egli et al. 2007, 2008, 2012), as well as the particular hydraulic behaviour of Andosols, which enhances the risk of landslide (Basile et al. 2003; Terribile et al. 2007). A comprehensive review on Andosols of Italy has been compiled by Lulli (2007), and further information on the pedogenesis of Andosols is also reported in Chap. 3 of this book.

The most frequent taxon of Andosols in Italy is the Vitric Andosols (Humic Vitrixerands according to Soil Taxonomy); other frequent genetic qualifiers are Silandic, Haplic,

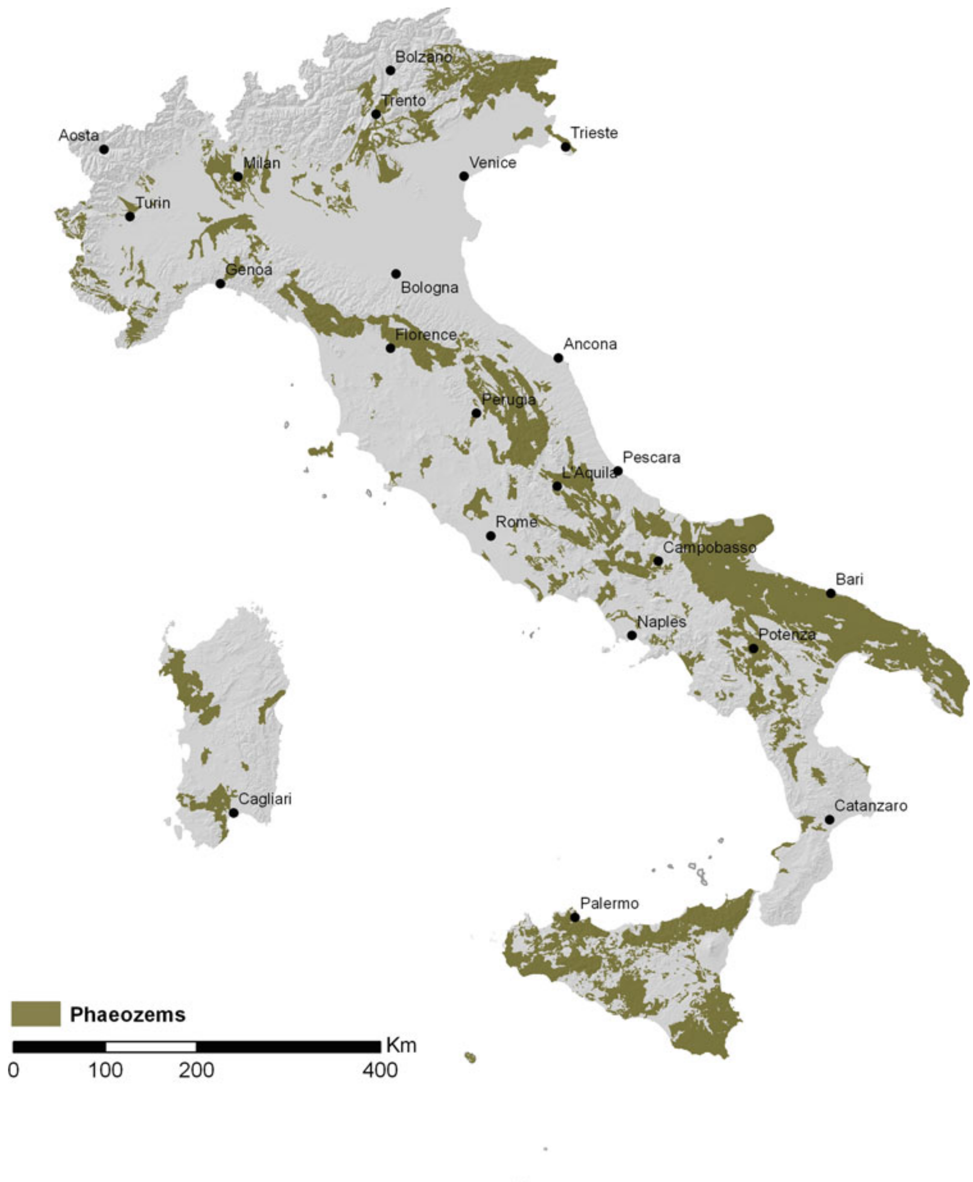


Fig. 6.34 Geographic distribution of Phaeozems (*density of profiles* 2.91 per 100 km^2)

Aluandic, and Umbric. Vitric Andosols of Italy are very fertile, but they mostly lay on strong slope and are often intensively cultivated, either with tree crops or with intensely coppiced forest stands; therefore, they are harshly threatened by degradation (Figs. 6.55, 6.56, 6.57), unless placed on anthropic terraces.

6.5.9 Podzols

Soils set by Fe/Al chemistry with surface eluviation of chelates and their illuviation in the B horizon are present in all the Italian Alps and in the northern Apennines (Fig. 6.58). More southern, their presence has been documented on the Amiata volcano (Tuscany) and spodic properties in the soils of the Vico volcano (Lulli et al. 1988). The overall extent of the Podzol distribution area is 14,976 km^2 (Fig. 6.59).

Values of climatic indices point for Podzols to colder and more rainy conditions than average (Table 6.13). As a result, the modal soil moisture regime is udic, and the temperature regime frigid or cryic (Fig. 6.60). The most represented Italian Podzols are Haplic Podzols that lay on steep slopes at high elevation, under coniferous forest. Parent material composition is commonly thought to be crucial for Podzols formation; however, permeability seems

Fig. 6.35 Geographic distribution of Kastanozems (*density of profiles* 3.78 per 100 km^2)

to be more important than acidity. Actually, main rock types are glacial and fluvial-glacial sediments, schist, phyllite, and sandy turbidite. The derived profile of 13 Haplic Podzols of the Alps and northern Apennines shows a diagnostic increase in the Bs horizon of Fe and Al extracted by oxalate. The ratio with the total value of the elements indicates that Al is predominantly translocated over Fe in the spodic horizon. The precipitation depth of the metal–organic complexes is marked by a sharp increase in pH and especially in base saturation, which suggests that the immobilization may take place at the point of zero charge and may also be influenced by the flocculating effect of base cations.

Italian Podzols have captured the interest of researchers especially in relation to clay mineralogy and transformation, and to their relationship with the underlying rocks (Carnicelli et al. 1997; Mirabella et al. 2002; Mirabella and Egli 2003; Egli et al. 2004). D'Amico and collaborators (2008) found that besides acid and permeable rocks, even mafic and ultramafic parent materials can undergo different degrees of podzolization.

An important focus was given to chlorite transformation. Smectite could be found in the E horizons of soils developed on chlorite-bearing parent materials. If nearly no other 2:1 mineral components such as chlorite were present in the

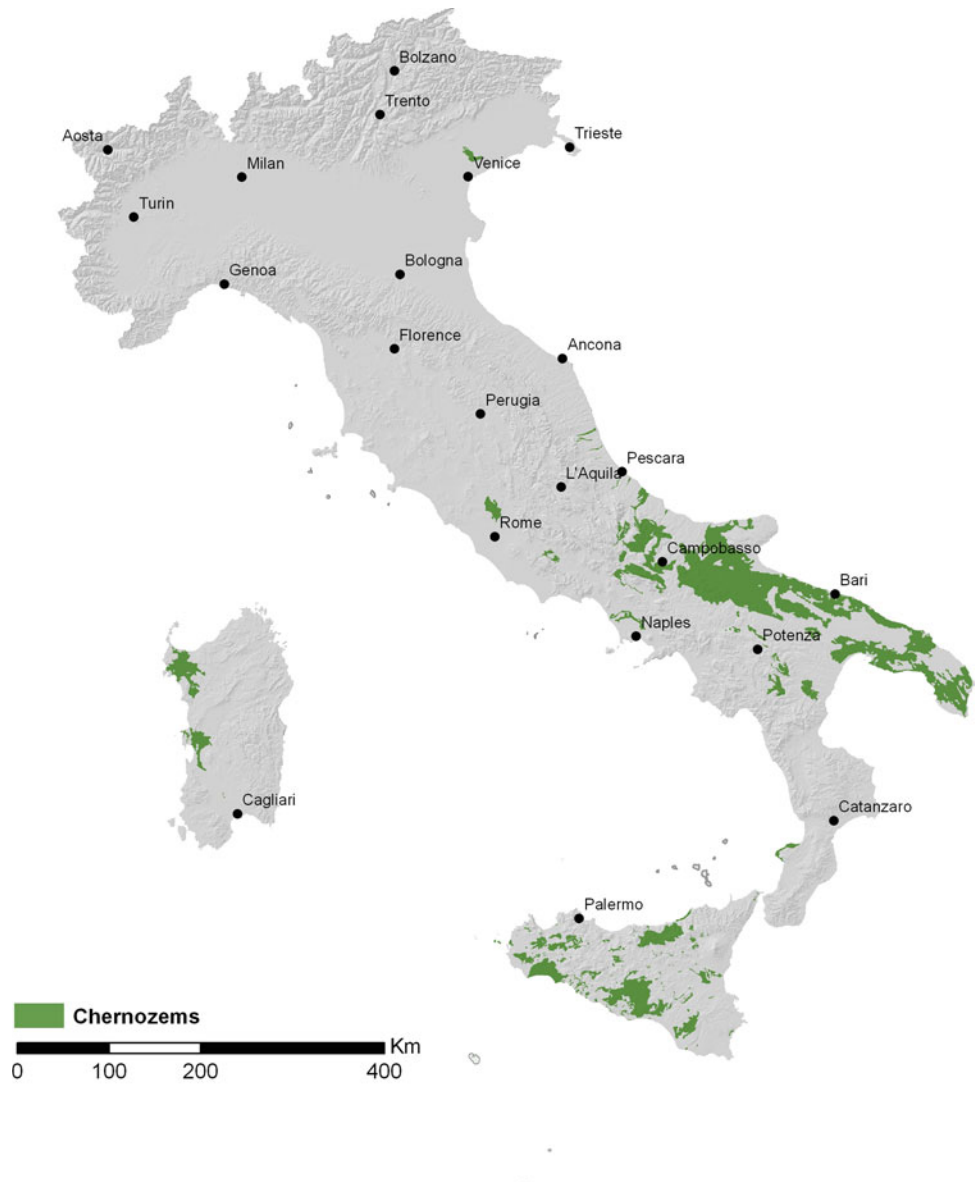


Fig. 6.36 Geographic distribution of Chernozems (*density of profiles* 1.82 per 100 km^2)

Fig. 6.37 Typical landscape and profile of a Luvic Phaeozem (Trentino, photos Giacomo Sartori)

Table 6.9 Average long-term climatic data of Luvic Phaeozems, Calcic Kastanozems, and Calcic Chernozems

Variable	Unit	Luvic Phaeozems			Calcic Kastanozems			Calcic Chernozems		
		Average	Standard deviation	Number of data	Average	Standard deviation	Number of data	Average	Standard deviation	number of data
Mean annual temperature	(°C)	14.8	1.68	357	15.5	1.18	279	16.9	1.25	71
Potential evapotranspiration	(mm)	1,143	65.1	357	1,160	57.5	279	1,231	61.3	71
Total annual rainfall	(mm)	665	157	357	608	73	279	588	77	71
Aridity index	–	0.59	0.19	357	0.53	0.09	279	0.48	0,08	71
Climatic aggressivity (F FAO)	–	64.3	15.5	357	58.6	8.5	279	66.9	8.6	71
Continentality	(°C)	14.8	0.5	357	15.1	0.5	279	14.2	0.52	71
Seasonality index	(mm %)	9.8	0.02	357	9.7	0.02	279	14.3	0.02	71

lower soil horizons, then a residual micaceous mineral became the dominant clay mineral.

Genesis of Italian Podzols has been also investigated with reference to slope aspect and degree (Egli et al. 2004; Elgi et al. 2009; D'Amico et al. 2008) and to vegetation pattern (Scalenghe et al. 2002). Podzolization should be more active mainly on stable and moderately steep northward slopes, where snow cover lasts for longer periods, evapotranspiration is lower and erosion is not a limiting factor for the pedogenesis.

Podzols are very vulnerable to disturbances even of low intensity. The impact of different disturbances on soil development leads to a pattern of soil development in which the vegetation plays a key role. Well-preserved Podzols have been considered a heritage, since they support endemic ecosystems that are threatened with degradation or even disruption (Zilioli et al. 2011) (Fig. 6.61).

6.5.10 Acrisols, Lixisols, Planosols, Alisols, Nitisols, Plinthosols, and other Palaeosols with a Fragipan

This set of soils are characterized by past or very long-lasting pedogenesis, most times older than the Holocene. Even though the extension of any single palaeosol is typically limited in size, their cumulative occurrence is definitely not negligible, and their geographic occurrence (probably underestimated) sums up 14,170 km^2, which corresponds to almost 5 % of the national soil coverage (Fig. 6.62). Palaeosols have particular spatial pattern. They typically show limited extension, but their occurrence is probable in almost every environment. They are usually independent from the current climate, topography, vegetation, and underlying substratum, so that Italian abundance of palaeosols largely contributes to the low predictability of soil distribution, and to the difficulty of soil mapping, at all scales (Fig. 6.63).

Alisols is the most widespread reference soil group of this soil set, and Cutanic Alisols the most representative of it. The derived profile of 52 Cutanic Alisols is reported in Fig. 6.64. As expected, this taxon occurs in contrasting geological, morphological, and vegetation environments. However, the climatic and pedoclimatic indices point to definitely more humid and chillier conditions than Italian average.

These soils show both physical and chemical limitations for agricultural husbandry, which have been overcame by farmers through the introduction of either specific crops, like rice, or practices, in particular liming (see also Chaps. 4 and 9).

The profusion of palaeosols of different types, in particular, red palaeosols of northern Italy, known with the local name "ferretto" (Cremaschi and Busacca 1994), their relevance both for basic and applied soil and earth sciences, let them being the object of many studies, some of which are reported in Chap. 5 of this book (Table 6.14) (Fig. 6.65).

The pedogenesis of fragipan, in particular, has been object of particular attention, and several authors documented various processes responsible for their formation, also different from those found in soils of central and northern Europe. Cremaschi and Van Vliet-Lanoë (1990)

Luvic Phaeozems

Soil Taxonomy
Pachic Argixerolls

Main geologies
limestone; calcarenite; mixed alluvial, lacustrine or fluvial sediments.

Main morphologies
karstified plateau, karst depression, marine terrace.

Main land uses
row crops, olive groves, heterogeneous croplands.

FUNCTIONAL HORIZONS

description	lower depth (cm)	SD	N
Ap, A	32	13	452
Bt	85	28	430
2Bt	170	62	47

Total number of observations: 357

Site description: mean and standard deviation, mode and frequency, and number of sites considered.

	mean	SD	N
Elevation (m a.s.l.)			
medium hills (200-400)	329	249	357
Slope (%)			
nearly level(3-5)	3	7	356
Stones (%)			
frequent (4-15)	12	32	336
Rocks (%)			
common (2-10)	7	15	112
Rock depth (cm)			
deep (100-150)	135	39	18
Potential rooting depth (cm)			
deep (100-150)	109	48	240
Water table upper limit (cm)			
moderately deep (50-100)	64	61	4
Available water capacity (mm m^{-1})			
moderate (100-150)	130	50	82
Soil moisture regime and aridity index (dry d y^{-1})			
xeric (80-115)	95	26	82
Soil temperature regime and value (°C at 50 cm)			
thermic (15-22)	16	2	76

	mean	SD	N
Crusting risk			
moderate (0.41 - 0.60)	0.56	0.1	64
Compaction risk			
high (1.71 - 1.80)	1.72	0.2	66
Internal drainage			
well to moderately well drained	3.2	1	111
Surface runoff		n	N
medium		63	103
Hydrologic group			
moderate infiltration (B)		31	72
Root restriction			
no restrictions and no impediments		55	100
Purifying capacity			
very high		30	55

Analyses: Mean, standard deviation and number of samples

Low. depth (cm)	Tex. Cl.	Sand (dag kg^{-1}) mean	Sand SD	Clay (dag kg^{-1}) mean	Clay SD	N	Coarse fragments (dm^2 m^{-2}) mean	SD	N	Bulk Density (g cm^{-3}) mean	SD	N	Permeability (µm s^{-1}) mean	SD	N
32	CL	38.0	18.9	31.3	14.4	100	2	5.3	362	1.4	0.3	7	36.4	48.9	120
85	C	33.3	17.7	43.6	16.9	119	2	8.7	349	1.3	0.3	7	22.8	38.1	154
170	C	32.7	20.7	45.8	19.0	22	3	7.7	37	1.1		1	23.3	33.5	37

Low. depth (cm)	pH (1:2.5 H_2O) mean	SD	N	Organic Carbon (dag kg^{-1}) mean	SD	N	CEC (cmol(+) kg^{-1}) mean	SD	N	Base saturation (%) mean	SD	N	ESP (%) mean	SD	N	$CaCO_3$ total (dag kg^{-1}) mean	SD	N	$CaCO_3$ active mean	SD	N	Salinity (1:2.5 dS m^{-1}) mean	SD	N
32	7.3	0.7	98	1.75	1.16	97	24.9	11.5	90	91	10.8	80	2.1	1.9	74	2.5	3.7	84	0.8	1.6	48	0.27	0.6	50
85	7.2	0.8	116	0.60	0.44	112	25.5	11.1	106	89	12.9	84	2.4	2.8	82	2.1	5.2	101	0.6	1.5	55	0.22	0.5	56
170	7.5	0.8	22	0.60	0.59	20	33.7	9.9	18	90	14.0	18	2.9	3.2	18	2.2	4.3	18	1.0	1.6	15	0.10	0.1	13

Fig. 6.38 Derived profile of Luvic Phaeozems

were first to contest that fragipan could be considered as a permafrost indicator in the loess of northern Italy. Consolidation of the material due to dewatering of earth flow deposits, rather than to frost action, was attributed to fragipan formation in central Tuscany by Costantini et al. (1996) and by Certini et al. (2007) in the Apennines. Scalenghe et al. (2004) instead pointed to liquefaction of soil material due to earthquakes, providing a dense parent material in which fragipan developed.

The low permeability and high bulk density of fragipan were attributed to the bonding of amorphous silica (Ajmone-Marsan and Torrent 1989) and associated to pore size distribution and pore shape (Ajmone-Marsan et al. 1994), in addition to the specific arrangements of the particles, that is, an open packing of the clay, associated to an extremely dense packing of silt and sand (Falsone and Bonifacio 2009). Slaking instead was related to clay arrangement and consequent porosity characteristics

Fig. 6.39 Location of the elaborated profiles of Luvic Phaeozems

Fig. 6.40 Typical landscape and profile of a Calcic Kastanozem of Sicily (photo courtesy of Regione Siciliana, Assessorato Agricoltura). The mollic horizon shows the effect of deep ploughing

Calcic Kastanozems

Soil Taxonomy
Pachic Calcixerolls

Main geologies
calcarenite; mixed alluvial, lacustrine or fluvial sediments; ruditic rocks.

Main morphologies
fluvial terrace in plain, marine terrace, slope dissected by small valleys.

Main land uses
row crops, fruit trees, heterogeneous croplands.

FUNCTIONAL HORIZONS

description	lower depth (cm)	SD	N
Ap, A	40	18	396
Bw	78	26	159
Bk	100	31	139
Ck, C	119	37	205

Total number of observations: 279

Site description: mean and standard deviation, mode and frequency, and number of sites considered.

	mean	SD	N
Elevation (m a.s.l.)			
medium hills (200-400)	231	175	279
Slope (%)			
gently sloping (6-13)	4	8	279
Stones (%)			
frequent (4-15)	10	25	270
Rocks (%)			
few (0-2)	2	5	49
Rock depth (cm)			
deep (100-150)	118	13	7
Potential rooting depth (cm)			
deep (100-150)	143	56	212
Water table upper limit (cm)			
deep (100-150)	101	66	6
Available water capacity (mm m^{-1})			
moderate (100-150)	126	52	85
Soil moisture regime and aridity index (dry d y^{-1})			
xeric (80-115)	111	23	85
Soil temperature regime and value (°C at 50 cm)			
thermic (15-22)	16	2	72

	mean	SD	N
Crusting risk			
moderate (0.41 - 0.60)	0.59	0.1	75
Compaction risk			
high (1.71 - 1.80)	1.77	0.1	75
Internal drainage			
well to moderately well drained	3.2	1	141
Surface runoff		n	N
medium		86	137
Hydrologic group			
slow infiltration (C)		41	74
Root restriction			
no restrictions and no impediments		44	98
Purifying capacity			
very high		20	49

Analyses: Mean, standard deviation and number of samples

Low. depth (cm)	Tex. Cl.	Sand (dag kg^{-1}) mean	Sand SD	Clay (dag kg^{-1}) mean	Clay SD	N	Coarse fragments (dm^2 m^{-2}) mean	SD	N	Bulk Density (g cm^{-3}) mean	SD	N	Permeability (µm s^{-1}) mean	SD	N	COLE (m m^{-1}) mean	SD	N
40	CL	29.6	17.2	35.0	14.1	116	3	7.3	317	1.3	0.2	10	32.3	50.2	116	0.06	0.02	18
78	CL	31.9	18.1	32.9	12.3	38	2	4.9	138	1.2		1	20.0	32.1	39	0.08	0.02	4
100	CL	29.3	17.5	34.5	12.5	66	4	10.5	110	1.5	0.1	12	17.0	28.1	63	0.08	0.02	10
119	CL	34.5	22.2	29.0	15.7	56	5	14.5	167	1.1	0.0	2	19.6	39.1	83	0.06	0.00	8

Low. depth (cm)	pH (1:2.5 H_2O) mean	SD	N	Organic Carbon (dag kg^{-1}) mean	SD	N	CEC (cmol(+) kg^{-1}) mean	SD	N	Base saturation (%) mean	SD	N	ESP (%) mean	SD	N	$CaCO_3$ total (dag kg^{-1}) mean	SD	N	$CaCO_3$ active mean	SD	N	Salinity (1:2.5 dS m^{-1}) mean	SD	N
40	7.9	0.5	116	1.34	0.76	116	27.3	10.7	95	98	3.3	92	2.2	2.4	93	19.6	16.1	111	5.5	4.9	91	0.34	0.4	87
78	8.0	0.3	37	0.85	0.44	38	26.1	9.8	35	100	1.7	29	1.5	1.7	32	23.8	21.1	36	7.9	5.6	27	0.20	0.2	18
100	8.2	0.4	66	0.50	0.34	66	22.4	9.8	59	99	1.9	56	3.3	4.2	56	33.8	19.5	66	9.0	5.8	56	0.33	0.3	55
119	8.1	0.4	55	0.38	0.62	52	23.5	13.2	40	99	1.7	39	3.9	9.4	39	43.5	20.4	55	7.0	4.4	38	0.36	0.6	39

Fig. 6.41 Derived profile of Calcic Kastanozems

(Falsone and Bonifacio 2006). Bulk density of fragipan was not found to be related to a particular clay mineral content, as well as formation of tongues in fragipan did not cause any significant difference in clay mineral composition between bleached and stained parts of the horizons (Costantini and Damiani 2004).

6.5.11 Gleysols

Groundwater-affected soils are concentrated in the Po plain, in internal basins, and along some coasts of southern Italy (Fig. 6.66). The occurrence of Gleysols has been documented in some 10,378 km^2. Many Italian Gleysols are located in areas that were periodically or permanently

Fig. 6.42 Location of the elaborated profiles of Calcic Kastanozems

Fig. 6.43 Typical landscape (Basilicata) and profile of a Calcic Chernozem (Basilicata, photos Fabrizio Cassi)

Calcic Chernozems

Soil Taxonomy
Typic Calcixerolls

Main geologies
limestone; mixed alluvial, lacustrine or fluvial sediments; marine clay sediments.

Main morphologies
small alluvial fans, linear slope, slope dissected by small valleys.

Main land uses
row crops, heterogeneous croplands, vineyards.

FUNCTIONAL HORIZONS

description	lower depth (cm)	SD	N
Ap, A	42	21	112
Bw	84	26	24
Bk, Bkm	101	36	61
Ck, Ckm	130	36	78

Total number of observations: 71

Site description: mean and standard deviation, mode and frequency, and number of sites considered.

	mean	SD	N
Elevation (m a.s.l.)			
medium hills (200-400)	259	173	71
Slope (%)			
gently sloping (6-13)	8	13	71
Stones (%)			
frequent (4-15)	10	18	60
Rocks (%)			
absent	0	0	51
Rock depth (cm)			
deep (100-150)	136	41	8
Potential rooting depth (cm)			
deep (100-150)	106	44	70
Water table upper limit (cm)			
deep (100-150)	143	25	2
Available water capacity (mm m^{-1})			
moderate (100-150)	134	55	69
Soil moisture regime and aridity index (dry d y^{-1})			
dry-xeric (>115)	124	16	69
Soil temperature regime and value (°C at 50 cm)			
thermic (15-22)	17	1	58

	mean	SD	N
Crusting risk			
moderate (0.41 - 0.60)	0.59	0.1	60
Compaction risk			
high (1.71 - 1.80)	1.76	0.1	60
Internal drainage			
somewhat excessively to well drained	2.8	1	70
Surface runoff		**n**	**N**
very low		18	66
Hydrologic group			
slow infiltration (C)		28	53
Root restriction			
compaction or paralithic contact		48	69
Purifying capacity			
very high		18	46

Analyses: Mean, standard deviation and number of samples

Low. depth (cm)	Tex. Cl.	Sand (dag kg^{-1}) mean	Sand SD	Clay mean	Clay SD	N	Coarse fragments (dm^2 m^{-2}) mean	SD	N	Bulk Density (g cm^{-3}) mean	SD	N	Permeability (µm s^{-1}) mean	SD	N	COLE (m m^{-1}) mean	SD	N
42	CL	26.6	16.6	35.2	9.9	97	8	11.5	94	1.3	0.2	22	26.53	37.8	96	0.07	0.02	20
84	CL	22.7	17.2	40.0	14.7	21	6	13.2	24	1.3	0.0	4	18.28	36.3	21	0.09	0.03	6
101	CL	22.7	14.5	36.3	9.7	52	7	14.4	53	1.3	0.1	3	24.48	35.0	54	0.07	0.02	10
130	CL	27.3	19.1	33.1	13.0	46	9	21.8	69	1.3	0.0	2	19.00	42.9	64	0.09	0.03	8

Low. depth (cm)	pH (1:2.5 H_2O) mean	SD	N	Organic Carbon (dag kg^{-1}) mean	SD	N	CEC (cmol(+) kg^{-1}) mean	SD	N	Base saturation (%) mean	SD	N	ESP (%) mean	SD	N	$CaCO_3$ total (dag kg^{-1}) mean	SD	N	$CaCO_3$ active mean	SD	N	Salinity (1:2.5 dS m^{-1}) mean	SD	N
42	8.1	0.2	97	1.29	0.45	96	22.5	8.9	78	100	0.0	75	3.1	3.2	75	19.9	15.5	97	6.8	4.7	88	0.32	0.4	91
84	8.0	0.4	21	0.99	0.34	21	26.6	10.2	17	100	0.0	17	6.1	8.5	17	13.4	11.5	21	5.5	3.1	16	0.52	1.0	21
101	8.2	0.3	52	0.62	0.37	52	19.3	8.1	39	100	0.0	39	4.3	4.1	39	29.5	13.9	52	9.1	4.2	51	0.40	0.7	46
130	8.3	0.2	46	0.25	0.14	37	20.3	9.4	29	100	0.0	31	4.8	7.0	28	33.9	18.0	46	8.7	5.0	33	0.82	1.4	38

Fig. 6.44 Derived profile of Calcic Chernozems

inundated, before the reclamation works carried out in the last centuries (see Chap. 9). The depth of the groundwater table is still controlled by artificial drainage in many of the reclaimed areas. Being fundamentally controlled by the groundwater presence and dynamic, Gleysols distribution is only marginally influenced by climatic variables (Table 6.15) (Figs. 6.67, 6.68, 6.69).

Many Gleysols share the same lowland environment of Histosols, with which are geographically related (Fig. 6.70). Many Mollic, Histic, and Thaptohistic Gleysols, in particular, are just degradation forms of Histosols (mainly Sapric Histosols) caused by the reclamation activities, in particular, drainage, addition of mineral material, and repeated ploughing, which mineralized the most elaborated parts of the organic matter. The representative profile of Italian Gleysols was obtained from 36 Mollic Gleysols, mainly placed in the Po plain. The taxon shows the consequences of reclamation on soils of environments that were frequently

Fig. 6.45 Location of the elaborated profiles of Calcic Chernozem

submerged in the past. The witnesses are, in particular, the presence of a mollic topsoil, in lands that are generally rather poor in organic matter content (Ungaro et al. 2005), and of a buried A horizon, rich in organic matter and with low bulk density, which calls for the probable presence of a former histic horizon.

Gleysols pose severe constraints to many cultivation and have specific crop suitability; however, they are very ecologically relevant, as they provide for many services, in particular, they regulate groundwater quality and host biological endemisms.

Groundwater nitrate contamination risk assessment, in particular, is a rising concern that has been faced through the introduction of several regulations. The methodologies used in the definition of Nitrate Vulnerable Zones were the study object of many authors (see among others, Sacco et al. 2007). Water table dynamic was also studied, and its relationship with contamination and irrigations needs. To that respect, Calzolari and Ungaro (2012) found a clear trend in water table lowering over a 12 year period (1997 to 2008), with an average rate of 4.5 cm per year. The negative trend was found driven by the reduced precipitation amounts,

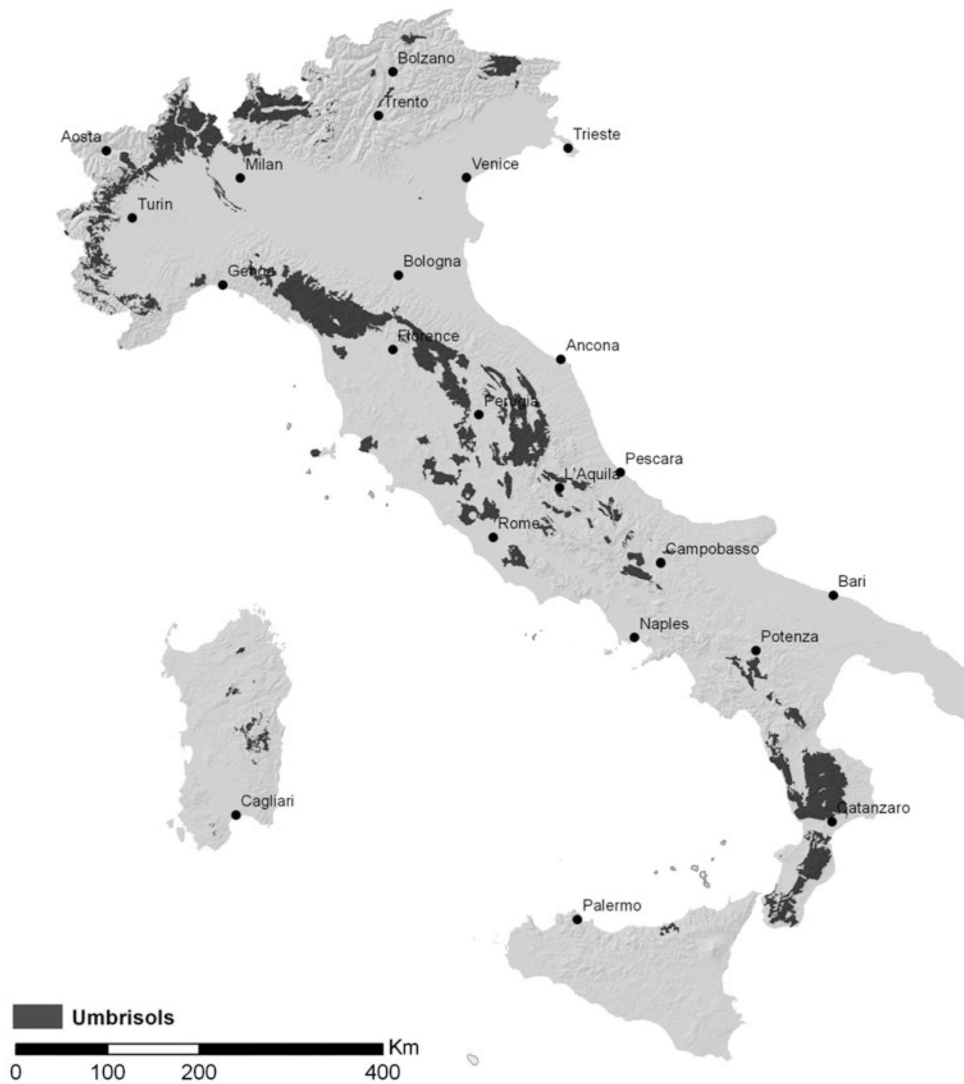


Fig. 6.46 Geographic distribution of Umbrisols (*density of profiles* 1.19 per 100 km^2)

Fig. 6.47 Cambic Umbrisols (Humic) on the weathered granite of the Sila Mountain (Calabria)

Table 6.10 Average long-term climatic data of Cambic Umbrisols (Humic)

Variable	Unit	Average	Standard deviation	Number of data
Mean annual temperature	(°C)	10.9	2.12	50
Potential evapotranspiration	(mm)	1,000	85.6	50
Total annual rainfall	(mm)	1,053	240	50
Aridity index	–	1.07	0.31	50
Climatic aggressivity (F FAO)	–	96.2	17.3	50
Continentality	(°C)	14.9	0.5	50
Seasonality index	(mm %)	11.5	0.03	50

which were between 2004 and 2008 constantly below long-time averages.

The dynamic of groundwater was put in relationship with seasonal changes in soil porosity by Pagliai et al. (1989). They demonstrated that total porosity is significantly higher when the level of the water table is lower. Changes in pore shape and size distribution were also observed. The proportion of large elongated pores (50–500 μm) was higher where the level of the water table was deeper. Consequently, the shallow water table seemed to deteriorate the soil structure, reducing the porosity to a level inadequate for plant development.

The study of endemisms in wet areas has also been object of several investigations. Among others works, it is worthy mention that of Antonellini and Mollema (2010), who demonstrated that species richness in a Pine forest of coastal Po plain was promoted by shallow water table and low salinity. The current trend towards water table lowering and increase salinization is then deemed to lead to an impoverishment of biodiversity in costal areas (Capotorti et al. 2011) (Table 6.15).

6.5.12 Histosols

The geographic distribution of soils with thick organic layers is nowadays restricted to about 3,005 km^2. Actually, native Histosols have been object of large reclamation works for their conversion in intensively cultivated croplands, which mineralized or mixed with mineral sediments much of the original organic matter. Even in the areas where Histosols are still present, their occurrence is limited to patches among the outcrops of other taxa, like Gleysols and Fluvisols. The vanishing of Italian Histosols is connected to that of wetlands, so it has been the object of some concern and of specific studies.

In the coastal basin of Venice, in particular, where overall land subsidence over the last 70 years ranges between 1.5–2 m and is still in progress at a rate of 1.5–2 cm y^1 (Carbognin et al. 2006), peat oxidation is a big concern as it increases subsidence (Fornasiero et al. 2003), CO_2 efflux (Camporese et al. 2008) and causes soil shrinkage by variation of porosity with moisture content (Camporese et al. 2006). Currently, a large fraction of the reclaimed land lies below the mean sea level, down to − 4 m locally, and saltwater intrusion may extend inshore up to 20 km away from the Adriatic coastline (Gambolati et al. 2005).

Yet Histosols are not only present in Italian lowlands, but some remains are still present in small basins and dried up lakes of the Alps and Apennines, where they assume great pedological heritage value (Zilioli et al. 2011).

Sapric Histosols are the most represented Histosols in the national soil database. These Histosols characterize remnants of old wetlands in major flood plains, for example, the Po plain, internal basins of the Apennines, and lowlands in coastal areas. The characteristics of the derived profile of 9 sites are reported in Fig. 6.72. The most striking property is the amount of organic carbon stocked in the profile, which is 38.30 kg m^2 in the first horizon, but reaches an amazing value of 110.98 kg m^2 in the first meter (Table 6.16) (Figs. 6.71, 6.73).

6.5.13 Rare Soils

The endemic nature of many taxa and the still incomplete knowledge about pedodiversity of Italy give reason to the presence in the national soil database of a relatively large amount of rare soils, that is, soil profiles which belong to a unique taxon, not found elsewhere in the country. Many rare soils possess a “cultural value” and can be considered

Cambic Umbrisols (Humic)

Soil Taxonomy
Typic Haplumbrepts

Main geologies
alternating pelitic-arenitic, arenitic-marly and arenitic-pelitic rocks; intrusive not calcareous massive rocks; shale metamorphic rocks.

Main morphologies
linear slope, slope dissected by small valleys, debris.

Main land uses
permanent grassland, grassland-pasture and pastures, coniferous and mixed woodlands.

FUNCTIONAL HORIZONS

description	lower depth (cm)	SD	N
O	3	1	14
A, Ap	30	17	85
Bw	74	27	63
C, BC	109	42	35
Cr	127	50	15

Total number of observations: 52

Site description: mean and standard deviation, mode and frequency, and number of sites considered.

	mean	SD	N
Elevation (m a.s.l.)			
low mountains (600-1500)	1004	390	52
Slope (%)			
moderately steep (20-35)	21	18	52
Stones (%)			
frequent (4-15)	6	24	38
Rocks (%)			
common (2-10)	3	6	28
Rock depth (cm)			
deep (100-150)	106	35	8
Potential rooting depth (cm)			
deep (100-150)	128	55	43
Water table depth (cm)			
absent			0
Available water capacity (cm m^{-1})			
moderate (100-150)	120	35	40
Soil moisture regime and aridity index (dry d y^{-1})			
udic (<65)	42	17	46
Soil temperature regime and value (°C at 50 cm)			
mesic (8-15)	9	1	35

	mean	SD	N
Crusting risk			
low (<= 0.40)	0.36	0.1	19
Compaction risk			
very low (<= 1.50)	1.48	0.1	19
Internal drainage			
somewhat excessively to well drained	2.8	0	29
Surface runoff		n	N
medium		8	20
Hydrologic group			
high infiltration (A)		15	38
Root restriction			
compaction or paralithic contact		19	43
Purifying capacity			
moderate		6	11

Analyses: Mean, standard deviation and number of samples

Low. depth (cm)	Tex. Cl.	Sand (dag kg^{-1}) mean	Sand SD	Clay mean	Clay SD	N	Coarse fragments (dm^2 m^{-2}) mean	SD	N	Bulk Density (g cm^{-3}) mean	SD	N	Permeability (µm s^{-1}) mean	SD	N
3						0	0	1.3	12			0	54.6	43.9	9
30	L	46.0	22.0	18.2	12.8	61	5	7.1	39	1.1	0.3	8	43.6	47.7	59
74	L	46.4	22.4	21.4	16.8	47	10	12.1	27	1.1	0.1	8	25.7	31.3	47
109	LS	59.8	24.3	14.9	13.5	17	20	29.1	17			0	46.6	61.1	19
127	LS	54.0	17.4	12.6	1.5	2	28	35.9	8			0	1.3	1.9	13

Low. depth (cm)	pH (1:2.5 H_2O) mean	SD	N	Organic Carbon (dag kg^{-1}) mean	SD	N	CEC (cmol(+) kg^{-1}) mean	SD	N	Base saturation (%) mean	SD	N	ESP (%) mean	SD	N	$CaCO_3$ total (dag kg^{-1}) mean	SD	N	$CaCO_3$ active mean	SD	N	Salinity (1:2.5 dS m^{-1}) mean	SD	N
3	3.5		1	37.20		1			0			0			0	0.0		1			0			0
30	5.4	0.5	60	4.14	2.07	61	21.1	9.1	29	24	16.0	26	2.4	2.8	18	0.0	0.0	33	0.0	0.0	9	0.06	0.03	8
74	5.5	0.6	47	1.41	1.63	48	17.4	8.1	22	28	18.3	21	2.6	2.3	12	0.0	0.0	27	0.0	0.0	7	0.04	0.01	5
109	5.7	0.8	16	0.58	0.50	17	9.3	2.2	3	40	28.2	3	9.3	11.4	2	0.0	0.0	9	0.0	0.0	2	0.06		1
127	5.6	0.4	2	0.69	0.17	2	9.1		1			0			0	0.0		1	0.0		1	0.02		1

Fig. 6.48 Derived profile of Cambic Umbrisols (Humic)

Fig. 6.49 Location of the elaborated profiles of Cambic Umbrisols (Humic)

to all effects and purposes, including legal aspects, having "cultural and/or natural heritage" (Costantini and L'Abate 2009). Soils with cultural heritage are important for science and teaching, for tourism and recreation, provide valuable insights into past environmental conditions and agricultural practices, and enhance the awareness of population towards the value of the land where they live.

As reported in Fig. 6.74, the occurrence of rare soils is widespread all over Italy. Among the 45 rare soils, there are many palaeosols, like Ferric Acrisols, Plinthic Alisols, Haplic Cambisols over Luvic Nitisols (Rhodic), some Lixisols, Planosols, and Plithosols, which testify very long pedogenesis and the effects of no more active processes, related to former environments during past geological eras (Costantini and Priori, 2007). On the other hand, very young soils like Anthrosols and Technosols are also rare, but in this case because of the scantiness of investigation on these recently created taxa. Actually, few studies have been car-

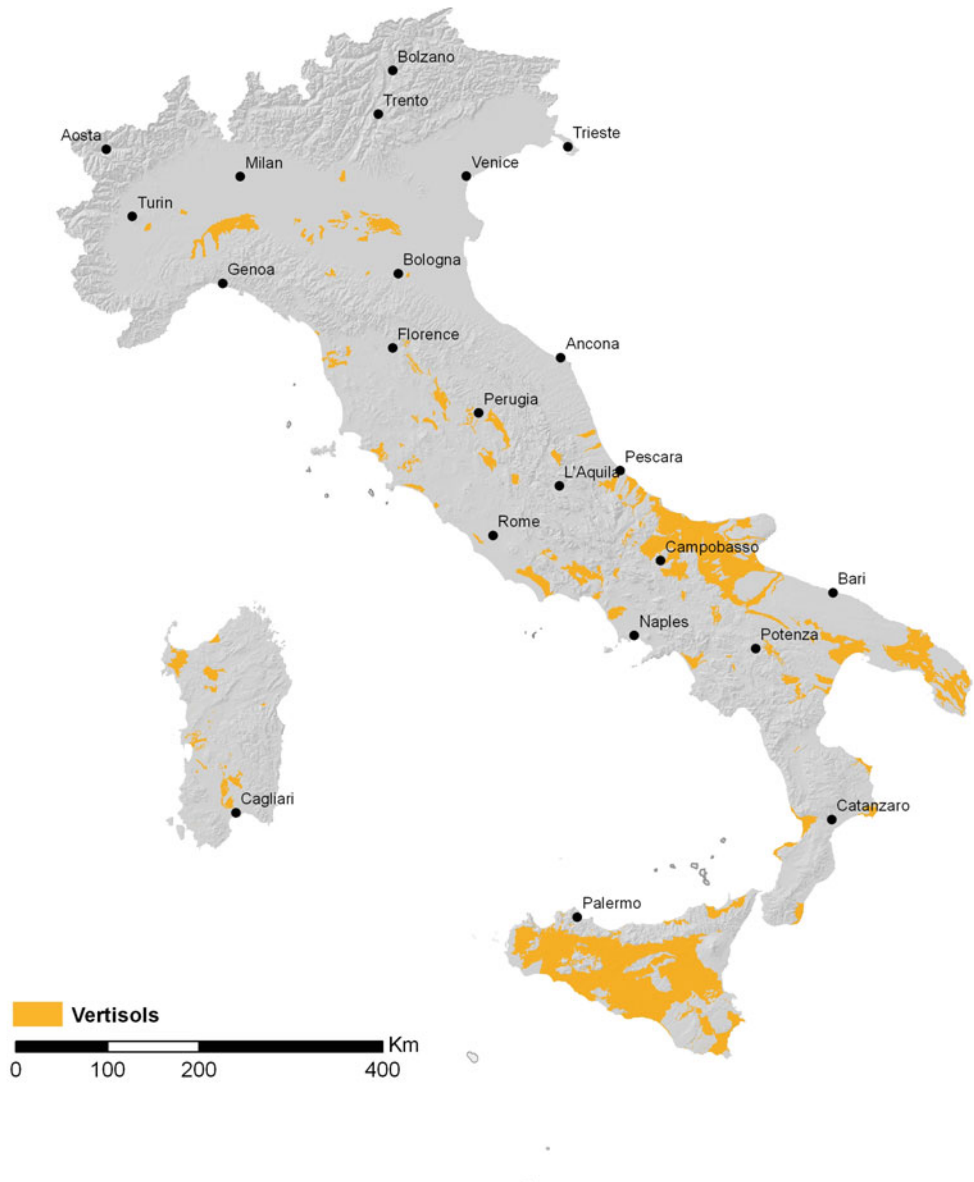


Fig. 6.50 Geographic distribution of Vertisols (*density of profiles* 4.31 per 100 km^2)

ried out on soils of mine spoils, that is, Spolic Technosols (Bini and Gaballo 2006), brownfields, and industrial disposals (Buondonno et al. 1998). Geomiscic Anthrosols, in particular, were proposed to classify soils with a layer made up of different kinds of earthy materials, added to the surface and subsequently deeply mixed into the underlying soil using heavy machinery (Dazzi and Monteleone 2007; Dazzi et al. 2009).

Fragic Albeluvisols (Anthraquic) of Piedmont are a peculiar example of palaeosols showing a recent anthropic process. The genesis of this taxon is polycyclical: on the original Fragic Albeluvisols, formed during Pleistocene, an Anthraquic horizon has been superimposed, as a consequence of prolonged rice cultivation. The taxon is not reported in Europe, but it is present in China (European Soil Bureau 1999; Panagos et al. 2012).

Fig. 6.51 Landscape and profile of a Vertic soil (Sicily) under "drunk" forest of Eucalyptus

Table 6.11 Average long-term climatic data of Haplic Vertisols (Calcaric) and Calcic Vertisols, and mean values for all Vertisols

	Soil typology			
Variable		Calcic Vertisols	Haplic Vertisols (Calcaric)	Total
Latitude (decimal degree)	Mean	41.0	41.4	41.2
	n	493	359	852
Soil Aridity index (days)	Mean	100.9	90.9	96.3
	n	231	198	429
Mean annual soil temperature (°C)	Mean	16.3	16.0	16.2
	n	222	179	401
Mean annual air temperature (°C)	Mean	15.5	15.3	15.4
	n	493	359	852
Potential evapotranspiration (mm)	Mean	1,140	1,120	1,131
	n	493	359	852
Total annual rainfall (mm)	Mean	638	665	650
	n	493	359	852
Aridity index	Mean	0.57	0.61	0,58
	n	493	359	852
Seasonality	Mean	9.8	9.4	9.7
	n	493	359	852

Other rare taxa, formed as a consequence of human activities, are Thaptohistic Fluvisols, in particular, Thaptohistic Fluvisols (Thionic, Humic), which testify the activity of reclamation in a former wetlands of coastal Tuscany, and Endogleyic Terric Anthrosols (Calcaric) of the Venice lagoon, currently not foreseen in the WRB classification system (IUSS/ISRIC/FAO 2006). Another unique taxon is Densic Podzols, that is, Podzols showing natural or artificial compaction in the first 50 cm, which seems to be rare also at the world level. Other taxa showing pedogenesis rare in Europe are Brunic Rubic Arenosols, Sapric Histosols (Protothionic), Haplic Regosols (Alumic), and Duric Luvisols.

Then there are some pedogenesis which are actually rare at the country level, but widespread elsewhere in Europe, like Aridic Arenosols, which are rare in Italy but more largely present in Spain, or Gleyic Umbrisols, extensive in Russia. Similarly, there are only a few of Solonetzs in Italy; therefore, it is not surprising that some of their sub-classes are also rare. Gypsisols instead are also particular, but in the sense that they have been documented only in some areas of Sicily.

Finally, there are some taxa that are probably rather common, but currently poorly studied or documented, in particular, Escalic Cambisols, that is, soils of the human-made terraces, Gypsiric, Salic and Mazic Vertisols, currently only found in Sicily, and Glacic Cryosols, reported only in northwestern Italy, but probably rife on the Alps and Appennines (Freppaz et al. 2009).

Haplic Vertisols (Calcaric)

Soil Taxonomy
Typic Haploxererts

Main geologies
mixed alluvial, lacustrine or fluvial sediments; alluvial, lacustrine or fluvial sandy-gravel; alternating pelitic-arenitic, arenitic-marly and arenitic-pelitic rocks.

Main morphologies
fluvial terrace in plain, flood plain, linear slope.

Main land uses
row crops, heterogeneous croplands, permanent grassland, grassland-pasture and pastures.

FUNCTIONAL HORIZONS

description	lower depth (cm)	SD	N
Ap, A	47	24	485
Bw, Bss	104	31	379
Bssk, Bssg	116	34	47
C, Cg, Ck	140	41	215

Total number of observations: 362

Site description: mean and standard deviation, mode and frequency, and number of sites considered.

	mean	SD	N
Elevation (m a.s.l.)			
low hills (0-200)	195	222	360
Slope (%)			
gently sloping (6-13)	5	10	362
Stones (%)			
common (2-3)	2	3	311
Rocks (%)			
	0	0	101
Rock depth (cm)			
deep (100-150)	145	7	2
Potential rooting depth (cm)			
deep (100-150)	115	53	259
Water table depth (cm)			
deep (100-150)	143	67	15
Available water capacity (mm m^{-1})			
moderate (100-150)	146	57	201
Soil moisture regime and aridity index (dry d y^{-1})			
xeric (80-115)	91	23	199
Soil temperature regime and value (°C at 50 cm)			
thermic (15-22)	16	2	180

	mean	SD	N
Crusting risk			
high (> 0.60)	0.63	0.1	158
Compaction risk			
high (1.71 - 1.80)	1.78	0.1	158
Internal drainage			
moderately well to somewhat poorly drained	4.2	1	251

	n	N
Surface runoff		
medium	106	204
Hydrologic group		
very slow infiltration (D)	91	150
Root restriction		
shrinkage-expansion movements	79	164
Purifying capacity		
very high	70	120

Analyses: Mean, standard deviation and number of samples

Low. depth (cm)	Tex. Cl.	Sand (dag kg^{-1}) mean	Sand SD	Clay (dag kg^{-1}) mean	Clay SD	N	Coarse fragments (dm^2 m^{-2}) mean	SD	N	Bulk Density (g cm^{-3}) mean	SD	N	Permeability (µm s^{-1}) mean	SD	N	COLE (m m^{-1}) mean	SD	N
47	C	16.1	12.7	47.8	11.9	244	1	4.4	385	1.3	0.2	28	14.9	26.5	175	0.10	0.01	6
104	C	15.0	12.3	49.1	12.3	221	2	6.6	299	1.3	0.2	20	3.9	17.2	216	0.09	0.01	10
116	C	13.2	10.8	50.5	9.4	41	1	2.1	40	1.4	0.2	3	1.5	2.2	38			0
140	C	17.3	18.7	44.6	15.1	103	2	10.0	189	1.5	0.2	11	9.1	30.5	141	0.09	0.01	4

Low. depth (cm)	pH (1:2.5 H_2O) mean	SD	N	Organic Carbon (dag kg^{-1}) mean	SD	N	CEC (cmol(+) kg^{-1}) mean	SD	N	Base saturation (%) mean	SD	N	ESP (%) mean	SD	N	$CaCO_3$ total (dag kg^{-1}) mean	SD	N	$CaCO_3$ active mean	SD	N	Salinity (1:2.5 dS m^{-1}) mean	SD	N
47	8.0	0.5	245	1.16	0.62	240	29.0	10.5	185	95	16.1	161	2.0	2.9	157	12.5	11.3	212	6.3	5.0	96	0.29	0.3	51
104	8.2	0.4	220	0.76	0.72	213	28.0	10.6	197	96	13.8	162	4.3	6.0	164	14.1	11.5	194	6.7	4.8	114	0.45	0.5	63
116	8.3	0.4	39	0.65	0.46	41	27.6	8.0	26	97	9.5	19	3.1	3.2	20	13.8	12.7	36	7.8	3.9	16	0.37	0.2	18
140	8.3	0.4	104	0.46	0.48	99	23.6	11.4	82	97	13.7	63	5.4	7.7	58	18.3	14.5	98	8.4	5.3	36	0.54	0.4	16

Fig. 6.52 Derived profile of Haplic Vertisols (Calcaric)

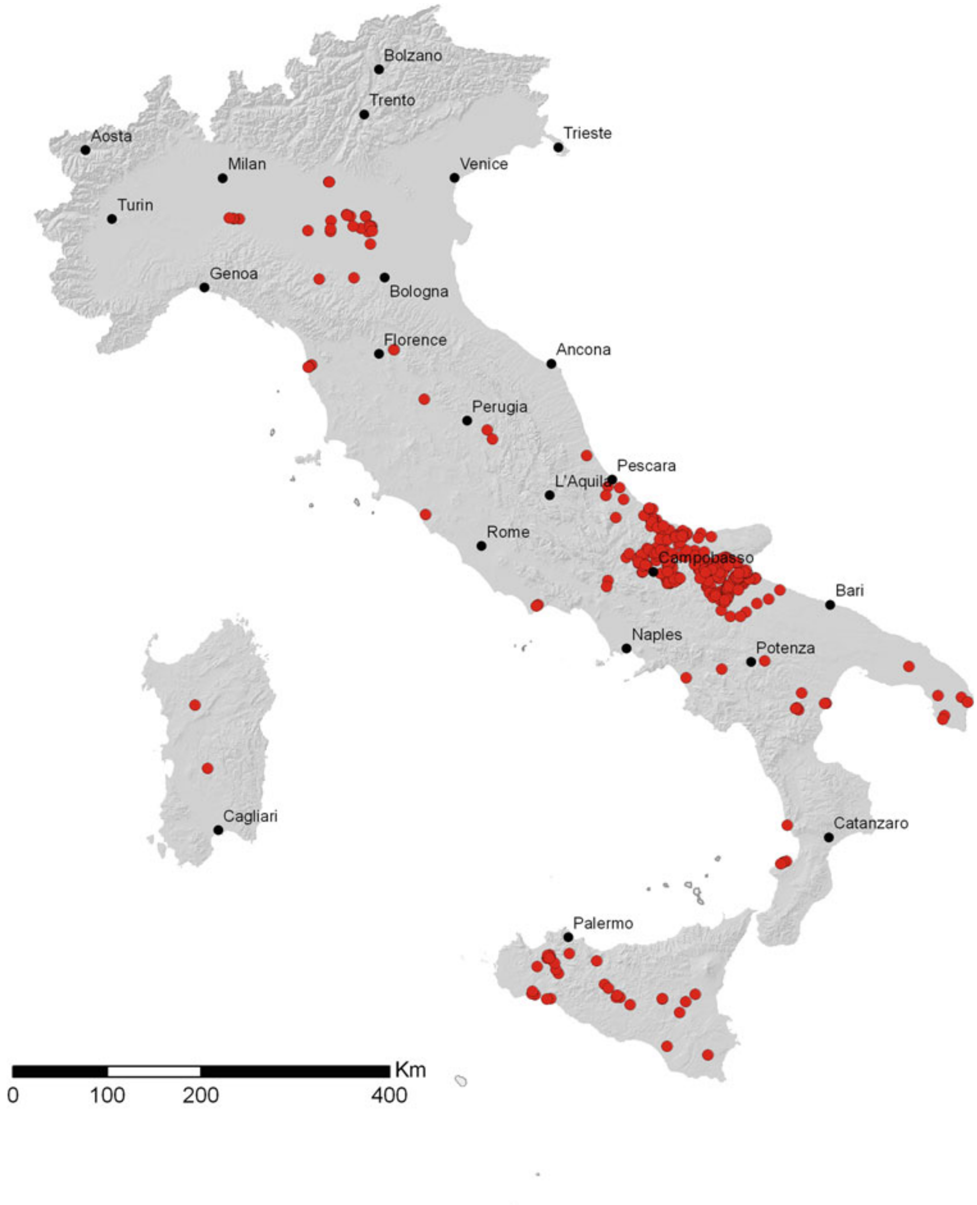


Fig. 6.53 Location of the elaborated profiles of Haplic Vertisols (Calcaric)

Fig. 6.54 Geographic distribution of Andosols (*density of profiles* 16.74 per 100 km^2)

Table 6.12 Average long-term climatic data of Vitric Andosols

Variable	Unit	Average	Standard deviation	Number of data
Mean annual temperature	(°C)	14.7	1.70	382
Potential evapotranspiration	(mm)	1,148	78.3	349
Total annual rainfall	(mm)	897	142	384
Aridity index	–	0.80	0.14	349
Climatic aggressivity (F FAO)	–	102.4	16.4	384
Continentality	(°C)	14.1	0.28	384
Seasonality index	(mm %)	15.6	0.02	384

Fig. 6.55 Typical landscape and profile of Vitric Andosols (Campania)

Vitric Andosols

Soil Taxonomy
Mollic Vitrixerands

Main geologies
extrusive igneous and volcaniclastic rocks; mixed alluvial, lacustrine or fluvial sediments; limestone.

Main morphologies
terraced slope, lava flow, slope dissected by small valleys.

Main land uses
broadleaved woodlands, fruit trees, heterogeneous croplands.

FUNCTIONAL HORIZONS

description	lower depth (cm)	SD	N
Oi, Oa	3	4	5
A, Ap	39	24	690
Bw, BC	84	45	227
C, AC	112	43	325

Total number of observations: 384

Site description: mean and standard deviation, mode and frequency, and number of sites considered.

	mean	SD	N
Elevation (m a.s.l.)			
height hills (400-600)	554	314	384
Slope (%)			
strongly sloping (13-20)	17	30	384
Stones (%)			
frequent (4-15)	10	14	341
Rocks (%)			
common (2-10)	3	9	336
Rock depth (cm)			
moderately deep (50-100)	62	37	74
Potential rooting depth (cm)			
deep (100-150)	131	68	313
Water table upper limit (cm)			
deep (100-150)	123	121	3
Available water capacity (mm m^{-1})			
low (50-100)	78	39	301
Soil moisture regime and aridity index (dry d y^{-1})			
xeric (80-115)	88	20	302
Soil temperature regime and value (°C at 50 cm)			
mesic (8-15)	13	1	210

	mean	SD	N
Crusting risk			
moderate (0.41 - 0.60)	0.48	0.2	248
Compaction risk			
very low (<= 1.50)	1.47	0.3	250
Internal drainage			
somewhat excessively to well drained	2.1	1	279
Surface runoff		**n**	**N**
negligible		32	99
Hydrologic group			
high infiltration (A)		192	254
Root restriction			
no restrictions and no impediments		143	311
Purifying capacity			
moderate		61	202

Analyses: Mean, standard deviation and number of samples

Low. depth (cm)	Tex. Cl.	Sand (dag kg^{-1}) mean	Sand SD	Clay mean	Clay SD	N	Coarse fragments (dm^2 m^{-2}) mean	SD	N	Bulk Density (g cm^{-3}) mean	SD	N	Permeability (µm s^{-1}) mean	SD	N	COLE (m m^{-1}) mean	SD	N
3						0	2	4.1	6	1.0		1	42.6	24.8	4			0
39	LS	71.6	19.6	7.7	7.6	491	18	18.9	543	1.1	0.3	66	96.2	58.3	183	0.06	0.01	11
84	LS	57.6	25.0	12.9	14.6	81	14	20.3	102	1.2	0.3	20	74.1	61.3	57	0.09	0.01	7
112	SL	76.7	19.0	5.3	6.2	111	38	31.3	281	1.2	0.3	9	75.8	65.6	45			0

Low. depth (cm)	pH (1:2.5 H_2O) mean	SD	N	Organic Carbon (dag kg^{-1}) mean	SD	N	CEC (cmol(+) kg^{-1}) mean	SD	N	Base saturation (%) mean	SD	N	ESP (%) mean	SD	N	$CaCO_3$ total (dag kg^{-1}) mean	SD	N	$CaCO_3$ active mean	SD	N	Salinity (1:2.5 dS m^{-1}) mean	SD	N
3	6.4		1	2.83		1	26.3		1			0			0	0.0		1			0	0.45		1
39	6.9	0.5	480	2.56	1.93	471	23.0	10.7	422	60	20.2	399	1.9	2.5	393	0.3	1.7	421	0.0	0.0	23	0.10	0.1	387
84	7.0	0.8	80	1.17	1.19	72	22.0	11.9	45	84	26.5	44	5.7	6.2	39	1.0	2.7	53	0.0	0.0	17	0.19	0.2	34
112	7.0	0.5	109	1.38	1.36	103	18.2	10.8	97	58	21.1	93	2.7	3.4	92	0.6	5.7	94	0.0	0.0	5	0.07	0.1	88

Low. depth (cm)	oxalate extractable Fe (g/kg)	Al (g/kg)	Al+0.5Fe (g/kg)	Si (g/kg)	glas (%)	pH NaF	P (g/kg)	P ads. (%)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)
39	10.0	8.6	13.7	5.5	58.7	9.1	13.8	5.8	60.8	0.4	3.8	2.6
84	6.2	9.7	12.8	6.8	63.9	9.4	10.0	16.3	101.4	0.8	5.4	2.4
112	10.2	8.3	13.4	5.9		9.7	15.0	1.4				

Fig. 6.56 Derived profile of Vitric Andosols

Fig. 6.57 Location of the elaborated profiles of Vitric Andosols

Fig. 6.58 Geographic distribution of Podzols (*density of profiles* 1.25 per 100 km^2)

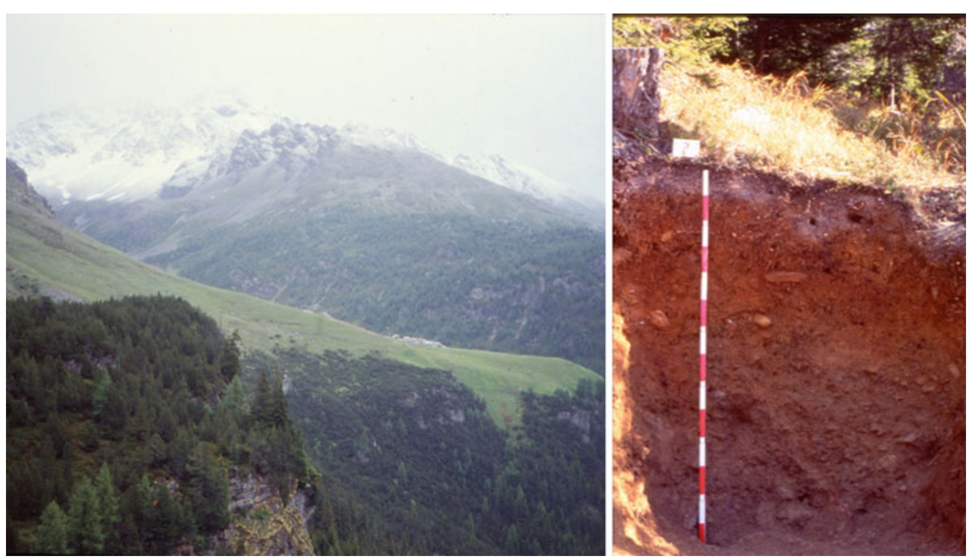


Fig. 6.59 Typical landscape and profile of Podzols (Lombardy)

Haplic Podzols

Soil Taxonomy
Typic Haplorthods

Main geologies
glacial deposits; shale metamorphic rocks; alternating pelitic-arenitic, arenitic-marly and arenitic-pelitic rocks.

Main morphologies
fluvial-glacial accumulation landforms.

Main land uses
coniferous woodlands.

FUNCTIONAL HORIZONS

description	lower depth (cm)	SD	N
O, Oe, Oi	6	6	21
A	15	14	9
E	21	13	13
Bs, Bhs	36	17	28
C	79	19	12

Total number of observations: 13

Site description: mean and standard deviation, mode and frequency, and number of sites considered.

Elevation (m a.s.l.)	mean	SD	N
height mountains (>1500)	1590	183	13
Slope (%)			
steep (36-60)	44	18	13
Stones (%)			
abundant (16-50)	24	58	11
Rocks (%)			
common (2-10)	4	11	11
Rock depth (cm)			
			0
Potential rooting depth (cm)			
deep (100-150)	126	81	10
Water table upper limit (cm)			
absent			0
Available water capacity (mm m^{-1})			
low (50-100)	67	37	9
Soil moisture regime and aridity index (dry d y^{-1})			
udic (<65)	30	15	9
Soil temperature regime and value (°C at 50 cm)			
frigid (<8)	4	2	9

Crusting risk	mean	SD	N
low (<= 0.40)	0.00	0.0	2
Compaction risk			
very low (<= 1.50)	0.00	0.0	2
Internal drainage			
somewhat excessively to well drained	2.9	0	7
Surface runoff		n	N
high		3	6
Hydrologic group			
moderate infiltration (B)		7	9
Root restriction			
no restrictions and no impediments		5	10
Purifying capacity			
very low		6	7

Analyses: Mean, standard deviation and number of samples

Low. depth (cm)	Tex. Cl.	Sand (dag kg^{-1}) mean	SD	Clay mean	SD	N	Coarse fragments (dm^2 m^{-2}) mean	SD	N	Bulk Density (g cm^{-3}) mean	SD	N	Permeability (μm s^{-1}) mean	SD	N
6						0	0	1.2	16			0	41.9	24.2	8
15	SIL	33.0	21.2	12.0	2.8	2	5	5.0	4			0	25.3	27.1	5
21	L	49.9	16.4	11.8	8.1	7	13	9.6	4			0	55.1	43.2	9
36	LS	56.0	13.4	8.9	5.3	13	23	18.7	11			0	72.5	58.7	17
79	LS	66.6	8.1	7.5	3.3	6	61	24.4	4			0	68.7	63.4	7

Low. depth (cm)	pH (1:2.5 H_2O) mean	SD	N	Organic Carbon (dag kg^{-1}) mean	SD	N	CEC (cmol(+) kg^{-1}) mean	SD	N	Base saturation (%) mean	SD	N	ESP (%) mean	SD	N	$CaCO_3$ mean	SD	N	total (dag kg^{-1}) mean	SD	N
6	3.7	0.4	7	30.81	6.95	7	30.1	7.8	3	50	24.7	3	0.5	0.1	3	0.0	0.0	5			0
15	4.1	0.5	4	11.40	7.70	5	22.1	4.1	4	37	22.3	4	0.5	0.0	3	0.0	0.0	4			0
21	4.1	0.4	9	3.96	1.96	10	19.4	7.4	8	16	10.5	8	0.6	0.2	8	0.0	0.0	7			0
36	4.8	0.4	22	3.49	2.53	23	10.0	9.3	20	40	28.5	20	2.3	3.0	19	0.0	0.0	18			0
79	5.2	0.3	8	0.79	0.71	9	3.7	3.3	7	60	35.4	7	3.6	2.7	6	0.0	0.0	7			0

Low. depth (cm)	Extractable Fe oxalate	pyr.	total (g kg^{-1})	pyr. - ox.	Extractable Al oxalate (g kg^{-1})	total	Al+0.5Fe oxalate (g kg^{-1})
6	5.3		8.9		2.4	17.3	5.0
15	6.8		20.5		3.6	20.0	7.0
21	4.7	4.6	19.1	-0.2	3.0	19.7	5.4
36	8.8	17.4	33.8	8.6	6.8	23.8	11.2
79	2.8	2.6	33.7	-0.2	2.7	24.0	4.2

Fig. 6.60 Derived profile of Haplic Podzols

Fig. 6.61 Location of the elaborated profiles of Haplic Podzols

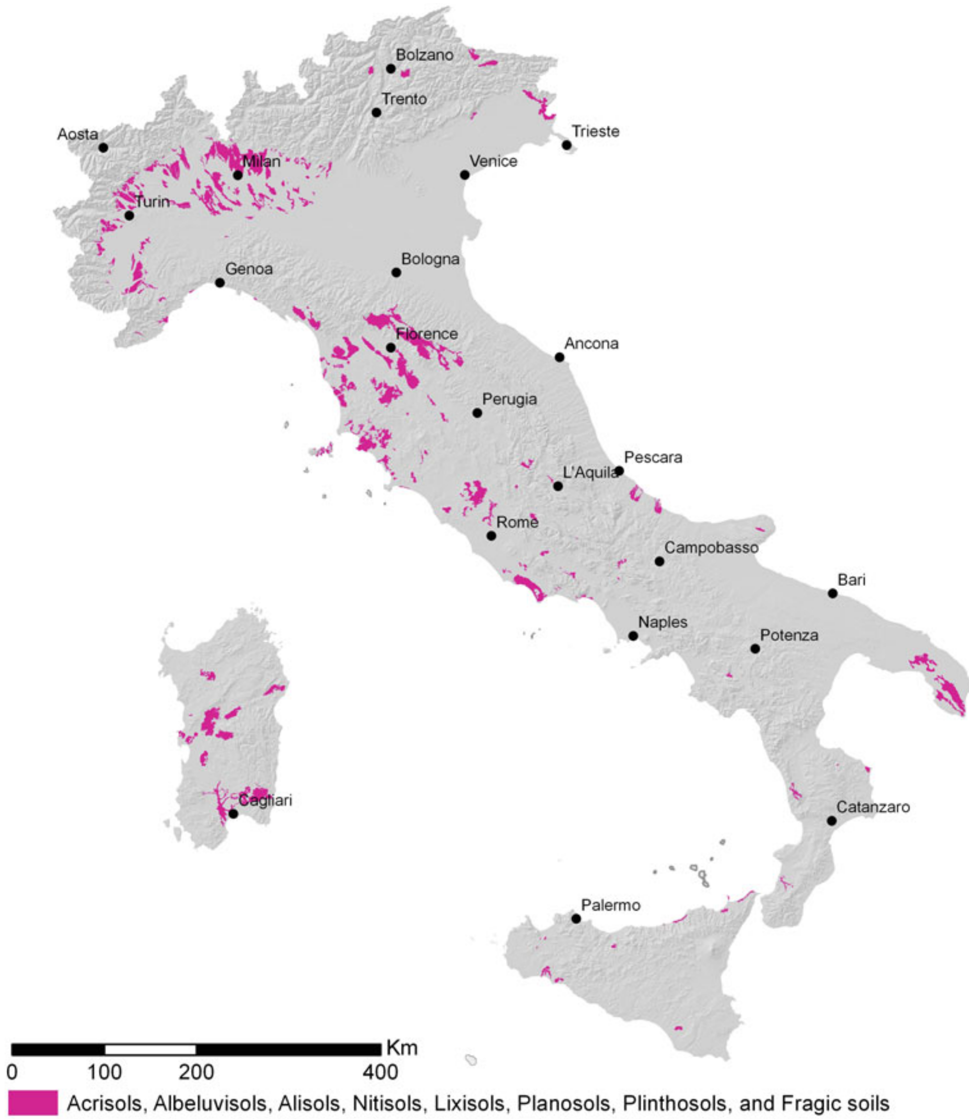


Table 6.13 Average long-term climatic data of Haplic Podzols

Variable	Unit	Average	Standard deviation	Number of data
Mean annual temperature	(°C)	5.4	1.92	13
Potential evapotranspiration	(mm)	762	54.5	13
Total annual rainfall	(mm)	1,136	334	13
Aridity index	–	1.48	0.37	13
Climatic aggressivity (F FAO)	–	96.5	17.1	13
Continentality	(°C)	15.6	0.2	13
Seasonality index	(mm %)	9.4	0.01	13

Fig. 6.62 Geographic distribution of Acrisols, Albeluvisols, Alisols, Nitisols, Lixisols, Planosols Plinthosols, and soils with a fragipan (*density of profiles* 5.52 per 100 km^2)

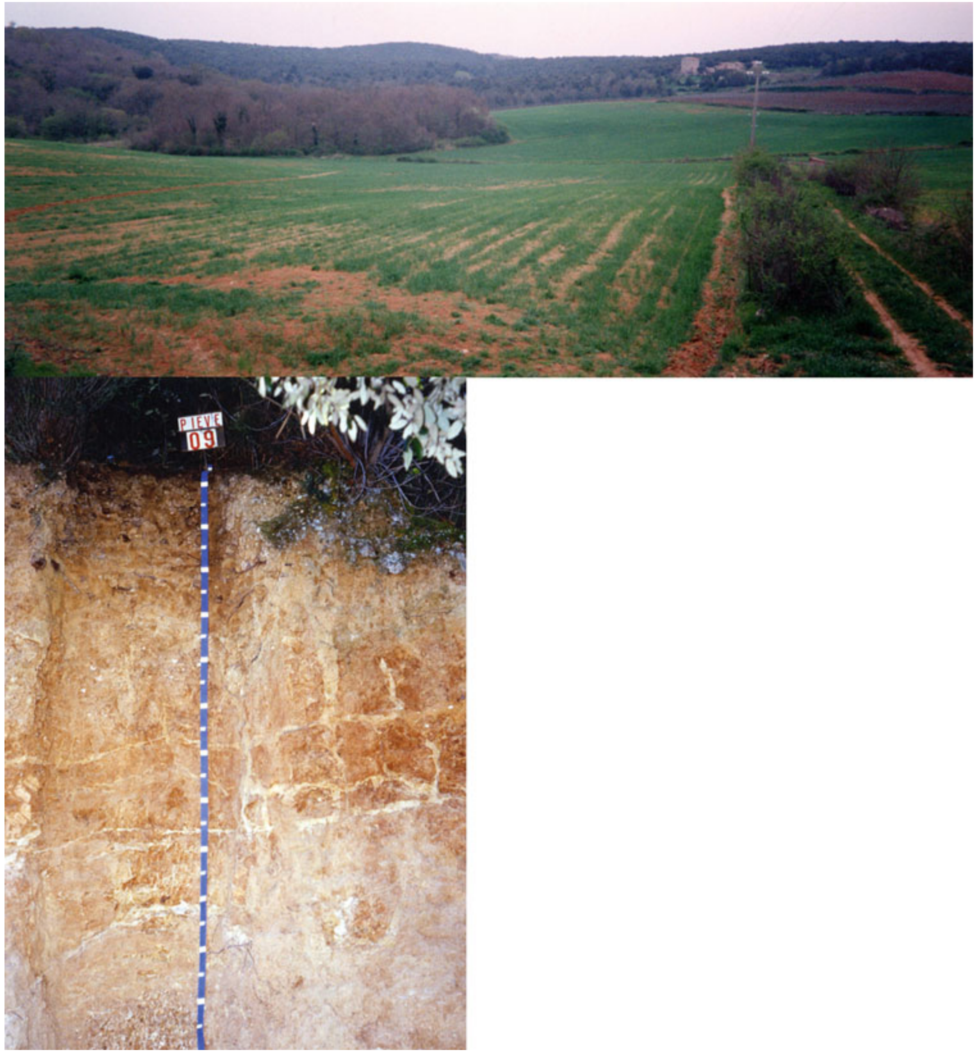


Fig. 6.63 Typical landscape and profile of a soil with a fragipan (Tuscany)

Cutanic Alisols

Soil Taxonomy
Ultic Haploxeralfs

Main geologies
alluvial, lacustrine or fluvial sandy-gravels; glacial deposits; alternating pelitic-arenitic, arenitic-marly and arenitic-pelitic rocks.

Main morphologies
fluvial terrace, linear slope.

Main land uses
row crops, permanent grassland, grassland-pasture and pastures, broadleaved woodlands.

FUNCTIONAL HORIZONS

description	lower depth (cm)	SD	N
A	28	14	62
E	50	25	17
Bt, Btx, Btg	131	78	146
2BC, BC, 2BCt	213	99	37

Total number of observations: 52
Site description: mean and standard deviation, mode and frequency, and number of sites considered.

Elevation (m a.s.l.)	mean	SD	N
medium hills (200-400)	255	198	52
Slope (%)			
gently sloping (6-13)	10	21	52
Stones (%)			
frequent (4-15)	6	23	48
Rocks (%)			
few (0-2)	1	4	48
Rock depth (cm)			
deep (100-150)	120		1
Potential rooting depth (cm)			
very deep (>150)	167	40	52
Water table upper limit (cm)			
very deep (>150)	160	42	2
Available water capacity (mm m^{-1})			
high (150-200)	171	68	52
Soil moisture regime and aridity index (dry d y^{-1})			
udic (<65)	53	18	52
Soil temperature regime and value (°C at 50 cm)			
mesic (8-15)	12	1	52

Crusting risk	mean	SD	N
high (> 0.60)	0.60	0.1	36
Compaction risk			
high (1.71 - 1.80)	1.78	0.1	36
Internal drainage			
well to moderately well drained	3.3	1	51
Surface runoff		n	N
negligible		1	4
Hydrologic group			
moderate infiltration (B)		34	48
Root restriction			
no restrictions and no impediments		35	52
Purifying capacity			
low		34	43

Analyses: Mean, standard deviation and number of samples

Low. depth (cm)	Tex. Cl.	Sand (dag kg^{-1}) mean	Sand SD	Clay mean	Clay SD	N	Coarse fragments (dm^2 m^{-2}) mean	SD	N	Bulk Density (g cm^{-3}) mean	SD	N	Permeability (µm s^{-1}) mean	SD	N
28	L	37.5	12.5	15.9	7.0	49	4	6.0	26	1.5	0.2	9	44.27	54.6	25
50	L	36.2	12.3	21.7	7.6	12	11	14.9	7	1.3	0.2	8	25.30	28.2	9
131	L	31.3	10.9	26.2	9.4	128	9	15.7	78	1.5	0.1	15	21.23	43.3	62
213	L	48.9	15.2	18.2	7.0	30	45	19.4	3			0	28.87	52.0	23

Low. depth (cm)	pH (1:2.5 H_2O) mean	SD	N	Organic Carbon (dag kg^{-1}) mean	SD	N	CEC (cmol(+) kg^{-1}) mean	SD	N	Base saturation (%) mean	SD	N	ESP (%) mean	SD	N	$CaCO_3$ total (dag kg^{-1}) mean	SD	N	$CaCO_3$ active mean	SD	N	Salinity (1:2.5 dS m^{-1}) mean	SD	N
28	5.6	0.6	49	1.46	0.63	49	15.2	3.9	49	32	18.0	48	3.0	3.9	39	0.0	0.0	37			0	0.08	0.1	4
50	5.5	0.7	12	0.64	0.30	12	11.3	4.7	12	20	13.2	12	8.9	13.0	3	0.0	0.0	11			0	0.06		1
131	5.9	0.6	127	0.38	0.28	124	15.2	5.7	127	36	14.3	127	2.1	2.7	103	0.0	0.0	104			0	0.09	0.0	3
213	6.1	0.5	30	0.38	0.40	29	14.6	5.3	29	38	15.6	29	1.6	2.3	29	0.0	0.0	26			0			0

Fig. 6.64 Derived profile of Cutanic Alisols

Fig. 6.65 Location of the elaborated profiles of Cutanic Alisols

Table 6.14 Average long-term climatic data of Cutanic Alisols

Variable	Unit	Average	Standard deviation	Number of data
Mean annual temperature	(°C)	12.7	1.5	53
Potential evapotranspiration	(mm)	921	57	53
Total annual rainfall	(mm)	1,152	172	53
Aridity index	–	1.26	0.22	53
Climatic aggressivity (F FAO)	–	100.5	9.8	53
Continentality	(°C)	15.9	0.65	53
Seasonality index	(mm %)	8.6	0.02	53

Fig. 6.66 Geographic distribution of Gleysols (*density of profiles* 3.36 per 100 km^2)

Fig. 6.67 Landscape with rice cultivation and profile of a Mollic Gleysol (Veneto)

Mollic Gleysols

Soil Taxonomy
Aquic Haploxerolls

Main geologies
alluvial, lacustrine or fluvial sandy-gravel and sandy-silt; glacial deposits.

Main morphologies
flood plain, fluvial terrace.

Main land uses
row crops, permanent grassland, grassland-pasture and pastures, vineyards.

FUNCTIONAL HORIZONS

description	lower depth (cm)	SD	N
Ap, A	36	19	49
Bg, Bw, BCg	61	18	21
Ab	94	37	14
Cg, C, Ckg	108	45	70

Total number of observations: 36

Site description: mean and standard deviation, mode and frequency, and number of sites considered.

	mean	SD	N
Elevation (m a.s.l.)			
low hills (0-200)	95	73	36
Slope (%)			
nearly level (0,2-2)	1	2	36
Stones (%)			
frequent (4-15)	10	30	35
Rocks (%)			
absent	0	0	32
Rock depth (cm)			
very deep (>150)	190		1
Potential rooting depth (cm)			
moderately deep (50-100)	99	56	36
Water table depth (cm)			
moderately deep (50-100)	99	34	22
Available water capacity (mm m^{-1})			
low (50-100)	95	51	34
Soil moisture regime and aridity index (dry d y^{-1})			
ustic (65-80)	73	13	32
Soil temperature regime and value (°C at 50 cm)			
mesic (8-15)	12	1	30

	mean	SD	N
Crusting risk			
moderate (0.41 - 0.60)	0.47	0.2	31
Compaction risk			
low (1.51 - 1.60)	1.56	0.3	31
Internal drainage			
moderately well to somewhat poorly drained	4.6	1	36

	n	N
Surface runoff		
negligible	2	5
Hydrologic group		
moderate infiltration (B)	17	34
Root restriction		
impediments: oxygen scarcity and redox phenomenons (water table)	28	39
Purifying capacity		
low	13	33

Analyses: Mean, standard deviation and number of samples

Low. depth (cm)	Tex. Cl.	Sand (dag kg^{-1}) mean	Sand SD	Clay mean	Clay SD	N	Coarse fragments (dm^2 m^{-2}) mean	SD	N	Bulk Density (g cm^{-3}) mean	SD	N	Permeability (µm s^{-1}) mean	SD	N
36	L	45.8	19.6	14.3	9.6	45	8	14.7	23	1.6	0.1	6	42.8	36.0	39
61	L	42.5	18.0	14.0	8.0	20	8	19.8	13	1.5		1	37.8	25.2	15
94	L	40.6	20.8	17.4	10.3	8	2	3.6	11	0.6	0.1	2	32.6	50.8	9
108	LS	55.6	26.2	10.9	10.0	49	25	28.7	28	1.3	0.1	3	33.8	52.7	50

Low. depth (cm)	pH (1:2.5 H_2O) mean	SD	N	Organic Carbon (dag kg^{-1}) mean	SD	N	CEC (cmol(+) kg^{-1}) mean	SD	N	Base saturation (%) mean	SD	N	ESP (%) mean	SD	N
36	7.5	0.7	45	2.61	1.52	45	20.8	10.1	44	92	16.0	38	0.6	0.5	31
61	7.6	0.4	20	1.33	1.10	20	16.9	8.8	19	96	6.2	17	1.2	1.2	12
94	7.1	0.5	10	8.25	1.43	10	37.1	17.4	10	100	0.0	10	0.6	0.9	9
108	7.9	0.6	49	1.11	1.41	48	11.9	11.5	45	95	10.4	40	1.0	1.0	32

Low. depth (cm)	$CaCO_3$ total (dag kg^{-1}) mean	SD	N	$CaCO_3$ active mean	SD	N	Salinity (1:2.5 dS m^{-1}) mean	SD	N
36	11.3	12.4	44	1.9	1.0	7	0.12	0.0	2
61	9.7	22.0	19	1.4	1.7	4	0.30	0.4	3
94	1.5	1.5	10			0			0
108	20.0	22.7	49	2.5	1.7	6	0.11	0.0	2

Fig. 6.68 Derived profile of Mollic Gleysols

Mollic Gleysols

Soil Taxonomy
Aquic Haploxerolls

Main geologies
alluvial, lacustrine or fluvial sandy-gravel and sandy-silt; glacial deposits.

Main morphologies
flood plain, fluvial terrace.

Main land uses
row crops, permanent grassland, grassland-pasture and pastures, vineyards.

FUNCTIONAL HORIZONS

description	lower depth (cm)	SD	N
Ap, A	36	19	49
Bg, Bw, BCg	61	18	21
Ab	94	37	14
Cg, C, Ckg	108	45	70

Total number of observations: 36

Site description: mean and standard deviation, mode and frequency, and number of sites considered.

	mean	SD	N
Elevation (m a.s.l.)			
low hills (0-200)	95	73	36
Slope (%)			
nearly level (0,2-2)	1	2	36
Stones (%)			
frequent (4-15)	10	30	35
Rocks (%)			
absent	0	0	32
Rock depth (cm)			
very deep (>150)	190		1
Potential rooting depth (cm)			
moderately deep (50-100)	99	56	36
Water table depth (cm)			
moderately deep (50-100)	99	34	22
Available water capacity (mm m^{-1})			
low (50-100)	95	51	34
Soil moisture regime and aridity index (dry d y^{-1})			
ustic (65-80)	73	13	32
Soil temperature regime and value (°C at 50 cm)			
mesic (8-15)	12	1	30

	mean	SD	N
Crusting risk			
moderate (0.41 - 0.60)	0.47	0.2	31
Compaction risk			
low (1.51 - 1.60)	1.56	0.3	31
Internal drainage			
moderately well to somewhat poorly drained	4.6	1	36

	n	N
Surface runoff		
negligible	2	5
Hydrologic group		
moderate infiltration (B)	17	34
Root restriction		
impediments: oxygen scarcity and redox phenomenons (water table)	28	39
Purifying capacity		
low	13	33

Analyses: Mean, standard deviation and number of samples

Low. depth (cm)	Tex. Cl.	Sand (dag kg^{-1}) mean	Sand SD	Clay mean	Clay SD	N	Coarse fragments (dm^2 m^{-2}) mean	SD	N	Bulk Density (g cm^{-3}) mean	SD	N	Permeability (µm s^{-1}) mean	SD	N
36	L	45.8	19.6	14.3	9.6	45	8	14.7	23	1.6	0.1	6	42.8	36.0	39
61	L	42.5	18.0	14.0	8.0	20	8	19.8	13	1.5		1	37.8	25.2	15
94	L	40.6	20.8	17.4	10.3	8	2	3.6	11	0.6	0.1	2	32.6	50.8	9
108	LS	55.6	26.2	10.9	10.0	49	25	28.7	28	1.3	0.1	3	33.8	52.7	50

Low. depth (cm)	pH (1:2.5 H_2O) mean	SD	N	Organic Carbon (dag kg^{-1}) mean	SD	N	CEC (cmol(+) kg^{-1}) mean	SD	N	Base saturation (%) mean	SD	N	ESP (%) mean	SD	N	$CaCO_3$ total (dag kg^{-1}) mean	SD	N	$CaCO_3$ active mean	SD	N	Salinity (1:2.5 dS m^{-1}) mean	SD	N
36	7.5	0.7	45	2.61	1.52	45	20.8	10.1	44	92	16.0	38	0.6	0.5	31	11.3	12.4	44	1.9	1.0	7	0.12	0.0	2
61	7.6	0.4	20	1.33	1.10	20	16.9	8.8	19	96	6.2	17	1.2	1.2	12	9.7	22.0	19	1.4	1.7	4	0.30	0.4	3
94	7.1	0.5	10	8.25	1.43	10	37.1	17.4	10	100	0.0	10	0.6	0.9	9	1.5	1.5	10			0			0
108	7.9	0.6	49	1.11	1.41	48	11.9	11.5	45	95	10.4	40	1.0	1.0	32	20.0	22.7	49	2.5	1.7	6	0.11	0.0	2

Fig. 6.69 Location of the elaborated profiles of Mollic Gleysols

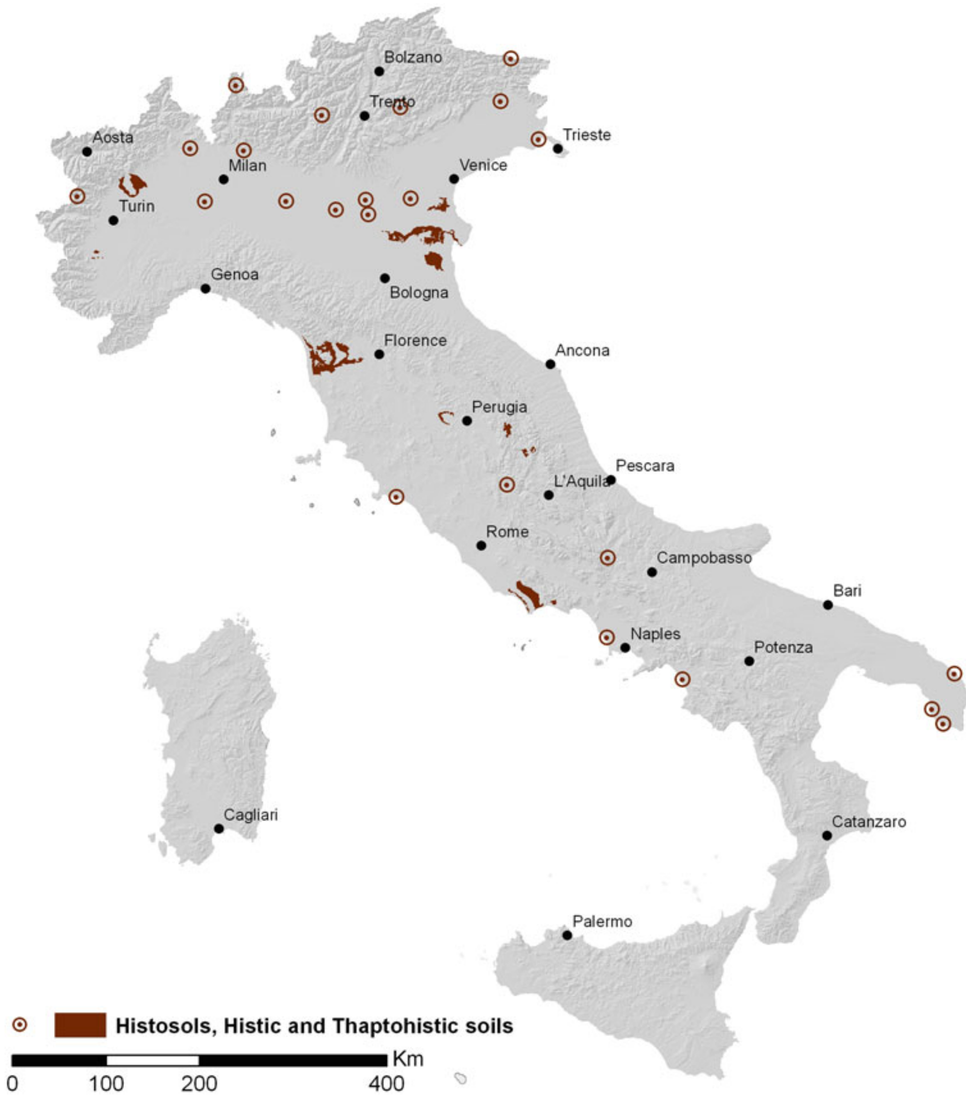


Fig. 6.70 Geographic distribution of Histosols (*density of profiles* 1.86 per 100 km^2)

Table 6.15 Average long-term climatic data of Mollic Gleysols

Variable	Unit	Average	Standard deviation	Number of data
Mean annual temperature	(°C)	13.4	0.83	34
Potential evapotranspiration	(mm)	913	57.8	34
Total annual rainfall	(mm)	909	169	34
Aridity index	–	1.00	0.22	34
Climatic aggressivity (F FAO)	–	80.7	15.0	34
Continentality	(°C)	16.3	0.6	34
Seasonality index	(mm %)	8.7	0.02	34

Table 6.16 Average long-term climatic data of Sapric Histosols

Variable	Unit	Average	Standard deviation	Number of data
Mean annual temperature	(°C)	11.9	3.00	9
Potential evapotranspiration	(mm)	898	79.8	9
Total annual rainfall	(mm)	1,146	404	9
Aridity index	–	1.32	0.60	9
Climatic aggressivity (F FAO)	–	92.4	23.3	9
Continentality	(°C)	15.8	0.7	9
Seasonality index	(mm %)	8.5	0.01	9

Fig. 6.71 Typical landscape (Veneto) and profile (Emilia-Romagna) of Sapric Histosols

Sapric Histosols

Soil Taxonomy
Terric Haplosaprists

Main geologies
peat, clayey and silty deposit of lagoon depression, retrodunal and delta plain deposits.

Main morphologies
flood plain.

Main land uses
row crops, permanent grassland, grassland-pasture and pastures.

FUNCTIONAL HORIZONS

description	lower depth (cm)	SD	N
A, Ap	39	11	6
Op, Oa, Oe	69	37	12
Cg, C	112	24	9

Total number of observations: 9

Site description: mean and standard deviation, mode and frequency, and number of sites

	mean	SD	N
Elevation (m a.s.l.)			
medium hills (200-400)	238	295	9
Slope (%)			
nearly level (0,2-2)	1	1	9
Stones (%)			
very few (<0.3)	0	0	4
Rocks (%)			
absent	0	0	4
Potential rooting depth (cm)			
deep (100-150)	121	63	4
Water table depth (cm)			
moderately deep (50-100)	60		1
Available water capacity (cm m^{-1})			
moderate (100-150)	132	86	8
Soil moisture regime and aridity index (dry d y^{-1})			
ustic (65-80)	67	21	8
Soil temperature regime and value (°C at 50 cm)			
mesic (8-15)	12	1	4

	mean	SD	N
Crusting risk			
low (<= 0.40)	0.21	0.1	6
Compaction risk			
very low (<= 1.50)	1.39	0.0	6
Internal drainage			
moderately well to somewhat poorly drained	4.5	2	6

	n	N
Surface runoff		
negligible	1	2
Hydrologic group		
slow infiltration (C)	3	7
Root restriction		
impediments: oxygen scarcity	2	4
Purifying capacity		
very high	1	2

Analyses: Mean, standard deviation and number of samples

Low. depth	Tex.	Sand (dag kg^{-1})		Clay (dag kg^{-1})			Coarse fragments (dm^2 m^{-2})			Bulk Density (g cm^{-3})			Permeability (µm s^{-1})		
(cm)	Cl.	mean	SD	mean	SD	N	mean	SD	N	mean	SD	N	mean	SD	N
39	SIL	29.6	28.9	14.4	11.9	6	2	4.0	4	1.2	0.5	2	40.40	76.4	4
69	CL	21.9	33.1	35.3	31.4	8	0	0.0	10	0.6	0.2	2	3.03	3.5	2
112	SIL	20.6	23.9	12.9	9.0	5	6	16.6	5	0.6		1	52.03	89.2	3

Low. depth	pH (1:2.5 H_2O)			Organic Carbon (dag kg^{-1})			CEC (cmol(+) kg^{-1})			Base saturation (%)			ESP (%)			$CaCO_3$ total (dag kg^{-1})			$CaCO_3$ active			Salinity (1:2.5 dS m^{-1})		
(cm)	mean	SD	N	mean	SD	N	mean	SD	N	mean	SD	N	mean	SD	N	mean	SD	N	mean	SD	N	mean	SD	N
39	6.8	1.0	6	8.35	2.85	6	31.4	12.0	3	69	39.1	2	2.0	2.8	2	6.3	5.0	6	0.0		1	0.32		1
69	6.3	1.1	11	22.59	11.24	12	57.4	38.2	4	81	33.7	3	41.5	51.5	3	2.1	2.8	8	0.7	1.2	3	3.70	0.3	2
112	6.5	0.9	6	6.12	4.03	6	22.6	15.6	3	97	5.9	3	100.0	106.8	3	20.6	15.4	4			0	3.72	1.1	2

Fig. 6.72 Derived profile of Sapric Histosols

Fig. 6.73 Location of the elaborated profiles of Sapric Histosols

Fig. 6.74 Geographic distribution of rare soils

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Soil Functions and Ecological Services

7

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7.1 Introduction

Soil functions are closely related to soil ecosystem services, defined as the complex of actions sustained by soils to guarantee life on the earth. Briefly, they can be summarized as: biodiversity and habitat, nutrient cycling, water regulation, filtering and buffering, physical stability and support (European Atlas of Soil Biodiversity 2010). As the majority of soil functions and ecological services are associated with the presence of a complex system of organisms in soils, in this chapter we will mainly deal with the management and diversity of biotic resources in soils and environments typical of the Italian landscapes.

According to the National Biodiversity Strategy (MATTM 2010), the concept of "eco-region" as ecological zones identified by different climate, vegetation and land use were identified and mapped for the whole Italy (Blasi and Michetti 2005). For example, by considering only vegetation of the Mediterranean area, this study recognized 25,000 species of plants, representing more than 10 % of all planet plants, compared with the 6,000 species living in the rest of Europe.

Another important phenomenon concerns endemisms: over 80 % of European plant endemisms are in this area. The same is true for some types of arthropods (collembola or spiders). Soil microbial biodiversity is the product of the interaction between the "ecological" component and "pedodiversity", recognized as the genetic differentiation of soils and horizons within landscapes.

The interaction of ecoregions with the distribution of soils and soilscapes was analysed by comparing soil information with land use, climate, pedoclimate and vegetation (forests and natural areas or areas in the process of naturalization) and by defining geographical levels in Soil Regions (Costantini et al. 1999) and Soil Systems (Costantini et al. Chap. 6).

Soil variability is represented by about 1,400 different Soil Typological Units (STU) all over Italy. Twenty-two reference groups and 146 types are represented at the first qualifier level in relation to soil diagnostic horizons, materials and properties and concerning only the main soil types in the Soil System Map units.

The national level of Soil Systems, developed within the national programme "Soil map of Italy at 1:250,000 scale", is still under construction; likewise, the national archive and database of soil physical characteristics and qualities (soil hydrology, fertility and biodiversity) linked to STU.

This study phase allows us to make a series of important assertions relative to the geographical and typological taxonomic distribution of the relationships between microbial biodiversity and pedodiversity, which will be reported in this chapter in the form of case studies. However, a single national thematic mapping of biological fertility and microbiological-based indicators till now is not available.

7.1.1 Microbial Biodiversity and Soil Functions

Soil biodiversity is a general term used to describe the variety of life below ground. The concept is conventionally used in a genetic sense and denotes the number of distinct species (richness) in a system and their proportional abundance (evenness), but may be extended to encompass phenotypic, functional, structural or trophic diversity.

On a microbial scale, the total below-ground biomass generally equals or exceeds the above-ground biomass,

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while below-ground soil biodiversity always exceeds that on the associated surface by orders of magnitude. A handful of grassland soil will typically support tens of thousands of genetically distinct prokaryotes (bacteria, archaea) and hundreds of eukaryotic species across many taxonomic groups. For instance, agricultural soil usually contains in the order of 3,000 kg of living biomass (fresh weight) per hectare, and we found between 55 and 98 % of the Earth's total biodiversity in soil.

At this level, the soil biota plays a vital role in delivering key ecosystem goods and services, and through nutrient cycling, decomposition and energy flow, it is both directly and indirectly responsible for many important functions in soil. And yet soil organisms have had a negligible influence on the development of contemporary ecological theories (Wardle and Giller 1996).

Soil organisms are the most important factor in soil formation as both their trophic and non-trophic effects define the difference between soils and non-soils (Jones et al. 1997). Through their non-trophic activities, soil organisms physically modify, maintain or create new habitats for other organisms, which may in turn lead to increased species diversity. Close interactions between microorganisms and other soil-forming factors lead to important biological processes with a major impact on the global carbon cycle as soil stocks carbon mainly in the form of soil organic matter and releases carbon in the form of carbon dioxide (CO_2) formed during the decomposition of soil organic matter (Schils et al. 2008; Lal 2004).

Microbes also play an essential role in soil water regulation and particle aggregation. Actually, soil structure formation is mediated by physicochemical processes and by the activity of living organisms such as bacteria, fungi, meso- and macrofauna and plant roots; while decomposing organic material, soil microorganisms excrete substances that can act as binding agents between soil particles and facilitate the formation of soil aggregates. A sound soil structure facilitates the germination and the establishment of crops, improves the water-holding capacity that can prevent or delay drought and ensures a better infiltration capacity, which prevents waterlogging, as well as improves aeration of the soil. Furthermore, good soil structure offers resistance and resilience to physical degradation, such as erosion and compaction, and helps the movement of organisms in the soil.

Many of the functions performed by soil microorganisms can provide essential services to human society: agricultural production and food processing depend heavily on this "hidden" biodiversity, and plants and animals cannot grow optimally without them. Without soil fertility, management of sustainable agriculture is impossible. A good example of the role of microorganisms in soil fertility and plant nutrition is represented by the fungi and other microorganisms that establish a mutually beneficial symbiosis with the roots of agricultural plants, like the symbiotic microorganisms whose actions directly improve plant growth (for example, root-nodulating bacteria enabling nitrogen fixation in legumes, mycorrhizae, etc.) or the free-living microorganisms that elicit a positive reaction when in intimate proximity with a plant or animal (for example, *azotobacter* by supplying small amounts of nitrogen to plants) or the microorganisms that decompose organic matter and transform mineral nutrients in the soil. Microorganisms are primary agents of nutrient recycling, greenhouse gas emission mitigation, soil structure, nutrient acquisition by plants, etc. Finally, microorganisms provide primary metabolites that act as mediators for the production of commodities and fine chemicals used in agriculture and play a key role in other biotechnological applications, involving bioremediation of polluted sites or restoration of loss of biological fertility caused by genetical erosion of microbial populations.

Soil life can be divided into trophic levels. On the lower trophic level lays the soil microbial population, which degrades plant, animal and microbial bodies as well as serving as a food source for some of the higher levels. For example, soil protozoa consume a big amount of bacteria as well as fungal spores.

The theory that biological diversity and ecosystem stability are based on community stability arises from food-web structures, rather than from the autoecological properties of certain species. In an ecosystem with many energy pathways, changing the number of a single species will have less effect on the other species than in an ecosystem with only a few energy pathways. In this food-web model, the effect of diversity or a sudden alteration of the abundance of one community member can act as a perturbation. Soils with greater levels of biodiversity are more resistant to environmental disturbances and are therefore more resilient.

A healthy soil biota needs an appropriate habitat. Hence, threats to soil such as erosion, contamination, salinization and sealing all serve to threaten soil biodiversity by compromising or destroying the habitat of the soil biota. Management practices that reduce the deposition or persistence of organic matter in soils or bypass biologically mediated nutrient cycling also tend to reduce the size and complexity of soil communities. It is however notable that even polluted or severely disturbed soils still support relatively high levels of microbial diversity at least. Specific groups may be more susceptible to certain pollutants or stresses than others, for example, nitrogen-fixing bacteria that are symbiotic to legumes are particularly sensitive to copper; colonial ants do not tend to prevail in frequently tilled soils due to the repeated disruption of their nests; soil mites are generally a very sturdy group.

In order to understand the soil microbial world and its role in ecosystem functioning, in addition to single organisms also density, diversity and activity of microbial populations, isolated from natural environments, need to be considered. These processes bring about variations in the microbial community structure and diversity in multiple situations and allow the identification of populations preferentially associated with various habitats and different environmental contexts. All these studies provided information about the high dynamic responses of microbial genetic resources under different human or climatic impacts. Microorganisms require only a brief time to reproduce (from hours to days), allowing them to react to pressure and to transfer genetic modification very swiftly at population levels (Van Elsas et al. 2006).

7.2 Soil Organic Matter and Microbial Activity-Related Soil Functions

Soil organic matter is the main nutritional substrate sustaining the development of microorganisms by means of processes capable of influencing community structure. In this paragraph, we will discuss the relationship between different quality and quantity characteristics of soil organic matter and the behaviour of soil microorganisms, focusing, in particular, on examples related to the Italian context.

Organic matter content in soil is adopted as a widespread soil quality indicator since it is correlated with multifarious aspects of productivity and sustainability of agricultural ecosystems and environmental conservation (Smith et al. 2000). In general, high soil organic matter content is held to be advantageous, even if it has been shown to have a negative impact on the environment or productivity within the framework of specific contexts and processes (Sojka and Upchurch 1999). Organic matter not only affects the chemical and biological properties of soil, as it is the main nutritional substrate for the microbial community, but also affects its physical properties. In fact, the sole non-modifiable physical property of soil is texture, whereas structure stability, water retention, colour and thermal capacity are related to the quantity and quality of soil organic matter.

The term soil organic matter embraces all soil organic material including decomposed and decomposing litter, microbial biomass, soluble organic material and stabilized organic matter (such as humus and mineral-bound organic complexes). Such matter is therefore extremely heterogeneous and chemically complex—especially more biochemically stable fraction commonly referred to as humic matter—and is currently a matter of investigation. Although many recent research projects are investigating molecular models facilitating the understanding of both the structure and functioning of soil organic matter as a whole (Schaumann and Thiele-Bruhn 2011), from an operative point of view, humic substances (amorphous dark-brown polymeric compounds with molecular weights ranging from hundreds of Daltons—in the case of fulvic acids—to hundreds of thousands of Daltons—in the case of humic acids) are normally divided in three main fractions on the basis of their solubility in alkali and acids: (1) humic acids (HA), fraction that is soluble in diluted alkali but precipitates for alkaline extract acidification; (2) fulvic acids (FA), humic fraction that remains in solution when the alkaline extract is acidified as it is soluble in both diluted alkali and diluted acids; (3) humin, humic fraction that cannot be extracted from soil by diluted alkali or acids. This approach is still adopted in order to characterize the distribution of these different fractions along the soil profiles or according to different land uses, since humic substances are characterized by intermediate carbon turnover times with respect to more labile fractions, which are more directly involved in soil microbial metabolism.

In Italy, there is a widespread gradual reduction in organic matter content in cultivated soils for multivarious and often interrelated causes. Some of these causes are related to reduced organic matter supplies (separation of animal husbandry and crop farming, non-utilization of crop residues, specialized crop farming, simplified crop rotation, almost exclusive use of inorganic pesticides, etc.), while others are due to increased organic matter mineralization rate (more frequent and deeper tilling, diffusion of irrigation procedures) etc. The entire Mediterranean area is one of the most exposed areas to depletion of agricultural soil fertility due to rapid organic matter mineralization processes. It is known that soil microorganisms making nutrients available to plants are regulated by temperature and moisture and that conditions for organic matter mineralization are ideal in spring and autumn and in irrigated and winter cultivations in areas of Italy where temperatures do not drop below 5 °C (mineralization stops below this temperature).

7.2.1 National and Local Studies on Soil OM Dynamic and C Storage

Two investigations on soil organic carbon (SOC) variations were recently carried out at national level in Italy using different methodological approaches and soil data. The first one (Fantappiè et al. 2011) predicted SOC using multiple linear regression analysis models as a function of climate change along with other landscape parameters for different time lapses all over Italy from 1961 to 2008. Results showed that temperature had the most relevant impact on SOC with an inverse correlation, whereas SOC was directly correlated with precipitations on arable lands and inversely in forests and meadows; from the 1961–1990 to the 1991–2006 period, there was a mean SOC decrease of 0.2, 0.57 and 0.76 dag kg^{-1} for arable lands, forests and meadows, respectively (Fantappiè et al. 2011). The second study (Chiti et al. 2011) calculated the total amount of SOC stock in the top 30 cm of mineral soil layer for the 1995–2005 period on the basis of soil data from the national SIAS project collecting SOC data from local databases using the INSPIRE geographical standard (EU 2007). The SOC stock for the whole cropland category was shown to be 490.0 ± 121.7 Tg of C; arable land and agroforestry represent about 70 % of this category (Chiti et al. 2011). Numerous studies in recent years have examined the most favourable management practices for increasing C storage and preventing soil erosion processes in agricultural soils. Recently, the results of long-term experiments carried out in various experimental farms were collected and published in order to monitor and assess the environmental protection measures imposed by the Common Agricultural Policy (Bazzoffi 2011). In particular, different types of behaviour were observed in case studies in different areas with different Soil Systems.

7.2.2 Case studies on Soil Organic Matter Trends Related to Different Cropping Systems

Case study 1: Mediterranean environment of Apulia in EU Soil Region 62.1 (see Chap. 6), soil system landscape "Stream terraces on alluvial deposits, alluvial lacustrine or glacial fluvial with mixed lithology covered by row crops" (Fig. 7.1).

Very slow soil organic matter–related processes were observed in an alluvial clay loam soil, classified as Grumic Calcic Vertisol (World Reference Base 2007) in south Italy, Foggia (41° 26′ N, 15° 30′ E, 90 m a.s.l.), in an agricultural area cultivated with cereal, leguminous vegetables and industrial horticulture (Fig. 7.2). Thirty-two years after the beginning of the experiment into the effects of different residue management practices on the chemical properties of soils, it was revealed that the mere incorporation of straw and stubble induced only a slight increase in soil organic matter (0.7 % on average) with respect to burning of residue, a common practice in that area (Ventrella et al. 2011). In the same area (41° 27′ N, 15° 30′ E, altitude 79 m above sea level), with a clay loam soil classified as Eutric Vertisol (World Reference Base 2007), it was also shown that crop rotations are not so effective as expected in maintaining or increasing the organic carbon content in soil (Borrelli et al. 2011). In particular, after 16 years from the beginning of the experiment, a decline in SOC was observed in all rotations (continuous wheat, wheat–oats–bare fallow; wheat–chickpea and wheat–wheat–tomato) with the exception of the wheat–wheat–bare fallow rotation where the organic carbon content remained constant.

Case study 2: Central Italy (Tuscany) in EU Soil Region 78.2, soil system landscape "Low hills and aggraded landforms (terraces and alluvial fans), on alluvial, alluvio-lacustrine and glacial fluvial deposits with mixed lithology" (Fig. 7.3).

In an experimental area in a hilly region of central Italy, near Florence, (43.98°N and 11.34°E) with climate characterized by dry summers and cold winters, mean annual rainfall of about 1,024 mm and mean annual temperature of 13.4 °C and on Calcaric Vertic Cambisols (WRB 2007), the effects of crop rotations (continuous maize and a three-year

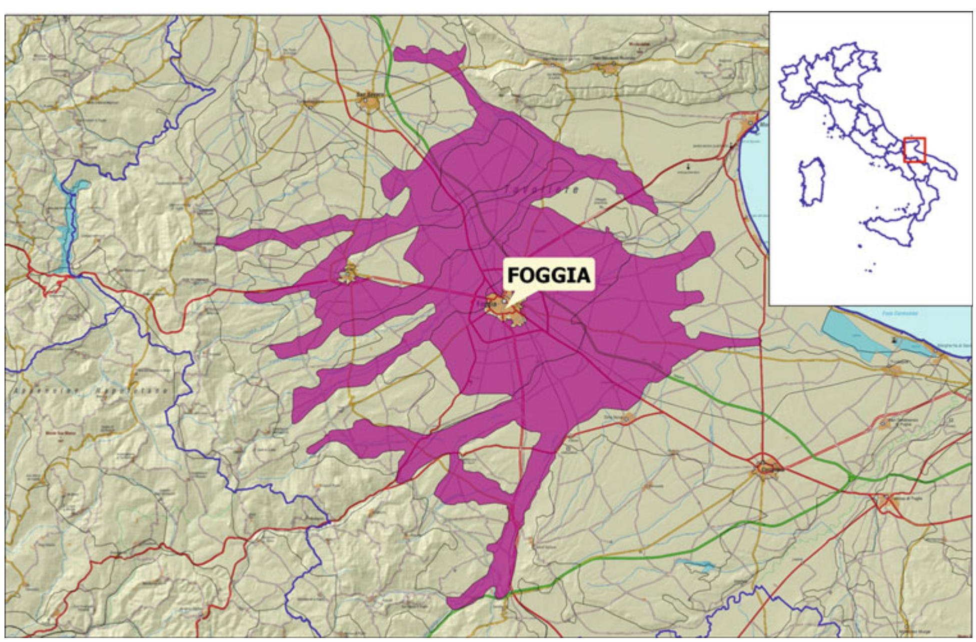

Fig. 7.1 Location of soilscape with Calcic and Eutric Vertisols, Apulia region

Fig. 7.2 Grumic Calcic Vertisol on alluvial fine deposits flat plain soilscape near Foggia

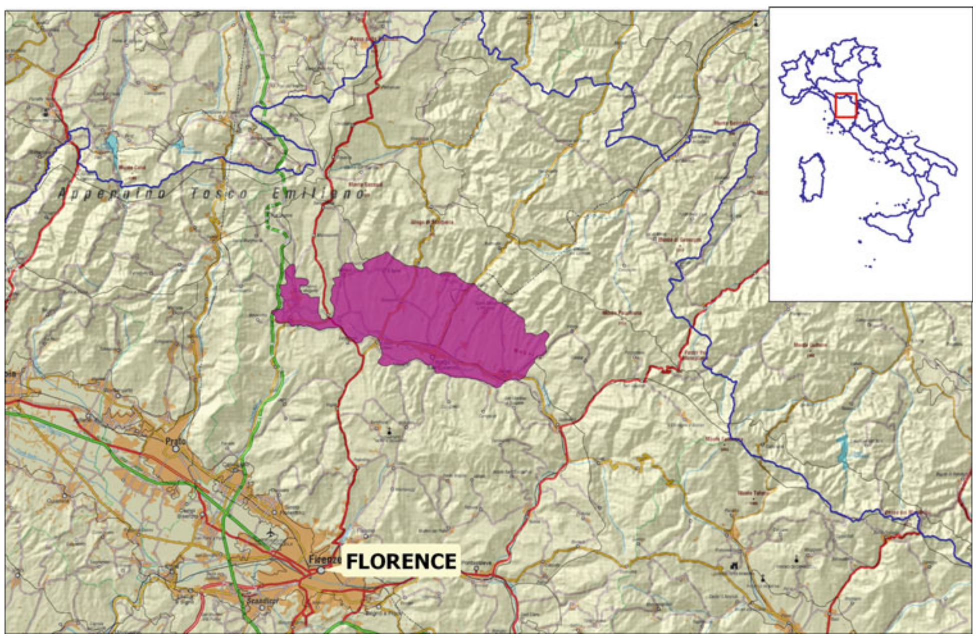

Fig. 7.3 Location of soilscape with Calcaric Vertic Cambisols, Tuscany region

rotation maize–wheat–field bean) on the soil organic carbon content were also negligible.

Moreover, cropping system and tillage (minimum tillage, ripper sub-soiling, conventional deep ploughing and shallow ploughing) did not impact on the relative size (rate) of the soil microbial pool (Cmic/TOC) although there was a significant difference in the metabolic quotients of the two cropping systems considered. The lower values of microbial-specific respiration (qCO_2) under maize monoculture seem to indicate a metabolic equilibrium of microflora, which optimizes its energetic requirements through constant plant inputs, whereas crop rotation probably stimulates metabolic activity by returning different types and amounts of organic substrates to the soil (Borrelli et al. 2011).

7.2.3 SOM and Microbial Activity Under Semi-Arid Mediterranean Climate and Different Land Use Conditions

Case study 3: Mediterranean environment of Sicily in EU Soil Region 62.2, soil system landscape "Low, medium and high hills with medium gradient, with rounded or flat summit, with subparallel to subdentritic drainage pattern on mainly, anhydritic or chalky limestone covered by row crops" (Fig. 7.4).

Correlations between vegetation type and soil characteristics were documented in various Italian environments, especially after afforestation programmes conducted with non-native species. One such programme involved the introduction to Sicily in the 1960s of fast-growing forest

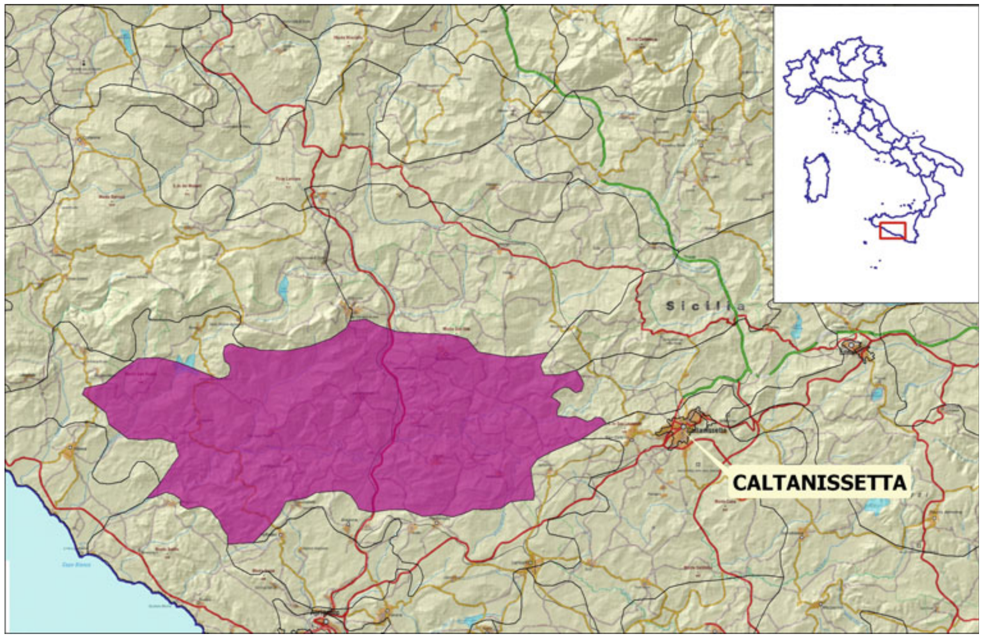

Fig. 7.4 Location of the Soil System in which prevails Xerofluvent–Haploxerert–Calcixerept toposequence (Dell'Abate et al. 2002b), respectively Fluvisols–Calcisols–Vertisols (WRB 2007) in Sicily region 62.2

species suited to warm climates, such as *Eucalyptus spp.*, in order to sustain the development of paper mills as well as help to prevent soil erosion processes. An investigation carried out a posteriori on land suitability for *Eucalyptus camaldulensis* (Fierotti et al. 1995) revealed that many soilscapes are not suitable or marginally suitable because of texture and/or salinity limitations. The limited plant growth and low soil carbon storage, both below the expected values, gave rise to an in-depth investigation of soil microbial activity in a toposequence selected along a morphological transect in that area, a gypsiferous hilly area near Caltanissetta. The toposequence starts from a small valley with alluvio-colluvial soil such as Typic Xerofluvent (profile MG16) or Humic Fluvisols (WRB 2007) and go to the hilltop considering from down to up Vertic Haploxerert (profile MG1 or Eutric Vertisols (WRB 2007), Gypsic Vertic Haploxerert (profile MG22)) or Vertic Calcisols (WRB 2007) and Gypsic Calcixerept (profile MG64, Fig. 7.5) or Gypsic Calcisols (WRB 2007; Dell'Abate et al. 2002b).

The main results obtained showed a sharp drop (approximately 50 %) in carbon content from the surface horizons to the layers below, followed by a gradual decrease along the profiles. A similar trend was revealed for the alkaline extractable fractions of organic matter and soil nitrogen content. A relatively high amount of humified organic matter was found in comparison with total organic carbon content: the humification degree, calculated as the percentage abundance of humic and fulvic fraction in the extractable fraction according to the classic approach based on different solubility in basic or acidic media, was close to 100 % in most samples at all soil depths, indicating the

Fig. 7.5 Gypsic Calcixerept (Gypsic Calcisol, WRB 2007) in hilly soilscapes of central Sicily, on "evaporitic deposits" under *E. Camaldulensis* afforestation

presence of active humification processes in deeper horizons leading to accumulation of humic substances and consequently to stabilization of soil organic matter.

However, the lack of labile organic substrates available for microbial metabolism within the soil ecosystem may indicate potential soil degradation because the functioning of the microbial community could be sustained by mineralization and depletion of more stable fractions, such as humified fractions.

Measurements of soil respiration and microbial biomass activity (Table 7.1) showed trends similar to those of total organic carbon content along the soil profiles, in particular, relatively high values of cumulative respiration in the deeper horizons indicated intensive microbial activity correlated with organic matter content, with C mineralization coefficients ranging from 3.3 to 4.8 % of total organic carbon up to about 100 cm in depth. Higher respiration rates and metabolic quotients were recorded in the deeper horizons of the pedons (all evaluated as not suitable for *E. camaldulensis*), indicating more rapid organic matter turnover than in the surface horizons and a possible stress condition for soil microorganisms.

Other investigations examining benchmark soils in xeric climates in south Italy (Fig. 7.6) also recorded high levels of microbial activity despite the low ratio of Cmic:Corg in deeper horizons (Marinari et al. 2010): the two benchmark Vertisols (Grumic Pellic Vertisol and Eutric Vertisol) were, respectively, located in gypsiferous hilly landscapes in Sicily (the same ones examined in Case study 3) and on a coastal plain with dune bars on littoral deposits and marine sublittoral, alluvial and delta deposits covered by row crops in Lucania (Soil Region 62.1), while the two benchmark Alfisols—a Ultic Haploxeralf (Chromic Luvisol, WRB) on karstic hills and upland plains with a Murge-type doline drainage pattern on mainly limestone covered by row crops (EU Soil Region 72.2) and a Mollic Haploxeralf (Luvic Phaeozem, WRB) on dissected marine terraces and coastal plains in the Rutigliano Mola di Bari areas on mainly anhydritic or chalky limestone covered by olive groves—were located in Apulia (Marinari et al. 2010). The increased values of metabolic quotients in deep horizons reflected the low energy-transforming efficiency of the microbial community, also deduced from the negative response of microbial biomass to a more complex humic acid structure along the profile. In fact, humic acids extracted from the upper horizons of these pedons showed a higher aliphatic character than those extracted from the deeper horizons, which had a higher content of aromatic structures and polysaccharides.

Previously, humic fraction distribution and chemical structural stability were studied (Dell'Abate et al. 2002c) along the soil profile of two Vertisols located in a hilly area of Sicily, a Typic Haploxerert (Grumic Vertisol, Hyposodic, WRB 2007) and a Typic Haploxerert (Grumic Pellic Vertisol, Hyposodic, WRB 2007), respectively. SOM

Table 7.1 Main C fractions and microbial parameters in soils under *E. camaldulensis*

		Cmic	Ccum	qCO_2	K	Corg	Cext	Cha + fa	DH
Typic Xerofluvent (Humic Fluvisol, WRB) MG16	(0–15)	227	551	2.43	3.55	13.5	10.3	9.8	95
	(15–30)	205	279	1.36	6.40	7.1	4.7	5.6	100
	(30–50)	185	301	1.63	5.71	7.3	5.6	5.7	100
	(50–90)	118	253	2.14	6.90	5.3	3.6	4.3	100
Vertic Haploxerert (Eutric Vertisol, WRB) *MG1*	(0–30)	339	599	1.77	5.51	14.3	11.5	11.9	100
	(30–70)	110	307	2.79	6.69	8.8	5.8	4.2	73
	(70–125)	77	226	2.94	8.76	7.0	3.9	2.8	71
Gypsic Vertic Haploxerert (Vertic Calcisol, WRB) *MG22*	(0–20)	315	478	1.52	5.06	17.0	12.3	13.0	100
	(20–50)	60	258	4.30	9.00	7.9	5.3	5.1	97
	(50–80)	170	194	1.14	7.86	4.8	2.3	2.7	100
	(80–95)	47	136	2.89	6.06	4.1	2.0	2.0	98
	(95–110)	48	137	2.85	5.93	3.8	1.5	2.0	100
Gypsic Calcixerept (Gypsic Calcisol, WRB) *MG64*	(0–15)	574	777	1.35	4.61	19.8	13.5	14.5	100
	(15–60)	154	333	2.16	5.68	9.7	5.7	6.3	100
	(60–80)	87	273	3.14	7.34	7.9	5.5	7.2	100
	(80–100)	72	232	3.22	6.11	5.2	2.7	3.2	100

Soil classification according to Soil Taxonomy, in Dell'Abate et al. (2002b), in parenthesis the corresponding WRB classification is reported. *Cmic* microbial biomass carbon, mg C kg^{-1} soil; *Ccum* cumulative respiration, C–CO_2 total production at 32nd day, mg C–CO_2 kg^{-1} soil; qCO_2 metabolic quotient, (mg C-CO_2) (mg Cmic kg^{-1} soil)$^{-1}$ h^{-1} ; *K* rate constant of carbon mineralization; *Corg* total organic carbon, g C kg^{-1} soil; *Cext* total extractable carbon, g C kg^{-1} soil; Cha + fa = humic and fulvic acid carbon g C kg^{-1} soil; *DH* humification degree, mg Cha + fa mg $Cext^{-1}$ 100

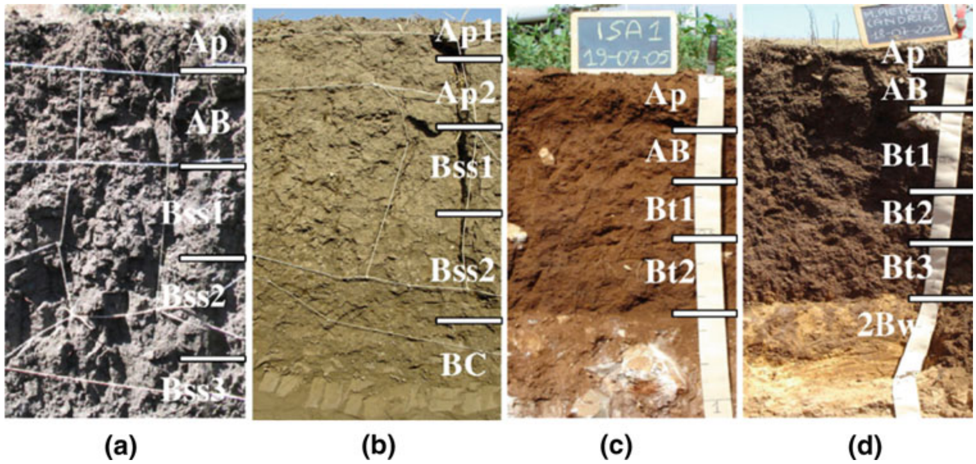

Fig. 7.6 **a** Typic Haploxerert (Grumi Pellic Vertisol, WRB), **b** Xeric Epiaquert (Chromic Vertisol, WRB), **c** Mollic Haploxeralf (Luvic Phaeozem, WRB) and **d** Ultic Haploxeralf (Chromic Luvisol, WRB) located in Sicilian hills (**a**), Basilicata plains (**b**) and Apulia plains (**c**–**d**) (Marinari et al. 2010, photo by C. Dazzi)

characteristics were also related to the different microbial activities and organic carbon turnover times in the two soil profiles (Dell'Abate et al. 2006).

The relationship between the presence of either labile or stabilized organic fractions along the soil profile and the rate of microbial activity in the subsoil, especially in deep horizons, were also observed in a floodplain soil sequence in a Mediterranean environment in Sicily comprising two Vertic Cambisols and a Calcaric Fluvisol (WRB 2007) (Fig. 7.7). In the deep horizons of the Calcaric Fluvisol, the organic matter was entirely in humified forms and the microbial indices indicated metabolic stress due to the harsh organic substrate decomposability, whereas in the two Vertic Cambisols, the microbial activity was almost constant along the soil profile (Dell'Abate et al. 2004).

The occurrence of mineralization activity in subsoil also observed in some Spanish environments was related to the more favourable temperature and water conditions in the deeper horizons in the Mediterranean climate (Rovira and Vallejo 1997).

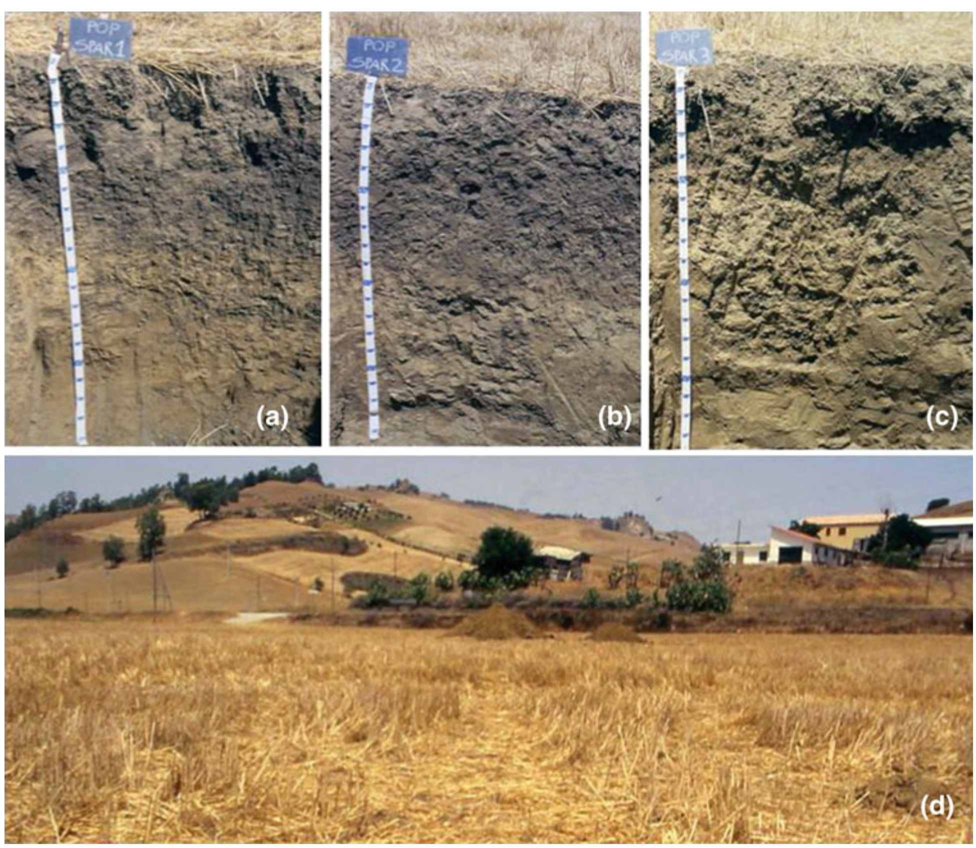

Fig. 7.7 Vertic Cambisol (**a**, **b**), Calcaric Fluvisol (**c**) and soilscape (**d**) of fluvial plain and terraces of Tumarrano Stream (Sparacia, AG, photo by C. Dazzi)

Another investigation (Pinzari et al. 2001) on the influence of plant cover on soil profile evolution was carried out in western Sicily in a homogeneous forested area on Lithic Haploxerolls (Leptic Phaeozems; WRB 2007) 40 years after afforestation with two different plant species, *Pinus halepensis* Miller (ten soil profiles) and *Cedrus atlantica* (Endl) Carrière (ten soil profiles) (Fig. 7.8).

Different types of soil profile evolution were recorded under the two tree stands with the formation of different humus forms—Moder–Mormoder under Cedrus and Mor–Hemimor under Pinus (Dazzi 1996)—along with different C storage in the forest floor—higher under Pinus than Cedrus (Pinzari et al. 2001). Different microbial metabolic activity levels were also recorded in the mineral horizons under the two tree stands; while the decay rate of organic matter (k) calculated by carbon mineralization did not differ significantly, basal respiration, metabolic quotients and microbial biomass carbon all differed. In particular, smaller amounts of microbial biomass sustained higher metabolic activity under the Pinus trees, indicating a condition of metabolic stress and a more rapid nutrient exchange rate between soil microbial biomass and the environment in the soils under *P. halepensis* than in the soils under *C. atlantica* (Pinzari et al. 2001). Finally, it was found that the plantation also influenced the humification process as the amount of humified organic fraction stored in both organic and A horizons was highest under Pinus, and elemental and some spectroscopic characteristics of humic acids separated along the soil profile were different under the two tree stands (Dell'Abate et al. 2002a), suggesting that microflora and plant coverage play different roles in soil profile evolution, which could affect the pedogenetic processes.

7.2.4 Influence of Diagnostic and Functional Soil Features on Microbial Biomass Inside SOM Balance

The geographical investigations carried out in north Italy (Po Plain and high-terraced surfaces in Lombardy) and in central Italy on volcanic, terrigenous sandstone–siltstone and marly calcareous hills and terraced sandy coastal dune soilscapes in Lazio identified the Cmic/SOC indicator trend for about 400 pedons belonging to 24 types of soils classified at WRB second level (IUSS, 2007). The Cmic/SOC ratio, expressed as a percentage, shows the relationship between "active" and "passive" organic carbon fractions within the SOC fraction and is "considered by some to be an indicator of health or stress of the soil microbial community, a healthy, low-stress community being able to sustain a relatively high level of Cmic with a given level of SOC" (Magdoff and Weil 2004).

In the first boxplot (Fig. 7.9), the first 12 soil types are grouped according to medium–low rate of pedogenetic evolution for the main reference groups (Arenosols, Cambisols, Phaeozems, Chernozems and Umbrisols), whereas in the second boxplot (Fig. 7.10), the second 12 types are grouped according a high evolution rate (Luvisols, Alisols, Andosols, Vertisols), except for soils with dominant redoximorphic features (Stagnic and Gleyic properties) both at reference group (Gleysols and Fluvisols) and second-level qualifiers that were kept aside.

Results of both the figures show that the Cmic/SOC rate is generally higher in the Arenosols, in some Cambisols type and in all the Phaeozems (Fig. 7.11c) than in the Pachic Chernozems. The presence of redoximorphic features

Fig. 7.8 Lithic Haploxerolls (Pinzari et al. 2001; photo by C. Dazzi) (Leptic Phaeozem, WRB 2007) and soilscape with *P. halepensis* of the Sicani Mountains (West-Central Sicily)

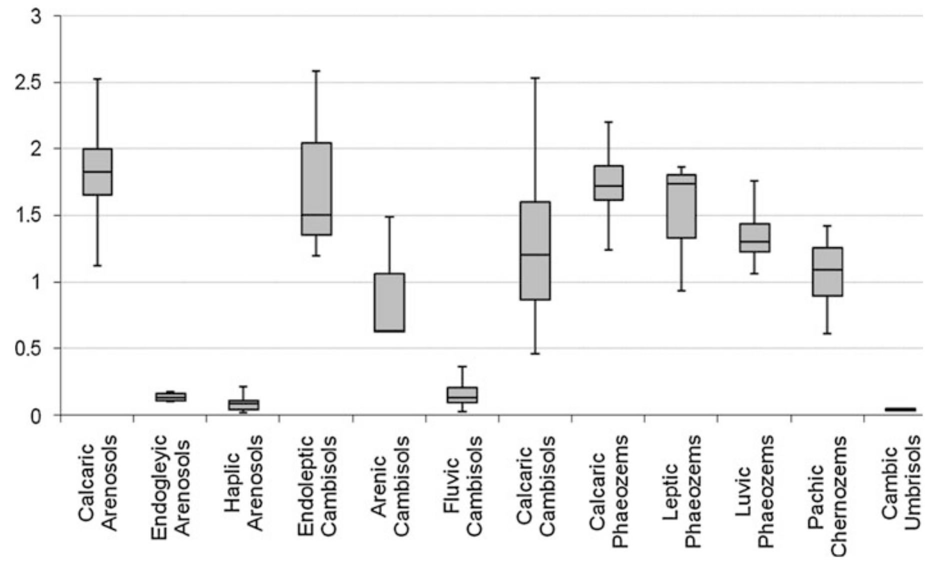

Fig. 7.9 Distribution of Cmic/SOC (%) within reference groups at medium–low rate pedogenetic evolution

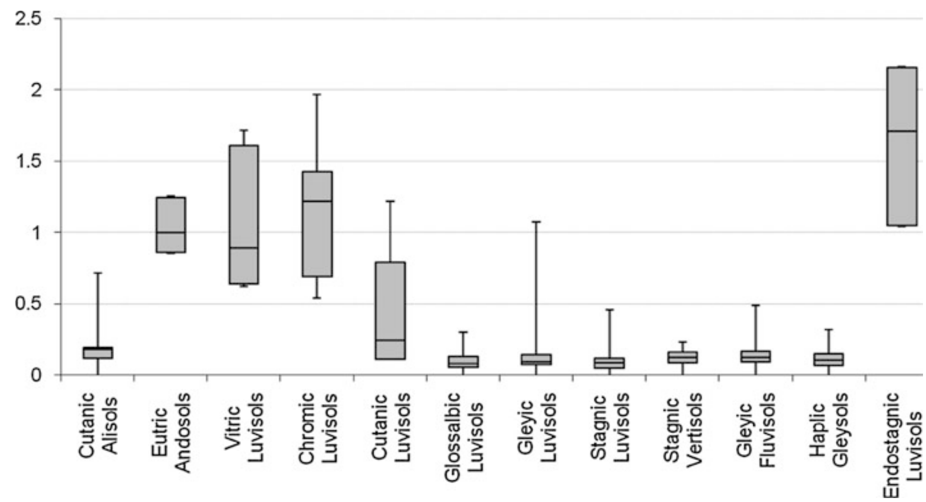

Fig. 7.10 Distribution of Cmic/SOC (%) within reference groups at high pedogenetic evolution rate

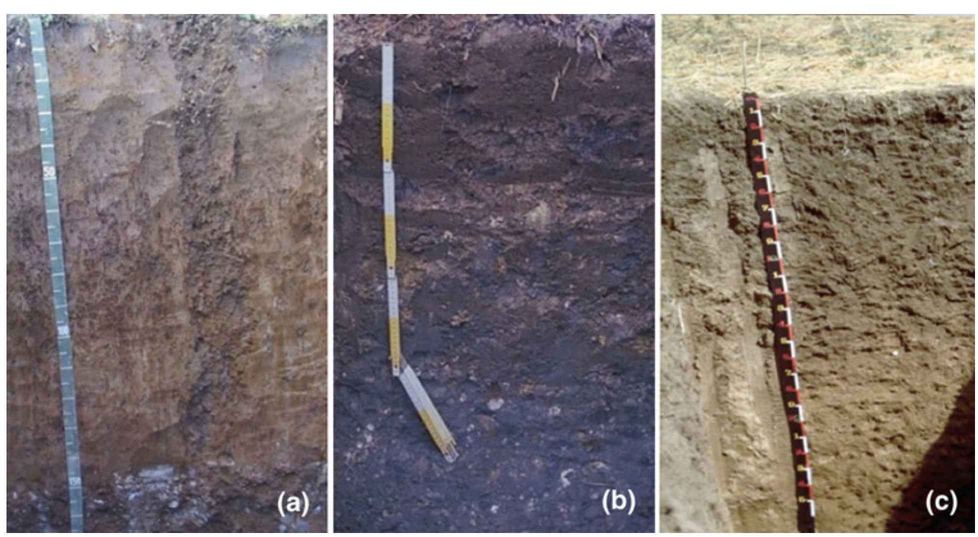

Fig. 7.11 Cutanic Alisol of the high sandy gravelly morenic terraces (**a**) and Gleysol of the low Po Plain (**b**) of Lombardy and Calcaric Phaeozem of Lazio inter mountain valley (**c**)

caused by less than perfect aerobic conditions in certain periods or all year round (as in the low-lying Po Plain areas with shallow groundwater tables) seems to strongly depress the microbial community in the presence of diagnostic Stagnic and Gleyic properties as do high aluminium values in the case of the Cutanic Alisols (Fig. 7.11a, b).

7.3 Ecological Services and Microbial Diversity (Genetic and Functional Diversity)

The ecological services provided by soil are guaranteed by microbial diversity. In this part of the chapter, we will discuss the prominence of soil biota resilience in maintaining soil fertility and sustaining ecological services, as well as providing a brief description of analytical methods.

All soil microorganisms (e.g. aerobic or anaerobic, free-living or symbiotic, culturable or non-culturable, etc.) can be used as indices for soil quality and soil health as they fulfil several key processes (e.g. nitrogen fixation, organic matter mineralization, nitrogen nitrification, etc.). A comprehensive index combining all aspects of soil complexity in a single formula and permitting accurate comparison among sites and plots has yet to be proposed. Some attempts have recently been made to transform groups of variables into indicators of soil biotic activity, using three different approaches: (a) a shopping list approach, whereby a set of different soil parameters is assessed; (b) a benchmark approach, whereby the degree of deviation between reference situations and actual measurements is evaluated; and (c) a numerical approach, whereby synthetic indices are developed (Bloem et al. 2006).

The traditional approach to studying soil microbes requires organisms to be cultivated in pure cultures and then characterized phenotypically and genotypically. However, soil microbial ecology is turning increasingly to molecular approaches, given that less than 1 % of total bacteria are generally recovered from most soils by means of conventional cultivation techniques.

In this part of the chapter, we will propose several examples of soil fertility depletion related to soil organic matter and soil biodiversity erosion.

Soil degradation forms such as soil erosion and soil contamination are among the fifteen emergencies that humankind must resolve in the third millennium to safeguard the planet and ensure its own survival (Zichichi 1993). Microbiological properties are held to be more sensitive to changes in land management and environmental conditions than chemical and physical properties, and changes in the composition of soil microflora can be crucial for the functional integrity of soil. Nannipieri et al. (2003) reviewed interrelationships between microflora, its diversity and function in soil; they discussed the impact on microbial diversity and soil functioning of different sources of stress, such as low pH and pollutants, although they did not mention genetically modified organisms (GMOs).

The ecological role of soil biodiversity in biogeochemical cycles is well known, but current scientific knowledge is unable to quantify microbial diversity loss using general criteria and shared methods tested in an environmental monitoring network. Even though microbial genetic diversity reflects the variation in species assemblages within a community, a broader view of functional diversity has advanced our understanding of the significance of biodiversity for biochemical cycling on several levels of resolution.

The first step involves using traditional approaches to determine the main chemical–physical properties of soil in order to relate soil biodiversity to soil functions and quality. The next step involves determining diversity using general approaches (i.e. microbial respiration, microbial biomass, etc.) as well as molecular approaches (Mocali and Benedetti 2010). In order to understand and monitor microbial diversity erosion processes, it is vital to proceed by analysing and comparing the information collected over a period of time. Microbial diversity of soil can only be defined by using molecular techniques monitoring data in time and space.

The lack of national monitoring data makes it extremely difficult to characterize Italian soils according to biological functions and ecological services. The only informations available are data from spot analysis of experimental fields or from research activities carried out by various authors in specific areas (Benedetti and Mocali 2008).

Microorganisms play a key role in determining soil biological functions. Measuring global biological fertility of soil provides suitable information to characterize the functionality of different soils. Benedetti et al. (2006) proposed a synthetic index of biological fertility (IBF) of soil that classified soils according to 5 different categories as shown in the following Table 7.2.

According to this ranking scheme, at a preliminary stage of classification, most Italian forest soils lie in Class V, a large part of agricultural soils managed by conventional techniques lies in Classes I and II, and all other agricultural soils are in Class III, while a minority of soils are in Class IV.

The results of two field surveys carried out at regional level are reported below.

7.3.1 IBF Monitoring Programmes and Soil Thematic Maps of Biological Fertility

Monitoring programmes of soil biological fertility were carried out both in northern and central Italy, throughout the agricultural areas of the Lombardy and Latium regions.

Table 7.2 Biological fertility index of soil (IBF)

Parameters	Range				
	1	2	3	4	5
Organic matter (%)	<1	1–1.5	1.5–2	2–3	>3
Basal respiration (ppm)	<5	5–10	10–15	15–20	>20
Cumulative respiration (ppm)	<100	100–250	250–400	400–600	>600
Microbial carbon (ppm)	<100	100–200	200–300	300–400	>400
Metabolic quotient	>0.4	0.3–0.4	0.2–0.3	0.1–0.2	<0.1
Mineralization quotient	<1	1–2	2–3	3–4	>4
For each biological parameters were prefixed 5 increasing ranges to which correspond 5 values (from 1 to 5)					
The sum of single values obtained for the six parameters (the minimum is 6 and the maximum 30) in a given soil establishes the class of biological fertility—IBF RANGE					
Biological fertility class	I	II	III	IV	V
	alarm	stress	medium	good	high
Range	6	7–12	13–18	19–24	25–30

At first level, the results were reported as relations between IBF values and soil classification types; at second level, relations with the physical and chemical characteristics of soils were analysed. Relations with soil types made it possible to create links with Soil Typological Units within the Soil System Map and to produce a first draft of the thematic map of soil biological fertility.

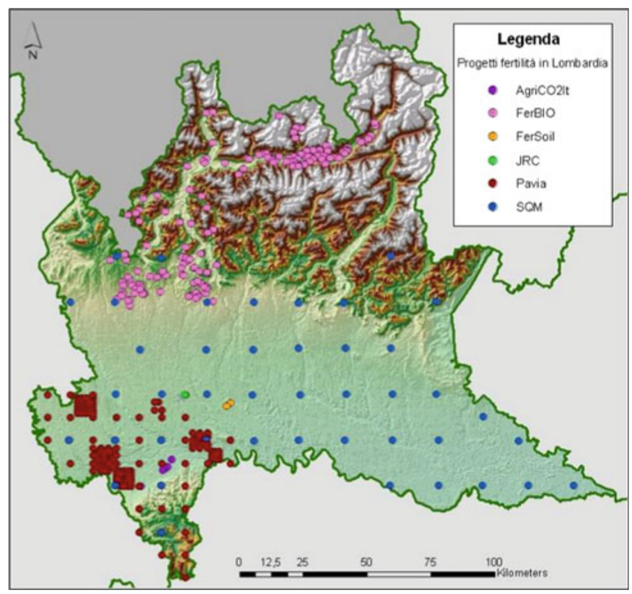

Fig. 7.12 Distribution of soil biological fertility monitoring points inside the different projects carried out in Lombardy

7.3.2 Biological Fertility Monitoring and Mapping Programmes in North Italy

In Lombardy, soil data were collected (and subsequently harmonized) from 400 sampling and monitoring points included in different monitoring programmes and projects: AgriCO2ltura, FERB I (2005–2006), FERSOIL (POC1 and POC2), Pavia and SOILQUALIMON. The projects, having different aims, used various types of soil samples, which were collected by means of different sampling strategies (single or multiple plots on the same site, different monitoring times, single or multiple times/sites). Sampling points distribution is shown on the map in Fig. 7.12.

IBF values obtained for all 400 soil sampling and monitoring sites were grouped by Soil Reference Group according to WRB (2007). The boxplot in Fig. 7.13 shows the distribution of IBF values for the 10 reference groups present in the Lombardy Po Plain and medium- and high-terraced areas with agricultural land use; very low values of IBF were found in some sites on sandy Arenosols, Luvisols and Gleysols in the low fluvial plain and Holocene terraces, placing such areas in the stress and alarm classes.

The thematic map of soil biological fertility drawn up for a 790,000 ha area in the Lombardy Po Plain—60 % of the total farmland—used the more restrictive IBF class for the Soil Map Unit (Fig. 7.14).

7.3.3 Biological Fertility Monitoring and Mapping Programmes in Central Italy

Several projects were conducted to monitor soil biodiversity in central Italy, in the Latium region, in particular. The 2004–2006 and 2010–2011 field campaigns of the BIORELA project investigated 100 and 88 sites, respectively. One hundred and twenty-seven sites producing complete data have been used so far for the purpose of IBF determination. These 127 monitoring points situated in the agricultural areas of Lazio were associated with 21 different Soil System Cartographic units.

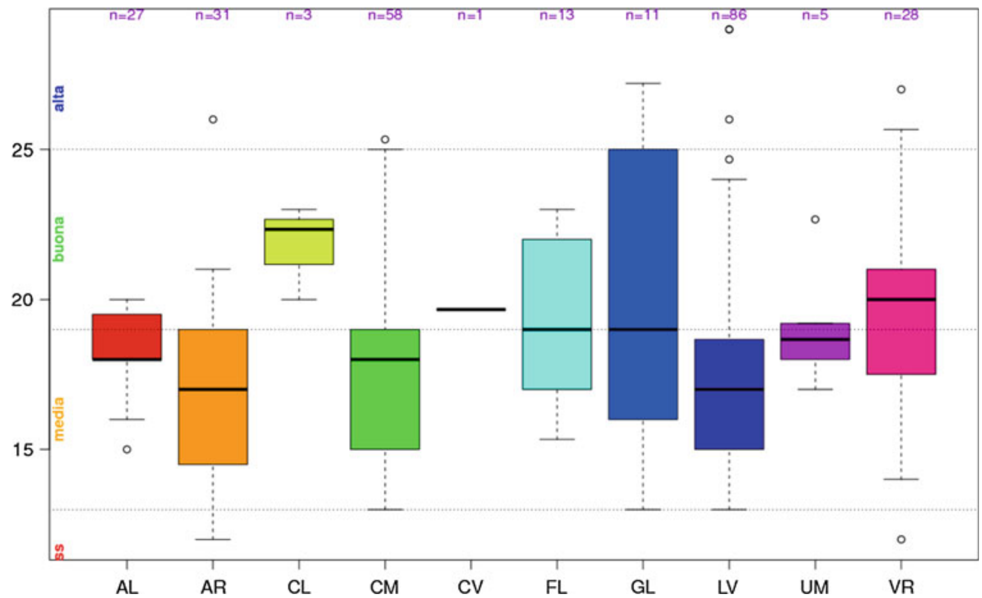

Fig. 7.13 Boxplot of distribution of IBF values within the major WRB Soil Reference Groups in monitored sites in Lombardy

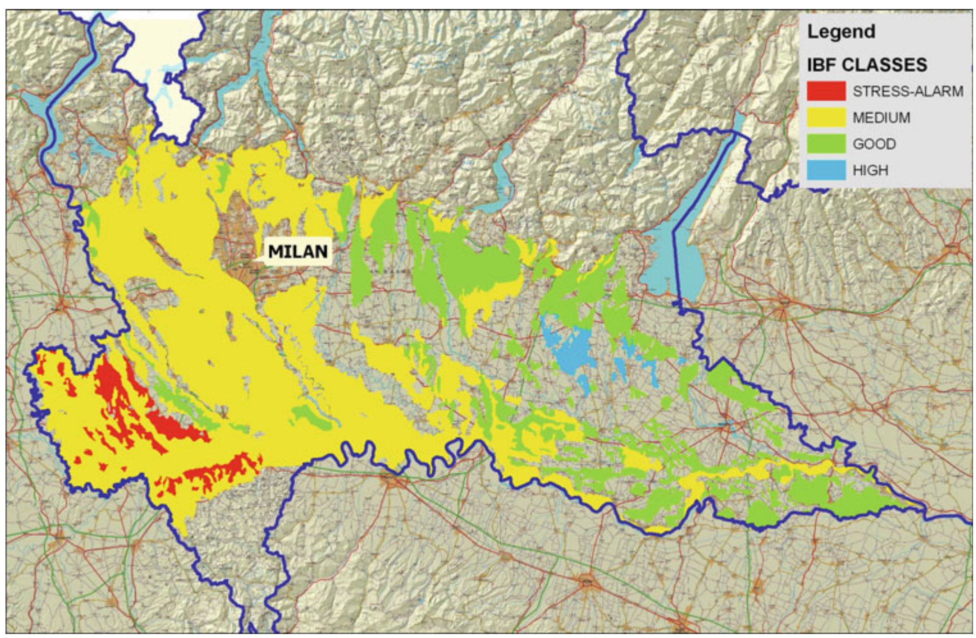

Fig. 7.14 Soil Biological Fertility Map of Po Plain and medium–high fluvio-glacial terraces in the Lombardy region

The exploration of the relationships between biodiversity and pedodiversity was based on the microbiological parameters used in the standard soil quality definition practice, intended as a biological fertility index IBF (Benedetti et al. 2006). The trend of these microbiological variables was assigned according to the placement of the monitoring points and the various soil types reported by the mapping of the various systems in the Latium region, with particular reference to the main types of soil (STS) in each mapping unit. A subsequent in-depth monitoring phase allowed us to check the correspondence of this soil information using a series of physical–chemical parameters and the characteristics of sampling biodiversity in the surface horizon concerned (class and textural fractions, total organic carbon, pH, $CaCO_3$ %).

These relationships were explored on various levels, starting with a general analysis of the IBF trend referred to soil types and classes of land use. Subsequent phases involved the in-depth study of the following: a) the distribution of performance values of individual microbiological indices grouped by general classification level (WRB referential group) and by the presence/absence of

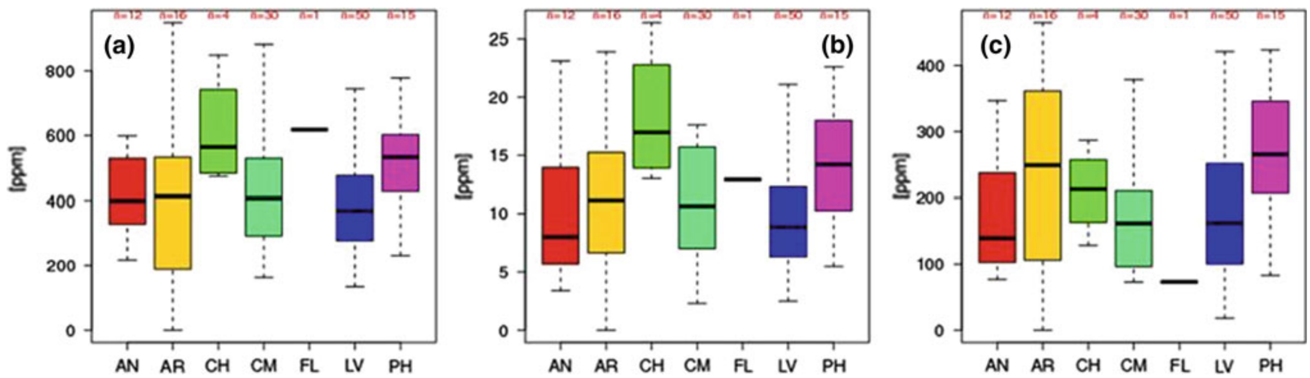

Fig. 7.15 Distribution of cumulative (**a**) and basal (**b**) microbial respiration and biomass carbon values (**c**) for different WRB Reference Group soils

horizons, properties and diagnostic materials and processes related to properties and pedogenic thresholds related to specific analytical and/or pattern recognition; b) individual "functional" soil characteristics (whether chemical, biochemical or physical) such as textural class (USDA), bulk density and packing density (an indicator of particle clustering which takes into account percentages of clay and $CaCO_3$, pH, and organic carbon content).

The first qualitative analysis shows that, overall, the distribution of IBF values ranges from fair to good for all types of soils, with high values for Luvisols (Chromic and Cutanic) and Phaeozems (Calcaric and Leptic Luvic) only and negative stress and alarm values in specific sites with Arenosols (Hypoluvic and Calcaric) and in just a few sites with Cutanic Luvisols.

On a more detailed classification level, comparison of the main microbiological indices of basal (Fig. 7.15a) and cumulative (Fig. 7.15b) respiration, and biomass carbon (Fig. 7.15c), with WRB Reference Groups indicates a high overall distribution of values for the Chernozem and Phaeozem groups and lower values for Luvisols, Cambisols and Andosols. The wide distribution of all three indices and the minimum values very low (stress and alarm classes) revealed for Arenosols seems to be related to the low soil evolution rate (Fig. 7.15).

The comparison with single physical and chemical functional characteristics (Fig. 7.16) showed positive trends in the case of transition to higher classes of apparent density and negative packing density increases; in the case of textural classes, a generally downward trend for the transition from fine to coarse classes; and finally, a tendency towards an increase in pH (from acidic to basic conditions) as well as increase in index values of $CaCO_3$ content up to a threshold value corresponding to the percentages for the presence of a diagnostic Calcic horizon, after which a marked decrease was measured.

A first rough Soil Biological fertility map was drawn up for the Latium region on the basis of the results from the 127 monitoring sites and classification within IBF classes. As in the case of northern Italy, the mapping criterion adopted used more restrictive IBF class for the Soil Map Unit (Fig. 7.17). Distribution according to the various local districts is reported in Table 7.3.

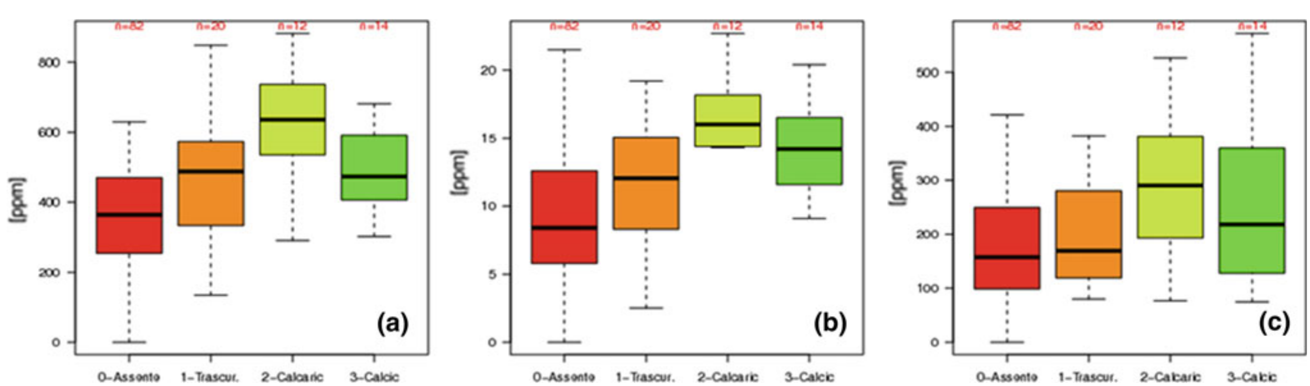

Fig. 7.16 Boxplot of the cumulative (**a**), basal (**b**) respiration and biomass carbon (**c**) distribution values versus diagnostic WRB $CaCO_3$ classes. *Box Legend* no $CaCO_3$ (red), negligible (orange), Calcaric (5–15 % of $CaCO_3$—yellow), Calcic (more of 15 % of $CaCO_3$—green)

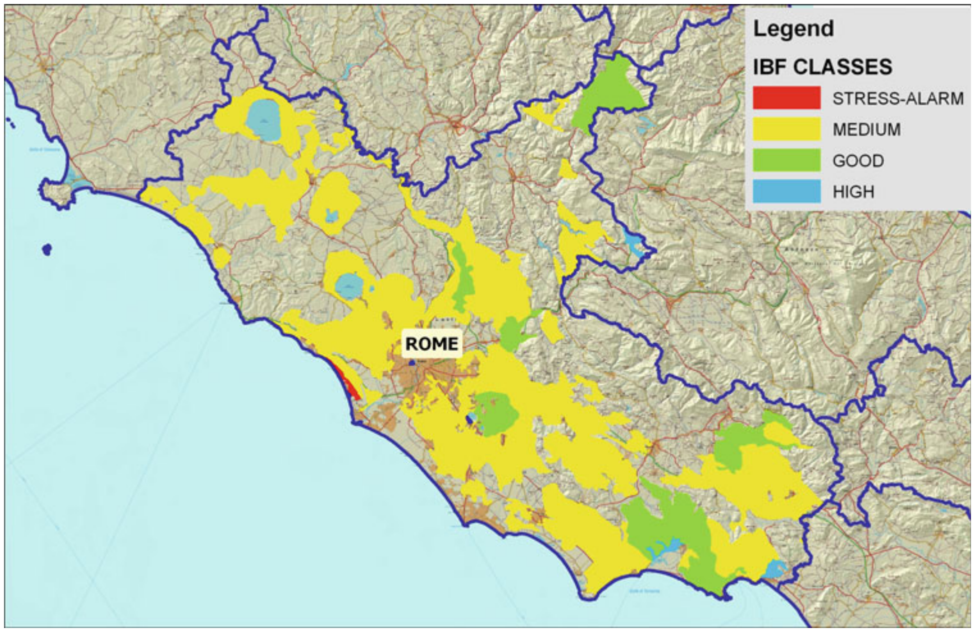

Fig. 7.17 Soil biological fertility map of the latium region

Table 7.3 Distribution of IBF values obtained in the monitoring programme carried out in various districts of the Lazio region (Rome, Latina, Frosinone, Rieti and Viterbo)

Location	Class				
	I	II	III	IV	V
Rome	0	0	30	57	13
Latina	0	0	61	22	17
Frosinone	0	0	35	59	6
Rieti	0	0	21	42	37
Viterbo	0	13	48	39	0
% on total	0	2.6	39	43.8	14.6

7.4 Soil Biological Degradation and Functional Loss

The biological erosion of the microbial genetic resources of soils is an important issue that must be taken into account when examining Italian soilscapes. Depletion in biological soil functions directly or indirectly caused by anthropic activities was identified at various soil depths. The main causes of loss of biological fertility and impairment of soil biological function are long-term use of inappropriate agricultural practices such as monoculture with high nutrient-demanding crops, common pathogen control practices such as fumigation as well as industrial pollution in the areas around cities and large urban settlements; the negative impact on soil microbial communities is even greater in areas where such soil management practices overlap. At the time of writing, we are not sure exactly to what extent natural pressures such as climate change or natural disasters worsen these effects, for example, the desertification processes taking place in vast areas in southern Italy may play an important role in these degradation processes.

Some examples of soil biological fertility status in relation to the harmful soil management practices described above are reported below. Moreover, the results of a study conducted by using biotechnological techniques revealed that different genetically modified (GM) crops could induce a significant impact on biogeochemical cycles and composition of the soil microbial community diversity, at different rates and in a wide range of soils.

7.4.1 Effects of Soil Fumigants on Monocultural Crops

This study (Mocali et al. 2008) evaluated the effect of the 1,3-D (dichloropropane) fumigant on microbial activity, microbial biomass and diversity of culturable heterotrophic

Fig. 7.18 Calcaric Arenosol and location of soilscape

microbial soil communities although they represent only a small proportion of bacteria-inhabiting soil.

The soil type was identified as a Calcaric Arenosol (WRB 2007) belonging to the Soil System with "coastal plain with dune bar and terraced dunes with artificial drainage on Aeolian deposits covered by row crops" (Fig. 7.18, lies within EU Soil Region 60.7).

1,3-D was used to fumigate soil in the Maccarese area (Rome) against nematodes. The analysis of the soil characteristics in this area, which has been cultivated with carrots for over 20 years, showed serious soil fertility depletion (sand 92 %, pH 8.3, organic matter 0.43 %; Fig. 7.19).

Fig. 7.19 Topsoil with monoculture (Carrots) from Maccarese, Rome (photo by A.Benedetti)

This case proved that fumigation with 1,3-D led to a great loss in soil biological fertility and reduction in a selected bacteria community. The amplified DNA restriction analysis produced an ARDRA profile (haplotypes), revealing the presence of only a few colonies in the soil: only 5 haplotypes corresponded to 64 % of the total bacterial species reported in Table 7.4. Selective pressure induced by 1,3-D strongly favoured microorganisms resistant to the fumigant through the formation of spores. However, it could be possible that the presence of very high percentage of Gram-positive bacteria in a fumigated soil and, in particular, of the genus Bacillus might be related to the ability of these bacteria to form spores to protect themselves from the fumigants rather than to a set of genes involved in biodegradation of 1,3-D.

7.4.2 Effects of Monoculture, Organic, Rotation Practices and Soil Natural Chemical Limitations

The biological fertility of three soils with different types of soil management was investigated using a "traditional approach": (1) Endoleptic Vitric Andosol with vegetable (Rome); (2) Eutric Cambisol with tobacco monoculture (Città di Castello, Tiberina Valley); and (3) Cutanic Luvisol with durum wheat (Paliano, Frosinone).

The three different experimental fields were characterized by different levels of physical–chemical fertility. On the basis of these characteristics (Table 7.5), the sites were identified as being representative of high (Endoleptic Vitric Andosol), medium (Eutric Cambisol) and low (Cutanic Luvisol) levels of fertility.

Table 7.4 Most of culturable bacterial species (about 64 % of the total) present in the fumigated soil

Haplotype	Species	% on total
C2L8	Bacillus firmus	26
FL13	Bacillus firmus	12.7
C2M7	Bacillus simplex	11.7
FL3	Bacillus licheniformis	8.4
F + CM7	Arthrobacter sp.	5.8

Table 7.5 General physical and chemical characteristics of the topsoils

Soil	Clay (%)	Field Capacity (%)	pH H_2O (1:2.5)	pH KC1	$CaCO_3$ (g kg^{-1})	$CaCO_3$ act. (g kg^{-1})	P_2O_5 (mg kg^{-1})	Extract. P (mg kg^{-1})	SOC (%)	Total N (%)	C/N	CEC (cmol kg^{-1})
Endoleptic Vitric Andosol	9.3	34.5	7.5	7	61	25	222	3453	2.44	0.175	13.94	27.8
Eutric Cambisol	26.5	18.0	7.9	7.2	73	23	24	145	1.18	0.131	9.01	17.4
Cutanic Luvisol	30.9	40.3	5.8	4	–	–	83	208	0.27	0.038	7.10	16.1

Table 7.6 Soil biological fertility parameters

Location	Respiration (C–CO_2 -mg $Kg^{-1)}$	Nitrification (%)	Ammonification (%)
Roma	349	100	89
Città di Castello	110	76	51
Paliano	87	55	29

The biological fertility analysis (Table 7.6) showed high values for the Andosol but extremely low values for both Cambisol and Luvisol. The soil respiration, nitrification and ammonification activity values for the latter two soils were very similar and at odds with their physical–chemical characteristics. The reasons seemed to be related to the management of the different experimental fields. In fact, the Andosol was managed according to good agricultural practices (organic fertilization, minimum tillage, plant rotation, etc.), whereas the Cambisol had serious limiting factors with regard to pH and organic matter content. The Luvisol site was a typical intensive farming site cultivated for over 20 years with a high-yield tobacco monoculture (massive mineral fertilization, deep tillage, irrigation, pesticide application and so on) (Benedetti 1983).

7.4.3 Restriction Effects on Microbial Activity by Industrial Oil Pollution

Although bioremediation of polluted soils can be achieved by using oil-degrading bacterial consortia as well as endogenous soil microorganisms, one of the factors limiting effective and complete degradation of hydrocarbons is their reduced bioavailability to soil microorganisms mainly caused by their limited solubility in aqueous media. The case study was performed on sandy soils (Table 7.7) classified as Arenic Calcic Phaeozems on low hillslopes with sandy quaternary deposits and calcareous gravel levels, located just north-west of Rome (Mezzaluna Soils of the Rome Municipality Soil Map at 1:50,000 scale, Arnoldus-Huyzendveld 2003).

This study compared the effects of adding cyclodextrin (Cy) and compost (C) upon the bioremediation of oil-polluted soil in an experimental trial (Fig. 7.20). Soils were added with three different amounts of oil (0.1, 2 and 6 % w/w) and incubated for 190 days.

Microbial biomass (Cmic) and soil respiration (Ccum) were determined in order to monitor the remediation process in microcosms. The functional and genetic diversity of soil microbial communities was determined by community level physiological profile (CLPP) and denaturing gradient gel electrophoresis (DGGE) analysis, respectively.

At the end of incubation, microbial carbon values in the bioremediated soils were higher than in the control trials. This result was caused by the enhanced mineralization

Table 7.7 Horizons and physico-chemical characterization of Arenic Calcic Phaeozem

Main analytical data/Horizons	Ap (0–30 cm)	Bw (30–50 cm)	BC (50–75 cm+)
pH (1:2.5)	7.9	8.0	8.2
Clay (%)	12	17	16
Silt (%)	6	2	3
Sand (%)	82	81	81
SOM (%)	2.4	0.7	0.6
C.E.C. (cmol kg $^{-1}$)	13.8	10.3	11.0
Base saturation (%)	100	100	100
CaCO3 (%)	4.2	6.1	8.4

Fig. 7.20 Experimental trial on Arenic Calcic Phaeozem and soil profile

processes in polluted soils (Fig. 7.21). In particular, the efficiency of carbon mineralization was higher in soils spiked with 2 % of petroleum and very low in the more polluted soils (6 % oil), suggesting a strong inhibition of microbial functions. Carbon flux behaviour differed between the more polluted soils and the others. The C + Cy combination appeared to be the most effective bioremediation treatment for 0.1 and 2.0 %, while the contribution of compost mineralization appears to be consistent.

The DGGE approach allowed us to monitor the composition of the bacterial community and its genetic diversity (Fig. 7.22). It showed differences between the communities in response to the different treatments, characterizing three microbial clusters corresponding to samples with three different levels of oil concentration, cyclodextrin and compost amounts. Samples with 0.1 % oil seem to resemble the control more than the 2 and 6 % samples although sample 0.1 PC is clustered with samples containing 2 % petroleum.

7.4.4 Impact of Cultivation of GM Crops on the Functioning of Microbial Communities

EU directive 18/2001 lays down general criteria on the release of genetically modified (GM) plants in Europe. For the first time ever, a law sets a limit for soil nitrogen and carbon recycling. Carbon and nitrogen mineralization or humification parameters should be able to detect carbon and nitrogen recycling in soil as they are indicators of biomass activity and ecosystem functions.

During the last decade, various authors tested different parameters in soil growing GM and non-GM plants (Bruinsma et al. 2003). In the present paragraph we refer about soil respiration rate, C biomass, nitrification test, humification parameters, total organic carbon and the metabolic quotient in order to evaluate the impact of GM crops. Molecular (DGGE and PCR analysis) and ecophysiological tests (Biolog analysis) were also carried out. A series of

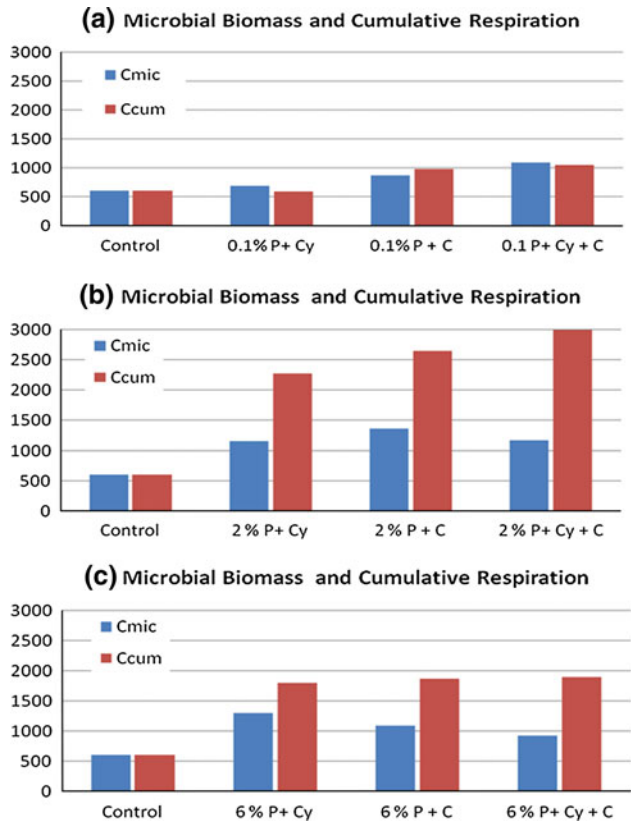

Fig. 7.21 Graph showing microbic biomass and cumulative respiration for 0.1 % (**a**), 2 % (**b**) and 6 % (**c**) oil amounts

experimental plots were evaluated for sweet rape, tomato, courgette and melon crops in central Italy (Lazio) on different types of Cambisols (Calcaric, Fluvic and Gleyic) and Luvisols (Vitric and Chromic).

Evaluation of results must take careful account of baseline biological soil fertility and microbial population management together with soil type and functional characteristics (Table 7.8). A general trend of loss in microbial biomass and a corresponding decrease in the Cmic/Corg rate was recorded for all soil types and all crops, depending on the start values. The lower the microbial biomass at start level, the greater the percentage decrease, with peaks of 40 % of the total (in the case of Vitric Luvisol with courgettes). This widespread decrease is accompanied by the enhancement of metabolic activity (qCO_2 values) that can reach values corresponding to fairly serious stress conditions (>0.3). Although the overall negative impact shown in soil biological erosion could be traced to the GM crops, further studies using molecular analysis will prove more effective in investigating plant–soil interaction within the rhizosphere in greater depth.

7.5 Soil Organic Matter, Biodiversity and Soil Physical Degradation

Following we describe some examples on how different management conditions can impact on soil organic matter content and biodiversity through soil physical degradation processes, as soil sealing, surface erosion, compaction and/or structural stability loss.

7.5.1 Structural Stability and Compaction Effects

SOM stabilization across soil types and disturbance regimes is also influenced by the rate of soil macroaggregate turnover and its changes. Microbial activity contributes to aggregate formation, stabilization and, eventually, degradation under the influence of various key factors including ratio of fungi to bacteria, soil texture and soil mineralogy. A review (Six et al. 2004) reported that in coarse-textured soils, aggregation is weakly related to microbial biomass and its metabolism products and more closely linked to the hyphal network, which is able to cross-link sand particles to form stable aggregates, whereas in clayey soils, both fungi and bacteria contribute to aggregation. Soil mineralogy was also found to influence the relationship between soil aggregation and soil biomass, with an high correlation in a Mollisol dominated by 2:1 clay minerals (illite) and no

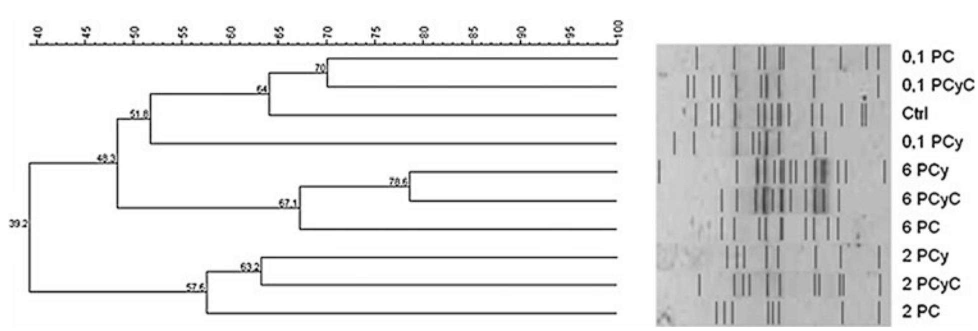

Fig. 7.22 Cluster analyses and 16S rRNA gene DGGE profiles (V6–V8 region) of eubacterial communities of polluted soils treated with cyclodextrin (*PCy*), compost (*C*), or both (*CyC*). Scale bar numbers indicate similarities among profiles

Table 7.8 Impact assessment of GM plants on soil biodiversity

Soil/Crop	Texture	pH	Corg (%)	HI	Cmic	Cmic/Corg	C–CO_2 bas.	qCO_2
Calcaric Cambisol								
Corn test	SiCL	8	1.8	0.4	343	1.9	12	0.15
Corn GM			1.8	0.4	319	1.8	12	0.16
Fluvic Cambisol								
Swiss rape test	CL	6.7	2.0	0.8	208	1.1	6	0.12
Swiss Rape GM			2.0	0.8	126	0.6	6	0.20
Chromic Luvisol								
Swiss rape test	CL	6.7	1.4	0.5	103	0.8	5	0.20
Swiss rape GM			1.2	0.6	72	0.6	5	0.29
Vitric Luvisol								
Tomato test	CL	6.1	0.6	0.4	165	2.5	2	0.05
Tomato GM			0.7	0.3	144	2.3	2	0.06
Vitric Luvisol								
Marrow test	LS	6.3	0.5	0.1	34	0.7	2	0.25
Marrow GM			0.5	0.2	20	0.4	2	0.42
Gleyic Cambisol								
Melon test	CL	6.7	5.5	0.3	159	2.9	16	0.42
Melon GM			5.6	0.3	148	0.3	14	0.39

Si Silty, *CL* Clay-loamy, *LS* Loam-silty

correlation in an Oxisol dominated by kaolinite (1:1 clay mineral) and oxides (Denef and Six 2005). On the other hand, a lesser-known aspect is related to the extent to which the physico-chemical characteristics of microaggregates and their response to environmental factors drive the microbial community structure and activity by determining the ecological niches of various microbial populations.

The Italian soils examined produced similar results in terms of distribution and stability of microaggregates, which varied according to soil type and SOM level. An experimental activity was carried out to verify the effectiveness of various Good Agricultural and Environmental Conditions (GAEC) standards laid down in the new EU CAP statements upon 6 different plots located in different Italian environments (Fig. 7.23): (1) Cutanic Luvisol on low Po Plain sandy terraces; (2) Vertic Cambisol on pliocene marine sediments on hilly slopes in central Italy; (3) Calcaric Cambisol on hilly fluvio-lacustrine sediments in central Italy; (4) Vitric Luvisol on volcanic plateau near Rome; (5) Eutric Vertisol on Campidano alluvio-lacustrine reclaimed areas in south Sardinia; (6) Grumic Calcic Vertisol on fluvio-lacustrine quaternary sediments on terraced areas in north Apulia (Dell'Abate et al. 2011).

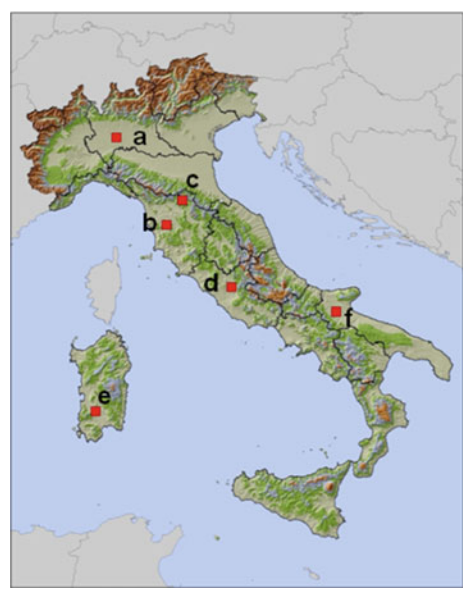

Fig. 7.23 Location of the 6 CRA experimental plots

Changes in microaggregate type and density were studied under controlled soil moisture and tillage conditions (Table 7.9). The results showed that although SOM content was almost identical, the distribution of microaggregates measured as mean weight diameter varied considerably within the 8.0–0.25 mm range as did the average bulk density of the same. In particular, Vertisols with dynamic clay minerals (mainly smectite and vermiculite) had low microaggregate density and distribution mainly in the smaller size classes, while central Italian Cambisols with different clay minerals (mainly illite) revealed fairly high density and distribution in the larger size classes (Fig. 7.24).

7.5.2 Soil Compaction, Crusting and Erosion Effects

Soil management is crucial for the prevention and control of its degradation. Different tillage systems such as deep ploughing, shallow ploughing, minimum tillage and ripper subsoiling all have different effects on soil conditions. The adoption of ripper subsoiling tillage is capable of reducing the structural damage caused by deep ploughing and of lessening the risk of formation of surface crusts and presence of compacted layers in the profile according to the findings of the micromorphological analysis and quantification of the pore system (Pagliai et al. 2006). Moreover, soil managed using ripper subsoiling conserves more organic carbon—especially in the top layer—and has greater amounts of organic matter than soils undergoing deep ploughing. Two sites located in Tuscany hillslopes on fluvio-lacustrine silty-clay deposits (site 1) and on marine silty-clay deposits (site 2), typical of hilly central Italian soilscapes, were investigated inside the Project "ATLAS—Indicators of Soil Quality" (Dell'Abate et al. 2006a).

The soils of these environments are quite similar: a Calcaric Vertic Cambisol (site 1) and a Vertic Cambisol (Fig. 7.25; site 2); even though the former is typical of udic and ustic soil moisture regimes and the latter of xeric ones, they both contain small amounts of organic carbon and are characterized by low structural stability and a poor regeneration capacity. This type of soils must be managed correctly to minimize the potential risk of formation of surface crusts, sealed surfaces and the risk of compaction by farming machinery. The resulting hazardous degradation in a hilly environment, reduced rainwater infiltration rate and creation of preferential surface runoff courses all play a role in triggering widespread rill and gully erosion processes.

Soil microbial activity was verified by determining soil microbial biomass carbon and respiration and then using the metabolic quotient (qCO_2) and C biomass/total organic C (Bc/TOC) ratio. Data concerning the quantity and activity of the microbial biomass for these two different situations demonstrated that ripper subsoiling (RS) is a better management practice than deep ploughing for the maintenance of total organic carbon and of the living fraction. In fact, microbial biomass content is greater than in RS management for both depths (Table 7.10). Results obtained for the two different management practices (Dell'Abate et al. 2006a) showed that qCO_2 was comparable with the two layers in the soil undergoing ripper subsoiling (RS), while it was higher at a depth of 20–40 cm in the soil where deep ploughing (DP) was adopted. A high value of qCO_2 in the ploughed zone (DP) reveals a lack of equilibrium due to the practice adopted. This conclusion was also confirmed by the Bc/TOC ratio: the value of microbial biomass in the deepest layer of the DP case was half the value found in RS to the same depth, while total organic carbon was practically constant.

The impact of two other types of soil management, a comparison of continuous wheat and continuous alfalfa, was assessed for site 2 in a field experiment established since 1994. The soil porosity values obtained in the 0–5 cm soil depth for the two areas on which the crops were grown showed that after heavy rain, soils supporting alfalfa had a higher porosity percentage than those from the wheat-growing area. The protective action of the alfalfa vegetation cover decreased soil surface vulnerability to the impact of rainfall and thus lessened the risk of formation of crusts. Moreover, wheat did not seem to be the most suitable crop as it depleted organic matter in the top soil horizon, while alfalfa conserved the organic matter better. Removal of the finest soil particles by water erosion led to preferential loss of the most stable and most strongly absorbed organic fraction (humin) that accumulated in the deeper layer (Pagliai et al. 2006).

The quantity of microbial biomass in the soil cultivated with alfalfa (L) was higher than in the soil cultivated with wheat (W). This was also confirmed by respiration data, which showed that the alfalfa crop seems more effective than wheat in preserving total soil organic carbon (Table 7.11). The C biomass/total organic carbon ratio had comparable values for the two crops at every depth as well as specific respiration (qCO_2). The latter was higher under both the crops in the deepest layer, indicating a metabolic stress condition. In brief, the alfalfa covering had a beneficial effect on the quantity of organic carbon and microbial biomass, whereas microbial metabolism was not affected by

Table 7.9 Texture, SOM and microaggregate bulk density under "*tilth*" conditions for 6 soils of CRA experimental plots

Soil type	Sand (%)	Clay (%)	Silt (%)	SOM (%)	Microaggregate bulk density
Cutanic Luvisol	44.88	20.88	34.24	1.43	1.71
Vertic Cambisol	11.00	42.00	47.00	1.48	4.82
Vitric Luvisol	31.05	21.85	47.10	2.03	1.18
Eutric Vertisol	41.84	33.58	24.58	2.07	0.94
Calcaric Vertic Cambisol	8.60	37.90	53.50	2.23	4.28
Grumic Calcic Vertisol	21.00	42.00	37.00	2.44	0.50

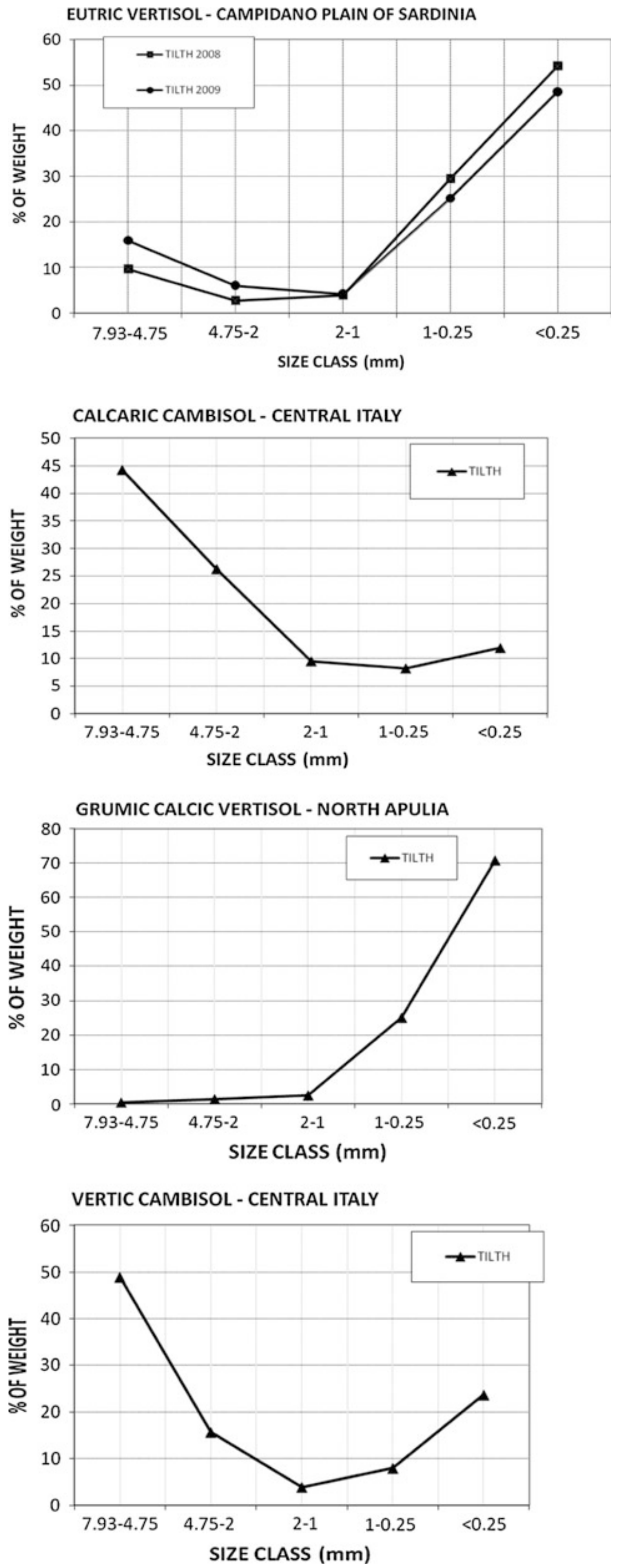

Fig. 7.24 Graphic distribution of microaggregates inside size classes as weight percentage for different soil types

the different crops (Dell'Abate et al. 2006a). The rationale for erosion environmental risk is to avoid sowing wheat in these soils, but indubitably, wheat is a more profitable crop than alfalfa.

7.6 Conclusions

This chapter discussed soil functions and ecological services mainly by considering soil microbial resources, a powerful driving force for many processes in soil, starting with soil formation. Many soil functions were not described given that they did not aim to provide a comprehensive overview of all ecological services linked to soil functions. This decision was mainly dictated by the fact that despite the growing impact of microbiological studies upon soil research, we have yet to attain an in-depth knowledge on how to manage soil microbial resources at field scale in order to preserve and improve soil functions. A number of examples relative to Italian soils were reported to demonstrate the possibility of describing soil functions and microbial activity at local level. We also drew up soil biological fertility maps for the Latium and Lombardy regions. The results of activities carried out in the different sites revealed the need to arrange the indicators on a hierarchical scale according to the study goal. The topic of hierarchical scales of different indicators is widely debated, and researchers are obviously more familiar, and expert, in using the standard parameters adopted in their laboratories.

In the case of Sect. 7.4 describing fumigated soils, the use of molecular techniques on culturable bacteria allowed us to verify the extent of genetic erosion induced by the fumigant. In addition, the bacteria isolated could be used to enhance the bioremediation of further fumigated soils. In the case of intensive monoculture adopted in Città di Castello, a significant reduction in biological fertility occurred although it is impossible to relate the results to any change in soil microbial diversity. Cases of genetic erosion of microbial genetic resources by intensive and aggressive agricultural management were also described. In these sites, IBF revealed loss in biological fertility. In the last example, the remediation of contaminated soils led to the modification in eubacterial diversity, revealed by DGGE. In this case, it was possible to evaluate the shift in the dominant bacterial species but not to identify them. Thus, different approaches are required in order to assess the erosion of microbial diversity, and an ecosystemic approach is recommended. In fact, the combination of appropriate traditional and molecular techniques allows us to monitor microbial diversity as well as provide a contextual environmental consequence.

Fig. 7.25 Vertic Cambisol on marine silty-clay sediments in hilly soilscape (Volterra, Tuscany)

Table 7.10 Soil microbial biomass carbon (Bc), C biomass/total organic carbon ratio (Bc/TOC) and metabolic quotient (qCO_2) in site 1

Sample soil (cm)	Bc (mg/kg)	Bc/TOC (%)	qCO_2 (μgCO_2-C/mg Cmic.h)
(RS) 0–20	203.8 ± 26.9	2.290 ± 0.004	0.0013 ± 0.0003
(RS) 20–40	137.7 ± 23.6	1.996 ± 0.004	0.0017 ± 0.0003
(DP) 0–20	121.3 ± 69.8	1.989 ± 0.012	0.0019 ± 0.0011
(DP) 20–40	73.8 ± 9.8	1.118 ± 0.010	0.0034 ± 0.0008

Table 7.11 Soil microbial biomass carbon (Bc), C biomass/total organic carbon ratio (Bc/TOC) and metabolic quotient (qCO_2) in the site 2

Sample soil (cm)	Bc (mg/kg)	Bc/TOC (%)	qCO_2 (μgCO_2-C/mg Cmic.h^{-1})
W 0–20	153.0 ± 40.2	3.188 ± 0.004	0.0017 ± 0.0005
W 20–40	89.9 ± 43.6	1.427 ± 0.008	0.0032 ± 0.0016
L 0–20	263.9 ± 144.0	3.341 ± 0.018	0.0013 ± 0.0007
L 20–40	151.3 ± 63.1	1.780 ± 0.007	0.0029 ± 0.0014

Finally, we reported some examples on correlation of soil organic matter content, microbial activity and other physical–chemical soil characteristics to demonstrate the possibility of qualifying soil quality in terms of soil functions.

Italy has yet to put into place a network monitoring biological fertility of soils in relation to soil function conservation. Currently, there are only data from individual sites at regional level (Lombardy, Latium, Marche, Sardinia and Piedmont) or at the level of experimental fields as in Fagna (Florence), Vicarello (Florence), Tor Mancina (Roma), all of which were reported.

This chapter aims to propose a methodological approach to the characterization of soil microbial resources by means of microbiological parameters of greater relevance and to exploit them at national level in monitoring programmes according to hierarchical level (Bloem et al. 2006; Mocali and Benedetti 2010).

A guide to the hierarchical use of indicators was provided by OECD requirements, whereby indicators must: be clearly correlated with a certain phenomenon or a certain feature that is being investigated or monitored; be highly correlated with the above-mentioned effect with minimum statistical variability; be unobscured by much less significant responses; have a sufficiently generalized, albeit not identical, validity in many analogous situations (OECD 1999).

It is clear that hierarchical levels can change depending upon whether the indicator is required for monitoring, for accurate characterization of a particular environment, for assessing or restoring previous changes or for starting up research. If the aim is to study soil quality in terms of fertility, the following hierarchical level could be applicable: C biomass and respiration rate, functional diversity, genetic diversity and case-by-case in-depth probes (heavy metals, genetically modified organisms, air pollution, erosion, etc.).

The first step in assessing biological soil fertility, that is, the expression of microbial turnover is to perform simple biochemical tests. The same tests can be used effectively for environmental monitoring. The next step could be to study the functional diversity of the ecosystem, followed by genetic diversity and then case-by-case in-depth probes. To date, some methodologies, for example, the ecophysiological profile and bacterial and fungal DNA studies cannot be utilized in nationwide, large-scale monitoring programmes.

Moreover, a minimum hierarchical level must also be identified for other correlated indicators in order to prevent false-negative and false-positive results. In the case where soil fertility is related to crop yield, physical fertility is just as important as chemical and biological fertility. Obviously, the correct functioning of aerobic microorganisms will not occur under, for example, conditions of oxygen limitation, extremes of pH or elevated salinity, and so on. Thus, it is crucial to build other hierarchical scales, which could be represented by the following for chemical soil indicators: organic matter, pH, available nutrients, various types of pollutants, etc.

The following factors could be adopted for physical soil fertility indicators (Vignozzi and Pagliai 2006): porosity, aggregate stability, compactness, sealing along the profile, structure loss, superficial crusts and potential risk of their formation, fissuring and erodibility.

The hierarchical scales will then be put together in an attempt to identify a minimum dataset taken from the point where the different hierarchical scales overlap. The scales used in different studies will obviously differ and range from environmental, pedological and agronomic indicators or factors to social and economic factors.

The examples reported in this chapter represent good applications of this methodological approach to describe Italian soils in terms of biological function.

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8 Soil Threats

Carmelo Dazzi and Giuseppe Lo Papa

8.1 Introduction

The environmental problems due to the soil threats are not newly known in the history of the world. The decline of the Mesopotamian civilization (6–7.000 b. p.) is ascribed by the historians, also to the salinization of the soils owed to the development of irrigation. The decline of more recent civilizations, like that Indians of the Viru Valley in Peru or that of the Harappa civilization of the Indoplains, in India and Pakistan or that of the Hohokam of the Salt River Valley in Arizona, are also to be imputed to the processes of secondary salinization of the soil (Tanji 1990). Nearly 2000 years ago, Cicero reported to the Roman senate on the destruction of the forests in North Africa and the resulting bare areas as similar to a desert.

A lesson that came from the past and that is important for Italians comes from the story of ancient Rome and the events leading to the decline and fall of the Roman Empire in the West (in 476). Historians maintain that Rome fell due to the decadence of its leaders, due to the corruption of its emperors and due to the superior military tactics of the barbaric invaders. There is obviously a lot of truth in this. However, the same historians reveal that the greatest cause of the decline is due to the slow process of fertility loss in the soils and, consequently, to their productive capability (Hughes and Thirgood 1982; Saltini 1984). The reduced agricultural production resulted in ever-diminishing harvests which were not sufficient to maintain the lifestyle of Roman citizens and their army or to supply enough wealth to maintain the great infrastructures of the Empire (roads, aqueducts, monuments, etc.).

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Italy was rich in forests at the beginning of Roman civilization, but the organization of the Empire and the demands from Rome, which was a real megalopolis with over a million inhabitants, led to transforming forests into pastures or agricultural land. The result was deforestation of most of the landscapes surrounding the Mediterranean basin. The same happened in Italy which had been stripped off most of its woodland towards the end of the Empire. The transformation of forest soils into pastures or arable land seemed to work at first because the soils were rich in organic matter and nutrients and they produced abundant crops. Unfortunately, deforestation left the soils exposed to the inclemency of the weather. The organic matter diminished due to oxidation, and the nutrients were washed away by the rain which was also an agent of erosion.

This progressive decline in soil fertility started just when Rome began to depend on agriculture as an alternative to its unsuccessful conquests. During the final period of the Empire, agriculture gave over 90 % of public income and products from the land were of vital importance to its survival.

Romans therefore tried to intensify agricultural production in order to provide food for citizens and soldiers. This led to the further exploitation of land which was already exhausted and caused a continuous slow depopulation of the country, which lasted for the whole period of the Empire. In some provinces of North Africa and along the entire Mediterranean basin, almost half of the arable land had been abandoned by the end of the third century.

Weakened by the depletion of its energy system, the Empire then fell. Basic services were reduced. The immense infrastructure on which it was based fell into ruin. Soldiers could no longer keep enemies at bay, and barbaric hordes began to weaken the Empire, beginning from its farthest lands. Towards the end of the fifth century, the invaders reached Rome. Its population, which had reached a peak of over a million, fell to under 30 thousand. Rome was reduced to a mass of rubble, a hard lesson on how pitilessly the earth can react (Dazzi 2008b). Such lesson from history

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should make us think about the close relationship between the quality of soils and the quality of life!

According to Rifkin (2001), in 2007, most of the earth's inhabitants have started to live in vast urban areas with populations of 10 million or more, mostly megacities with huge urban suburbs. Urbanization has certainly many positive aspects, starting with the benefit of cultural diversity, social exchange and commercial activity, but also causes enormous pressure on the natural soil systems.

Throughout Europe and particularly in Italy, people depend on the soil system for the services it provides, for other resources like water, wood, fibres and for some functions like climate regulating, waste disposal, detoxification of polluting agents and the protection of the ozone stratum in the atmosphere (all of which are dependent on the soils in some way).

Over the past decades Italians—as well as other European inhabitants—have loaded their soilscapes more intensely and quicker than ever before, in order to improve well-being and support economic development (EEA 2005). Italians live where rapid changes are reshaping the landscape as never before, modifying the quality of the soils and the environments. Wet areas have been drained for urban development; the use of mountain areas and plateau areas has changed in favour of leisure activities; hilly landscapes have become more and more eroded; coastal areas have become more saline and alkaline; forest areas are more and more prone to fires (Dazzi 2008a).

8.2 Main Threats of the Italian Soils

Italian soils range from the less to the most developed (see Chap. 6), and due to the features of the landscape (see Chap. 3) and of the climate (see Chap. 2) where they evolve and consequently to their characteristics, they are particularly vulnerable and fragile. Moreover, and particularly after the World War II, Italian soils have been subjected to an enormous anthropic pressure, which varies even in a considerable way from one environment to another.

Italy is one of the countries with high tourist traffic in the world (more than 40 million people each year) and has a population of a little bit more than 60 million people (200 persons/km^2). This anthropic pressure has such a strong impact on the environment that it sets off degradation processes in the soil endangering them in various ways.

As well as happens for many other European countries, the threats that endanger the soil of Italy can be traced back to the following types:

1. *Soil erosion* most of the Italian soilscapes are prone to water erosion, while areas prone to wind erosion have only a limited extension.
2. *Soil sealing/consumption* in Italy is very high and lead to a definitive loss of the soils of wide areas with a heavy influence on the surroundings soilscape.
3. *Soil pollution/contamination* mainly due to industrial development and/or settlements that in many cases determine local pollution/contamination.
4. *Soil salinization/alkalization* mainly due to irrigation with saline waters is particularly diffused in the plains and along the coastal areas.
5. *Soil decline in organic matter* mainly due to changes in land use and in soil managements even if Italian soils are generally poor in organic matter.
6. *Soil diversity loss* mainly linked to large-scale farming for growing large-income crops.
7. *Others soil threats* such as forest fires and landslides.

In the following chapters, each of these soil threats will be taken into consideration and discussed.

8.2.1 Soil Erosion

8.2.1.1 Introduction

Soil erosion is a naturally occurring process on all land surfaces. It is one of the main factors of soil genesis and occupies the intermediate slot in the sequence: weathering–erosion–transportation–deposition. Soil naturally removed has been called "background" or "geological" erosion. This natural soil-forming process can retard the soil development by continuous removal of surface soil particles. In steep slope gradients, natural erosion inhibits the development of soils contributing therefore to bareness or absence of vegetation. In general, background erosion removes soil at roughly the same rate as soil is formed, while the term *accelerated* soil erosion indicates the process involving soil loss at a much faster rate than it is formed. Accelerated soil erosion is one form of soil degradation affecting both agriculture and natural environments and, together with its associated impacts, nowadays is one of the most severe environmental problems. Ever since soil erosion is studied, it has been conceptually differentiated by agents causing transportation of soil material: *water erosion*, *wind erosion*, *mass wasting* or *mass erosion* (erosion by gravity) and *glacial erosion*. More recently, the use of powerful agricultural machinery has led to damaging amounts of soil moving downslope under the action of gravity: this is the so-called *tillage erosion* (Lobb et al. 2003; Torri 2003; Van Oost et al. 2006). All these forms of erosion share the negative impact in degrading soils by removing the particles from surface. This is the main on-site impact of soil erosion causing decreases in chemical, physical and biological soil fertility and complete biological unproductiveness whenever the process is accelerated and severe.

Fig. 8.1 Typical morphology of areas under intense soil erosion (badlands) in Italy, *calanchi*, on *left* and *biancane*, on *right*. (*Photos* from personal archive of G. Lo Papa and E.A.C. Costantini, respectively)

Mediterranean regions are particularly prone to soil erosion by water being subject to long dry periods followed by humid periods frequently characterized by erosive rain (storms). In arid and semiarid areas of Italy, this situation generally occurs during late summer when most of the agricultural soils are just ploughed. However, soils with a low rate of water infiltration are subjected to great run-off during winter–spring months when they are usually saturated. In Italy, clayey soils in arid lands subjected to this climate regime, cultivated without any anti-erosive practice and occupying steepest slopes are sensibly vulnerable to accelerated erosion by water. In these places, soil erosion has reached a stage of irreversibility and sometimes has practically eroded all the soil.

Morphological evidences of erosion by water on the soil surface are sometimes clearly visible, and generally, the erosion process is classified according to the following:

- Splash erosion, just the detachment of small soil particles caused by the impact of raindrops.
- Sheet erosion, soil particles after the detachment of the raindrop splash and reduction in soil infiltration are removed downslope by water flowing as a sheet.
- Rill erosion, when water flows in small, ephemeral concentrated flow paths on the soil surface, continuously evolving in time and space. Rills are small enough to not interfere with field machinery operations.
- Gully erosion, when water flows in narrow channels sufficiently deep that they would not be routinely destroyed by tillage operations. Gullies may range in depth from few dozen of centimetres to many metres.
- Stream erosion, in which there is a direct removal of sediment from stream banks.

These forms of erosion may sometime occur all together in the same field or slope. Evidences of sheet erosion may be noted in the field from soil loss (upper field border, longitudinal field border, areas close to electricity and telephone poles) and soil deposition (lower field border). Further evidence, especially clear to surveyors during the description of soil profiles, is the reduction in thickness or complete lack of topsoil horizons in some part of the landscape. Peculiar geomorphological evidences of intensive water erosion are the so-called *calanchi* and *biancane* (Fig. 8.1), both definable as badlands, which are two distinct erosional features common in the Neogene to Quaternary clays and widespread in the northern region of Emilia-Romagna, the central regions of Marche and Tuscany and the southern regions of Basilicata, Calabria and Sicily (Philips 1998).

Soil loss is the main on-site effect of soil erosion both in terms of decrease in soil thickness and in terms of soil quality. Loss of nutrient-rich upper horizons and the reduced water-holding capacity of many eroded soils results in a reduction in soil quality in terms of diminution of the soil fertility and suitability for agriculture. Sediment transported and deposited away from the soil surface causes so-called off-site impacts of erosion by water. Erosion of silty and clayey soils that contain smaller particles generates turbidity and diminishes light transmission compromising aquatic ecosystems. Soil lost from agricultural land may contain pollutants which, transported together with soil particles and deposited, can lead to damage, even disruption, of the ecosystems of lakes and rivers and to contamination of drinking water. Especially during extreme rainfall events, sediment may cause also problems to infrastructures involved by sediment transfer and deposition, that is, roads, human settlements. Furthermore, eroded sediment causes problems for water resource development through reservoir filling up (Bazzoffi and Chisci 1999).

The on-site and off-site impacts of soil erosion are key concerns for a sustainable land management. Moreover, the knowledge of their location and intensity has a huge importance because of the considerable economic impacts of soil erosion. In fact, estimates show that the costs of soil erosion damage can be considerable. On-farm costs correspond essentially to the agricultural production loss as a result of soil degradation and decrease in crop productivity. Off-farm costs, resulting from sediment flows and deposition, include extra expense to treat drinking water; costs of dredging rivers, lakes and reservoirs; damage to roads and buildings; and harmful effects on aquatic ecosystems, including recreational and commercial fishing (OECD 2008).

8.2.1.2 Assessment of Soil Erosion in Italy

Assessment, prediction and control of soil erosion in time and in space are not so easy, principally because of its affecting events which can be both common and rare. Besides, variability in space must be considered, as influencing factors of soil erosion vary with spatial scale. Exhaustive assessment of soil erosion would require studies over both short and long time spans and in a wide range of spatial scales. Most used methods to estimate erosion rates include the following: purely statistical models; subjectively determined models using expert knowledge combined with database of erosion rates; surveying and dating of existing erosional or depositional features to determine average erosion rates; site-specific empirical models that relate topographic features, watershed and climate; empirical, semi-empirical or deterministic models based on laboratory and field measurements of erosion under simulated rainfall or flow conditions; physically based erosion models; GIS-based landscape scale models that apply statistical relationships to predict changes in topography and erosion rates; sediment-budget models based on watershed monitoring. Data from field studies demonstrate the high variability and episodic nature of soil erosion, and this is widely agreed in the scientific literature and indicates the risks in using short-term monitoring for prediction over long terms (Rose 2001). Many models have been assembled and calibrated at a certain scale, or in a particular range of spatial scales, this implies often high ranges of uncertainty when up- or downscaling such models for erosion prediction. Erosion models with high complexity are frequently the most problematic to deploy at different scales and in different contexts. Some of these models have been tested and used in Italy to predict rates of soil erosion in term of soil loss, sediment yield or deposition rate (Table 8.1).

Any predictive model is affected by statistic uncertainty due to its own statistical nature. It is not so uncommon that missing data or specific data required by a model are generated by other specific models, that is, climatic data or soil data by pedotransfer functions; in this case, error propagation in estimating uncertainty must be considered. Soil erosion models, especially when applied in very large and different spatial contexts, may provide a consistent rate of uncertainty. For this reason, scientists prefer to make reference to potential soil erosion or better to soil erosion risk. Potential soil erosion or actual soil erosion risk maps are important documents in land planning and management.

According to OECD (2008), 30 % circa of the Italian land is exposed to soil erosion risk greater than 10 t/ha/yr. Besides, while the trend of other world countries seems to show some improvement or stability, due to conservation measures and conversion of agricultural land into pasture or forest, in Italy and in other Mediterranean countries, risks of erosion still remain a concern because of some human factors, that is, continued cultivation of fragile and marginal soils, overgrazing in hilly/mountainous areas, the scarce adoption of soil conservation practices in agriculture and natural factors like the increasing incidence of drought and/or high-intensity long rainfall events.

Since the last century, in Italy, many studies have been carried out to assess soil erosion at different spatial scales, especially in basins where geological instability and soil degradation were particularly noticeable. Only in the last years, Italian regions undertook programmes to provide soil erosion maps for their own territory as basis for the rural development and for planning allocation of CAP from EU to support soil conservation measures in agriculture and forestry. In most Italian regions eligible under convergence objective of the EU regional policy, programmes for soil maps and derived soil threat/degradation maps were all EU cofunded. The working scale of those maps is commonly 1:250,000. Actual or potential soil erosion risk was mapped at regional extent using USLE, RUSLE or MUSLE models. A specific programme to collect, harmonize and correlate regional geoinformation on soil erosion, and other environmental threats have been undertaken at national level (geoportal SINA.net). A first pilot study on this direction, which describes rationale and methods, has been already carried out in central and southern Italy using available regional soil geodatabases (Costantini et al. 2009).

At present, the only spatial information on soil erosion by water covering the whole national surface can be derived from some maps generated from different EU projects. A first attempt in Italy aiming to assess erosion risk at national level was made using the USLE approach (van der Knijff et al. 1999). Maps of actual and potential soil erosion were produced as an aid to identify regions that are prone to erosion, and this project is a part of the major project of the Soil Map of Italy aimed at compiling a 1:250,000-scale soil map and associated database for Italy. The soil erosion maps address only rill- and inter-rill erosion and do not take into consideration other forms of erosion such as gully, wind, tillage or mass erosion. A map of actual soil erosion risk (Fig. 8.2), with a spatial resolution of 250 m, indicates very high long-term soil erosion rates (>40 t/ha/yr) for alpine areas, coastal areas of southern part of Calabria

Table 8.1 Soil erosion models, scale and application in Italy

Model	References	Scale of application	Tested or calibrated in Italy	References
AnnAGNPS (annualized agricultural non-point source)	Geter and Theurer (1998), Bingner and Theurer (2001, 2009)	Watershed	x	Licciardello et al. (2007)
ANSWERS (areal non-point source watershed environment response simulation)	Beasley et al. (1980)	Watershed		
ARMSED (runoff and sediment yield model for army training land)	Riggins et al. (1989)	Basin		
ACRU (agricultural catchments research unit model)	Smithers and Schulze (1995)	Field, catchment		
AGQA	Ciccacci et al. (1987)	Basin	x	Ciccacci et al. (1987)
CASC2D	Julien and Saghafian (1991)	Basin		
CORINE erosion	EEA (1995)	Regional	x	EEA (1995)
CREAMS (chemicals, runoff and erosion from agricultural management systems)	Foster et al. (1980)	Field		
CSEP—water erosion	Kirkby and Cox (1995)	Regional		
EPIC (erosion-productivity impact calculator)	Williams et al. (1984)	Field		
APEX (agricultural policy extender)	Gassman et al. (2009)	Farm, small-watershed		
EROSION 2D/3D	Schmidt (1991)	Watershed, catchment		
EUROSEM (European soil erosion model)	Morgan et al. (1998)	Field, small-catchment	x	Rosenmund et al. (2005)
GLEAMS	Leonard et al. (1987), Knisel (1993)	Field, watershed		
KINEROS2 (kinematic runoff and erosion model)	Woolhiser et al. (1990)	Small-watershed		
LISEM (Limburg soil erosion model)	De Roo et al. (1992)	Small-watershed		
MEDRUSH	Kirkby and McMahon (1999)	Catchment		
MIKE SHE	Danish Hydraulic Institute (DHI) (1998)	Catchment		

(continued)

Table 8.1 (continued)

Model	References	Scale of application	Tested or calibrated in Italy	References
MOSES (modular soil erosion system)	Meyer et al. (2001)	From watershed to basin		
MULTSED	Simons et al. (1980)	Basin		
MUSLE (modified universal soil loss equation)	Williams (1975)	Catchment		
PESERA (Pan-European soil erosion risk assessment)	Kirkby et al. (2004)	Regional	x	Kirkby et al. (2004), Licciardello et al. (2009)
PISA	Bazzoffi (1987, 1993)	Basin	x	Bazzoffi et al. (1996)
RillGrow 1, 2	Favis-Mortlock (1996, 1998)	Plot, field		
RUSLE 1, 2	Renard et al. (1991)	Field, watershed, basin	x	Di Stefano et al. (2000), Diodato (2004), Onori et al. (2006), Diodato et al. (2008), Capolongo et al. (2008a), Marker et al. (2008), Bosco et al. (2008), Terranova et al. (2009), Bagarello and Ferro (2010), Grauso et al. (2010)
SEMMED (Soil Erosion Model for MEDiterranean Regions)	De Jong and Riezebos (1997)	Basin, regional	x	De Jong et al. (1999)
SERAE (soil erosion risk assessment in Europe)	Le Bissonnais et al. (2002)	Regional	x	Le Bissonnais et al. (2002)
SHESED	Wicks and Bathurst (1996)	Catchment		
SIMWE (SIMulated Water Erosion)	Mitas and Mitasova (1998)	Field, watershed		
STREAM (sealing, transfer, runoff, erosion, agricultural modification)	Cerdan et al. (2002)	Catchment		
SWAT (soil and water assessment tool)	Arnold et al. (1998)	Catchment	x	Licciardello et al. (2007)
SWRRB (simulator for water resources in rural basins)	Arnold et al. (1990)	Watershed		
USLE (universal soil loss equation)	Wischmeier and Smith (1978)	Field, watershed, basin	x	Bagarello (1994), Ferro and Porto (1999), Mendicino (1999), Van der Knijff et al. (2000), Brath et al. (2002), Van Rompaey et al. (2003), Amore et al. (2004), Bagarello and Ferro (2004), Diodato and Bellocchi (2007), Bagarello et al. (2008), Bagarello and Ferro (2010), Bagarello et al. (2010), Bagarello et al. (2011)
USPED (unit stream power-based erosion deposition)	Mitasova et al. (1996)	Field, watershed, basin	x	Capolongo et al. (2008b)
WATEM (water and tillage erosion model)	Van Oost et al. (2000)	Catchment	x	Van Rompaey et al. (2005)
WEPP (water erosion prediction project)	Flanagan and Nearing (1995)	Field	x	Amore et al. (2004), Pieri et al. (2007), Bruno et al. (2008)

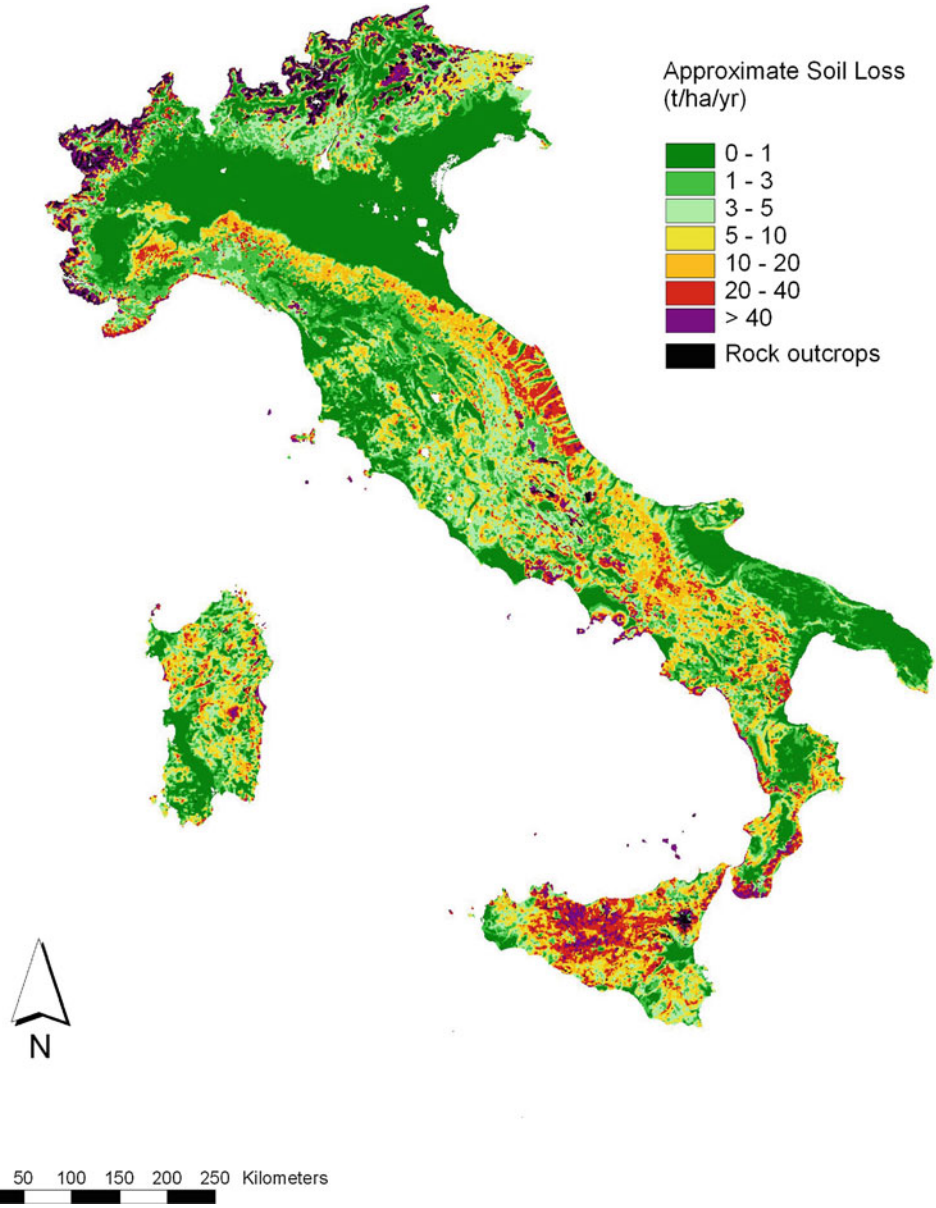

Fig. 8.2 Map of actual soil erosion risk from USLE model (van der Knijff et al. 1999)

region, areas in central Sicily and widely and sparsely in the Apennine.

The United States Department of Agriculture (USDA) fixed the soil loss tolerance between 2 and 10 t/ha/yr, depending on soil type. According to this criterion, the surface interested by annual soil loss >10 t/ha/yr (considered non-sustainable), as calculated within this project, is quite impressive and worrying. Map of potential soil erosion risk (Fig. 8.3), calculated by running the USLE model on the assumption that there is total absence of vegetative cover (i.e. C-factor = 1) predicted that almost everywhere, with exclusion of flat areas, the limit of soil erosion tolerance could be copiously exceeded.

The authors did not run a proper model validation but explained only empirically the uncertainty by comparing results with regional data from technical and scientific literature. Severe limitations of this model are mainly due to the intrinsic unpredictability of gully erosion, which in some regions can be the prevailing form of soil erosion by water. Part of the uncertainty in prediction derives from the coarse resolution of spatial data used as an input in the model (for example, DEM spatial resolution, NDVI temporal resolution and pour soil information). Besides, the model did not include the anti-erosive practices (USLE P-factor) in the calculation, which can be one of the most important factors in limiting soil erosion. It should be realized that most of uncertainty of the model is associated with the uncertainties of the data sources used to calculate every single USLE factor. Error propagation is hardly possible to assess because of the difficulties in assessing the

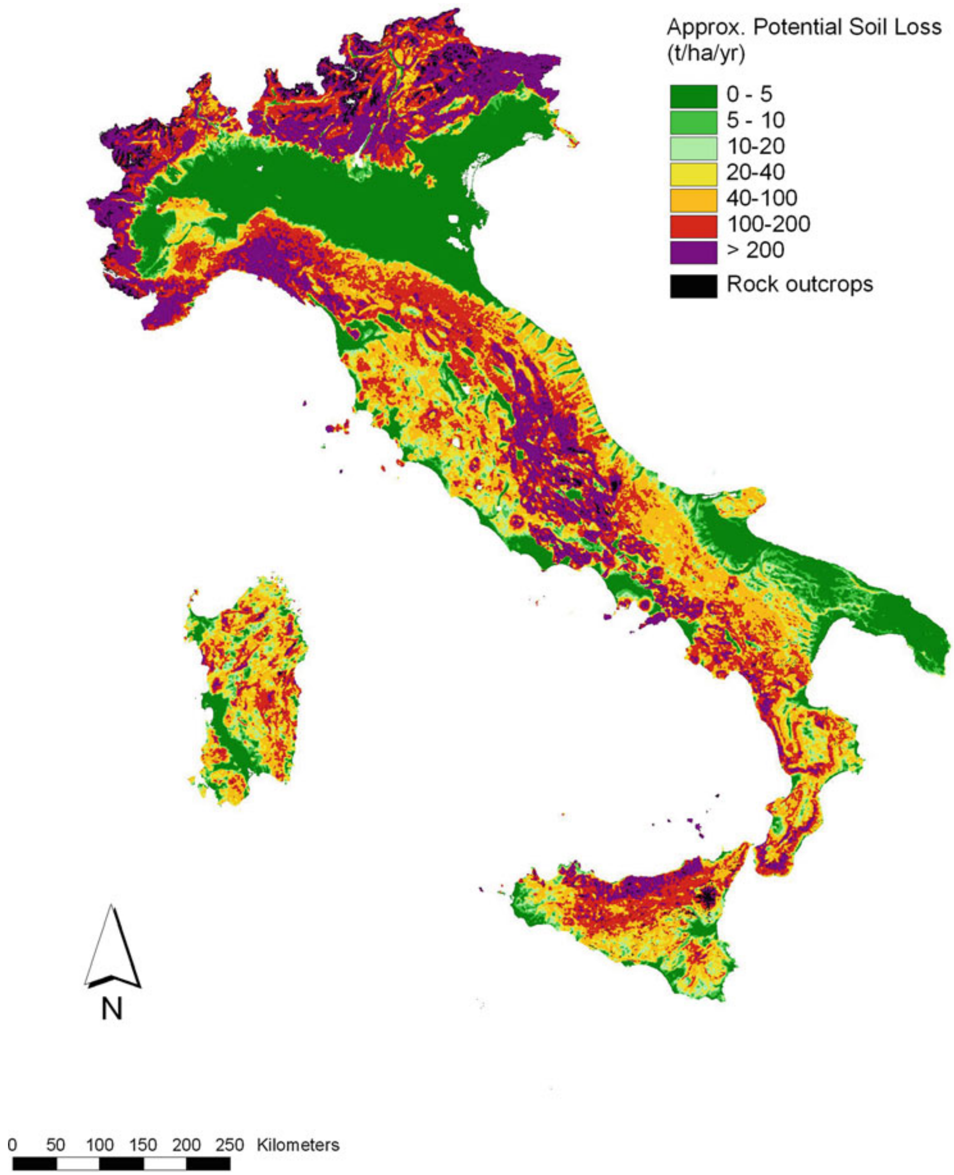

Fig. 8.3 Map of potential soil erosion risk from USLE model (van der Knijff et al. 1999)

uncertainty of the individual factors and because of the interdependence of the individual factors. Certainly, the model is affected by the quality of the data available at that time. Some years later, Grimm et al. (2003) refined the USLE application for Italy by: (a) ameliorating the rainfall erosivity map (R-factor) using data from more meteorological stations combined with more sophisticated interpolation procedures and (b) including in the calculation of the soil erodibility (K-factor) the susceptibility of soil surface to form crust or become sealed. The differences in the annual erosion risk estimated in the original model are noticeable in the mountainous area (Alps and Apennines) where the risk became lower and in the central part of Sicily where on the contrary the risk value became higher, while for the most part of Italy, the absolute values of the differences are below 5 t/ha/yr. Immediately after this revision, an attempt at an indirect validation of the revised USLE results for Italy was made using measured data on sediment yield in some catchments across the Italian territory (Van Rompaey et al. 2003). Predicted soil loss rates from the USLE erosion risk map were used as input in a specific spatial model to predict sediment yields in those basins where measured data were available. Comparing observed values with predicted values, the error on the predicted sediment yield was quite high (70 %); nevertheless, considering all limits of an indirect validation, this test helped to draw some assessment on the quality of the USLE erosion risk map. Notwithstanding the high total error in predicting sediment yield, the main conclusions from Van Rompaey et al. highlight that the soil loss values from revised USLE erosion risk map: (a) are probably over predicted in the forested mountain catchments and (b) have acceptable accuracy in

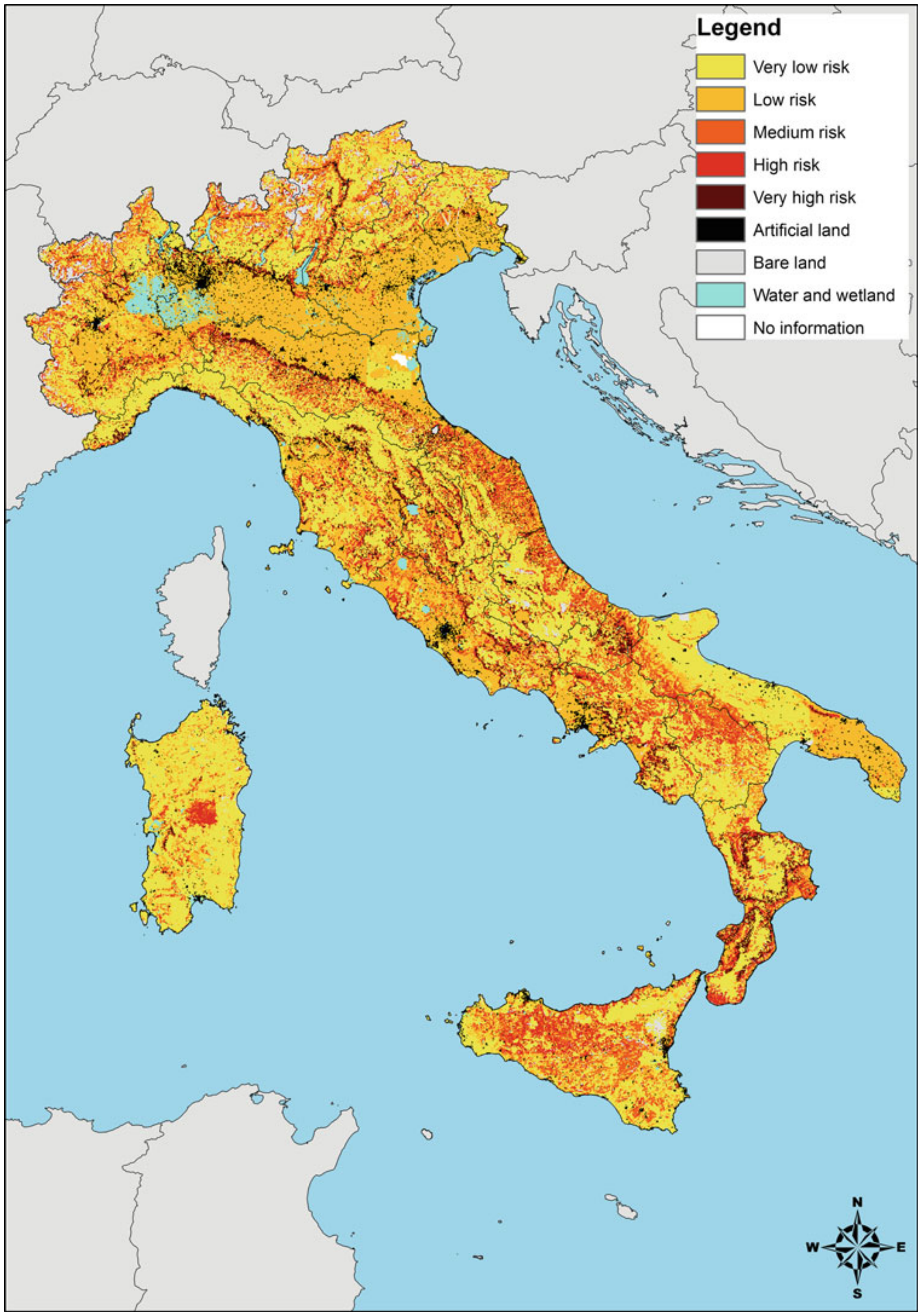

Fig. 8.4 Map of soil erosion risk for Italy extracted from MESALES map at European level (van der Knijff et al. 1999)

hilly areas under cropland. As a final evaluation, the authors agree that the soil erosion risk map of Italy produced by revised USLE model can therefore be profitably used for the regional delineation of areas susceptible to soil erosion in agricultural areas in soil conservation planning.

More recent map than USLE but at European level was generated in the MESALES project (*Modèle d'Evaluation Spatiale de l'ALéa Erosion des Sols*—Regional Modelling of Soil Erosion Risk), using a model originally developed by INRA for France (Le Bissonnais et al. 2002) and subsequently extended to all Europe. MESALES is a model based on expert rules and pedotransfer functions using the following spatial dataset: CORINE land cover, Soil Geographical Database of Europe at scale 1,000,000, slope map derived from 30 × 30 arc seconds (~1 × 1 km) resolution hydrologically correct digital elevation model (DEM), 25 years of daily meteorological data covering Europe at a resolution of 50 × 50 km cells. Main outputs of

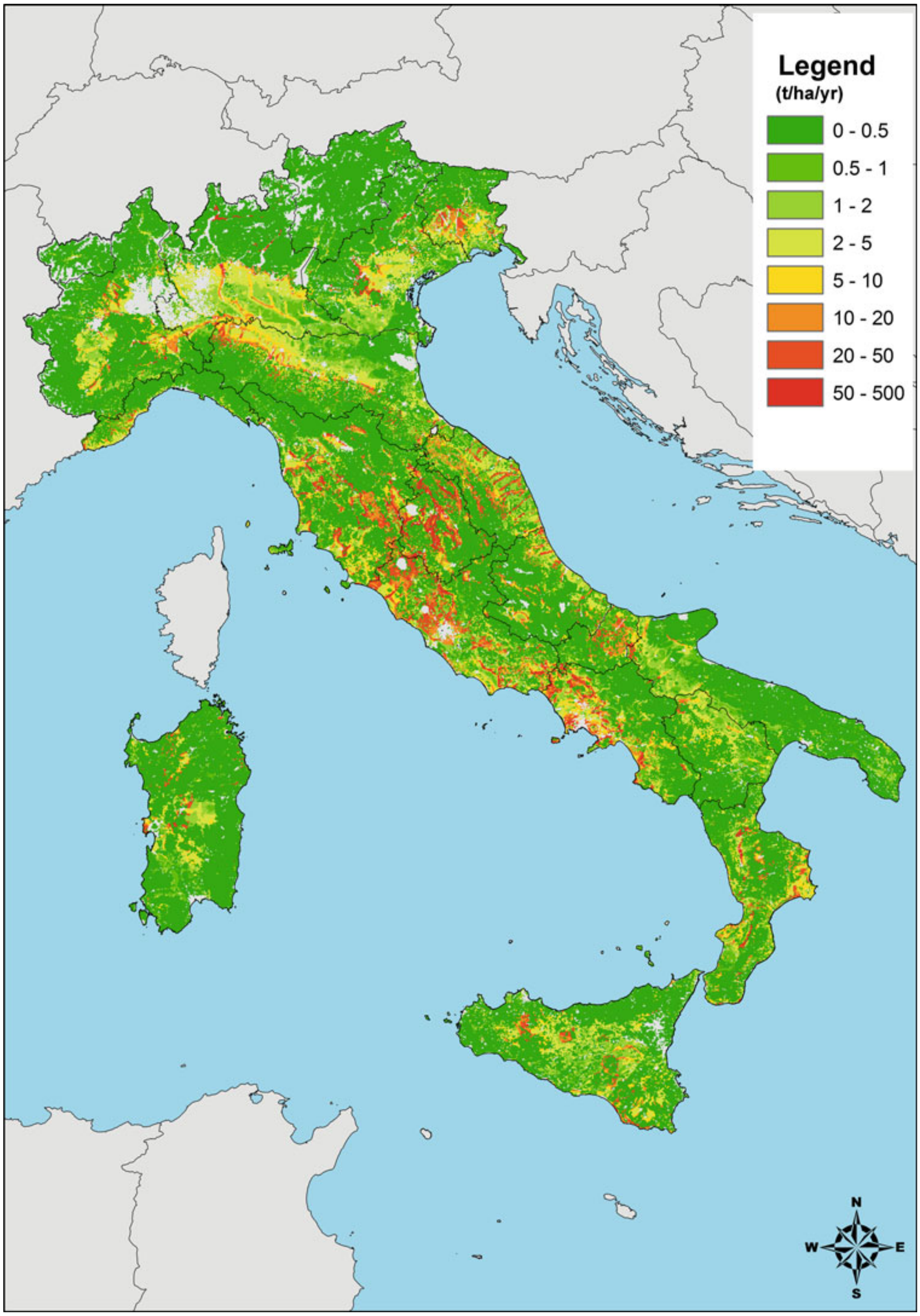

Fig. 8.5 Map of actual soil erosion risk for Italy extracted from PESERA map at European level (Kirkby et al. 2004)

this model are a map of soil sensitivity to erosion and a map of erosion risk (Fig. 8.4) in five categories (very low, low, medium, high and very high), as inferred from soil sensitivity and rainfall erosivity.

The most recent regional soil erosion risk model at European level, after MESALES, is the Pan-European Soil Erosion Risk Assessment (PESERA) project. PESERA uses a process-based and spatially distributed model to quantify soil erosion by water and assess its risk across Europe (Kirkby et al. 2004). The model was implemented with the aim to replace comparable existing methods, such as the Universal Soil Loss Equation (USLE), which are less suitable for European conditions and have poor compatibility with other models at higher resolution. Unlike USLE, PESERA results (Fig. 8.5) show risk for certain flat regions (i.e. Po Valley), even if low, indicating that in these areas, other factors have a greater influence on the erosion risk assessment than slope. For mountainous and hilly areas

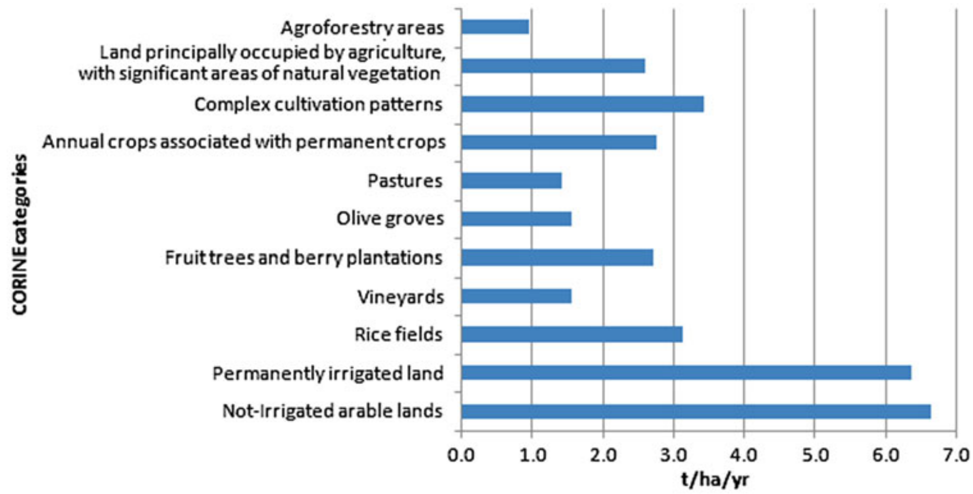

Fig. 8.6 Mean value of soil erosion risk for agricultural areas of CORINE land cover map 2000

(i.e. Alps and Apennines), the risk of erosion is very low or absent, and these are largely forested areas for which the model estimates that soils are well stabilized.

Spatial statistics of PESERA values by CORINE land cover agricultural classes (Fig. 8.6) indicate that in arable lands, both permanently and not irrigated, the mean value of actual soil erosion exceeds 6 t/ha/yr, while basically agroforestry areas have the lowest rates or soil loss (average less than 1 t/ha/yr).

In terms of tolerance of soil erosion, according to the USDA indications, the total area where potential soil loss exceeds 10 t/ha/yr in Italy is 30 %. Spatial analysis of PESERA results (Fig. 8.7) also indicates those hotspots where the soil loss has been estimated as going beyond the tolerance limit.

The model results have been validated in Italy using data of sediment deposition in lakes and reservoirs measured in of 44 catchments across the country (Van Rompaey et al. 2003), following the same methodology used for the validation of USLE map. Results have shown that accuracy of the predictions in Italy is generally poor both in terms of relative patterns and in terms of absolute values with a trend to underestimate the observed sediment yield values. Results of preliminary validation suggest that although the model can be applied at regional, national and European levels, low resolution and poor quality input data cause errors and uncertainties. However, soil erosion indicators developed from a process-based model, like USLE and PESERA, assist in understanding the links between different factors causing erosion, providing a practical advantage for policy makers in the field of soil conservation.

An important follow-up step, according to PESERA project and philosophy, should be a programme to monitor soil erosion at regional level across different agroecological areas and under different land uses (Gobin et al. 2004). Regional models should use input data with high spatial resolution to reduce the uncertainty, should estimate risk of soil erosion and should be combined with periodical monitoring of actual erosion in test areas serving as validation. These models should include also links between biophysical factors of soil erosion and socio-economic factors, providing strategies for the most vulnerable areas which may urgently require appropriate measures of soil conservation.

8.2.1.3 Conclusions

Water and wind erosion can occur in both agricultural and natural environments representing the main erosion processes worldwide, while other forms of erosion are circumscribed in particular environments where the intensity of the process can be significant: mass erosion in very steep areas, glacial erosion in glacial and periglacial regions and tillage erosion in steep arable lands. Obviously, slopes having steeper gradients are subjected to more intensive erosion as the run-off kinetic effect is more powerful; thus, soils occupying steeper positions in the landscape are prone to greater regimes of soil loss than soils in flat positions. The water erosion processes also increase as the slope length increases due to the greater flow accumulation. Vegetation or organic residues covers reduce the impact of water erosion. This effectiveness depends on type, quantity and spatial pattern of the cover. Soils covered by forest, shrub and permanent grass are less subjected to water erosion due to the interception of raindrops and to the break-off of run-off flow. Vegetation generally limits the splash erosion avoiding the formation of soil crusts. Permanent vegetation also has indirect effects on controlling erosion principally due to the constant organic matter supply and preservation of macroporosity by roots, which improve soil aggregation state and the infiltration rate of water through the soil. Bare soils during the rainfall seasons are the most vulnerable whenever other erosion factors lead the soil loss. Tillage and cropping systems which involve decrease in soil

Fig. 8.7 Areas with a soil loss tolerance above 10 t/ha/yr

organic matter contribute noticeably to increases in soil erodibility. Perennial forage crops, covering soils for all seasons of the year, can reduce water erosion much more than annual crops or row crops, which leave the soil bare for a longer period of time and particularly during periods of highly erosive rainfall events. If from one side, soil tillage operations tend to increase the infiltration rate, from the other side, tillage can affect soil erosion disturbing or removing the vegetation and residues cover, and this negative effect depends on the type, depth, direction and time of ploughing. Generally, a rationale tillage limiting the factors of soil erosion could result in a practice for reducing soil loss, therefore in a conservation measure against erosion. Conservation measures such as crop systems and rotation, appropriate tillage practices adopted at farm level (e.g. strip cropping, mulching, contour ploughing, terracing) may reduce soil erosion noticeably when carried into effect in rational combinations, while irrational tillage and crop systems management could result in accelerated erosion. Nevertheless, other forms of soil degradation such as compaction, loss of organic matter, structure deterioration, salinization, already deleterious in themselves, can contribute to accelerate soil erosion. In this context, human activity plays a crucial role in limiting or accelerating soil erosion processes.

8.2.2 Soil Sealing and Consumption

8.2.2.1 Introduction

As previously outlined, Italy, as well as any other European country, is characterized by a long agricultural tradition that dates back to the beginning of the Roman period. Soils and their management, in particular, were always regarded with a high consideration as it testifies the worshipping of a long list of gods, each one responsible for a particular aspect of soil management (Saturn, god of agriculture and seedling; Ceres, goddess of wheat and yields; Sarritor, god of weeding; Messor, god of reaping; and so on). Therefore, it is hardly surprising that during the centuries,[1] the application of the land reclamation measures for soil and water management and conservation has long been a common practice, and considering the wide variability in the Italian landscape, several different soil and water conservation measures were devised, which were well adapted and friendly with environmental conditions (Chisci et al. 1986). It is also to be pointed out that till the end of the 1950s, the structure of the Italian society was characterized by a sharp prevalence of the farmers, and the economy of the country was of a rural type: peoples produced more or less any kind of goods inside the farms.

The so-called "economic boom" during the 1960s together with the development of the industrialization of several areas of the country, mainly in the north, experienced accelerated economic growth and encouraged many changes. The development of the industrial sector, in particular, directly influenced the social evolution and indirectly the request of land. For instance, the movement from countryside to cities (from south to north Italy) and in general the migration flows were triggered by the possibility of finding employment in the factories. These phenomena led to an increased use of soil, due to the urbanization process linked to the migration flows which was responsible for a huge soil consumption and sealing which characterized (and still characterize) the Italian landscape.

We must underline that even if, originally, the meaning of sealing related to the soil indicated an impermeabilization of the soil surface due to a decay in the soil structure linked to irrational agricultural management or to natural causes, today the concept of soil sealing was expanded to the loss of soil resources due to the covering of land for housing, roads or other construction work that determines a "soil consumption" (JRC 2011). We wish also to stress that if we take into consideration the meaning of the word "consumption", we should remember that such term derives from Latin "*consumere*" that means "to destroy". In the case of the soils, the destruction of an essential and not reproducible resource is not a rational behaviour.

8.2.2.2 Environmental Aspects Concerning Soil Sealing/Consumption

In these last years, several opinion movements arose against soil sealing and soil consumption (the so-called "wild concreting") trying to stress the collective consciousness on the risks of this problem. But even if, in these last years, several surveys were performed on such topic, the perception of the risk linked to the soil sealing/consumption among the people is very low. It increases, but for a limited period of time, only after a disaster (landslide, flooding) due to soil consumption that shake the civic responsibility.

Indeed, as also indicated by a recent workshop on the perception of the soil in the different spheres of the contemporary society (Dazzi 2011), the awareness that the soil is, above all, a common resource for all humankind has not yet found its way into the common feeling.

Even today, in the environmental legislation that considers the soil, an economic concept prevails, which refers to the ownership of the land.

Nobody considers that the soil is, first of all, an ecosystem critical to the maintenance of the biosphere's equilibrium and that performs several ecological functions essential for man and that therefore soil consumption is to be considered primarily an environmental damage.

The extent of such damage results not only by the impairment of the chemical, physical and biological functions of soil acting as an environmental component of the biosphere but also by the ecological meaning of the surface organization in relation to both the expression of biodiversity and to the features of the economic and social aspects (Di Simine 2011).

When soil is sealed, its biological and ecological functions are affected to some extent (Scalenghe and Ajmone Marsan 2009). In particular, its ability to function as a carbon sink and its capability to sustain biodiversity, to exchange gas and to favour water infiltration are very depressed or even cancelled. This last aspect is particularly worrying because not only the water table recharge is very limited or even stopped, but also the consequent run-off considerably increases and can cause others hazards (such as flooding) to the soils of the surrounding areas.

[1] Not considering the environmental and socio-economical problems that lead to the decline of the Roman Empire (see Sect. 8.1).

Table 8.2 Effects and dangerousness (1 = low; 2 = medium; 3 = high) of the soil sealing on the environment

	Effect on	Dangerousness
Decrease in	Carbon sink	2 → 3
	Sustain biodiversity	2 → 3
	Gas exchange	2 → 3
	Water infiltration	2 → 3
Increase in	Run-off and erosion	3
	Fragmentation of habitat	1 → 3
	Break of ecological lanes	1 → 3

Other negative effects are represented by the fragmentation of the habitat and by the break of the ecological lanes for any kind of wildlife. It is also to be noted that urban areas, regardless of their dimension, act as heat islands because asphalt and concrete may absorb over 10 % more solar energy than the surrounding vegetated areas. A survey within the Parma municipality demonstrated that the increase in urban area occurred in 122 years caused, on average, a reduction of 0.1 % per year of the solar energy dissipated by evapotranspiration and a consequent increase in sensible heat (Gardi et al. 2007). Table 8.2 reports a list of the effects and of the dangerousness of the soil sealing on the environment.

8.2.2.3 Soil Sealing/Consumption in Italy

In all European countries, the relationship between population growth and urban growth was not linear: urbanization developed in more and more pervasive and complex forms and experienced, in recent decades, an unprecedented acceleration, faster than those concerning the demographic and economic trends (Giudice and Minucci 2011; Tempesta 2008). This suggests an evolution in a consumerist meaning of the relationship of the people with their landscape that affected not only the countries with a high rate of development—as European countries—but also the countries traditionally considered to be developing.

In Italy, a country of ancient and intense human activity, this phenomenon is certainly more worrying because of the particular characteristics of the Italian landscape: hills (41.6 % of the landscape) and mountains (35.2 %) prevail on the plains (23.2 %). These morphological features historically resulted in a strongly variable land use according to the area where there was consumption and soil sealing and, in many cases, led to the utilization of marginal areas or even more inappropriate for new settlements (i.e. prone to hydropedological risk).

Generally speaking, soil consumption is much more evident in all the main Italian metropolitan areas, where there is the highest amount (in percentage) of soils covered by buildings. In these areas, in some cases, the abandonment of unproductive industrial settlements has determined the creation of wide brownfields such as in the surrounding of Naples (Fig. 8.8).

Besides soil consumption due to the development of metropolitan areas, we should also highlight that in the last 30 years, a significant contribution to soil consumption has been linked to the urbanization of coastal areas.

Another important cause of soil consumption is linked to the development of the transport network which was favoured by increased human living standards and by continuous increase in the distance between residential areas and offices, which are covered by train or, as happens in Italy in many cases, by cars. Most of the rail and road networks are mainly built up in flat areas (alluvial plains) because their maintenance works are easy to perform. They occupy long strips of land surface (Fig. 8.9) whose width ranges from a few metres to several tens of metres that, as happens for the highways, can be fenced off. Rails and roads break the soilscape continuum, hamper surface run-off and heavily disturb wildlife at all levels.

We should also mention the soil sealing problem linked to the spread of photovoltaic installations that, as happens for roads and rails, are preferentially established in flat areas, regardless to any aspect of soil quality. Indicative data on soil consumption due to the presence of roads, railroads and photovoltaic installations are reported in Table 8.3.

In Table 8.3, direct consumption takes into consideration the area directly covered by different kinds of roads or rails. For instance, a four-lane motorway, 30 m wide on average, consumes 3.0 ha/km of, generally, good flat soil. Such value increases up to 6.0 ha if we take into consideration all the surfaces that run along the motorways. Concerning soil consumption due to photovoltaic installations, in general, it depends on the surface needed to produce 1 kWp that is a function of the technical characteristics of the photovoltaic panel.

In recent years, many surveys have been performed and many reports published on soil consumption in Italy and many cries of alarm have been reported by the mass media to raise public awareness on the soil consumption phenomenon. Nevertheless, in Italy, the measurement of soil consumption is very heterogeneous as the data are not collected in a uniform manner and are not all taken at the same time period (Di Simine 2011). The official data available on land use at national basis are those concerning the CORINE land cover (APAT 2005b). From these findings, in Italy results an urbanized area of 1,474,000 ha, with a growth rate of 1.4 m^2/inhabitant/year and a value of 255 m^2/inhabitant of urbanized area. These data seem to be underestimated not only for the low level of detail of the CORINE, but also because data that come from surveys on specific areas show higher values.

Fig. 8.8 The ex-industrial area of Bagnoli (Naples) is characterized by the presence of brownfields that are heavily polluted by heavy metals (*Source* Google Earth. *Image acquisition* 13 Sept 2007)

An authoritative source from which to obtain useful information for a general analysis on soil consumption in Italy and on its diffusion and impact on the landscape is a recent report from the National Institute of Statistics (ISTAT 2008) which reports data on building permits. The average values per capita can be considered indicative of the pressure that the population and the productive system develop in the areas where they are located.

Such values are very different in the different geographical areas in which it is possible to subdivide Italy: the maximum levels of pressure are recorded in the north–east, in which there are high-intensity patterns of settlement and therefore a high impact on the soilscape (Fig. 8.10), considering both the residential aspect (35.2 m^3 per inhabitant, compared to 22.3 in average for Italy) and the productive activities (147.7 m^3 per inhabitant against the 96.4 of the Italian average). The north–west values are, in general, the closer to the average, while those referred to central Italy, southern Italy and the islands (Sicily and Sardinia) are significantly lower and not very different for the residential settlements (from 17.0 to 18.4 m^3 per inhabitant).

For the not residential component, however, the south Italy and the islands show average values per inhabitant much higher than those of the central Italy. It can be assumed, however, that the data from the south and the islands for the residential component significantly underestimate the values of soil consumption due to illegal construction (Fig. 8.11).

Therefore, it is easy to identify the most critical areas considering the human settlements and the productive one: in the north–east, for the absolute intensity of human pressure, while in central and southern Italy, for a development model that combines low productivity and high costs in terms of soil consumption.

Another significant aspect (ISTAT 2008) concerns the spatial distribution of urbanized areas. The largest concentration is found around the main metropolitan areas: it is easy to recognize the scattered settlements linked to the landscape morphology and the settlement concentrations in the foothills, plains and along the coasts.

Particularly impressive is the soil consumption, almost seamless, in the foothills area from Lombardy to Veneto, one of the largest conurbations in Europe. Clearly visible are also the settlement concentrations that grow along the main roads. In the south, it clearly stands out the distinctive settlement pattern historically associated with the large

Fig. 8.9 Motorway with several junctions nearby Mancasale in the province of Reggio Emilia (*Source* Google Earth. *Image acquisition* 8 May 2005). The presence of roads becomes a pole of attraction for different types of settlements that contribute to consume and to impermeabilize vast areas

Table 8.3 Soil consumption (in average) due to rail and road networks and to photovoltaic installations (modified from Barberis 2005)

Soil consumption	Motorways (ha/km)	State roads (ha/km)	Province roads (ha/km)	Local roads (ha/km)	Railroads (ha/km)	Photovoltaic installations
Direct way	3.0	1.5	1.2	0.7	1.0	1.0 ha/ 400–1000 kWp
Indirect way	6.0	2.5	2.0	1.8	2.0	1.3 ha/ 400–1000 kWp

landed estate (*latifundium*) economy, based on the contrast between densely populated areas and deserted countryside and the intense urbanization of the coastal areas.

A recent survey on the level of impermeabilization and soil consumption between 1999 and 2006 in 26 urban areas variously distributed in Italy (Munafò et al. 2009) showed an increase in soil sealing in all surveyed areas (Table 8.4).

Although the data obtained are only partially comparable because of the different sizes of the surveyed areas (some are very large, others not), they allow to highlight a phenomenon that exists and increases year after year due to urban expansion and the development of new infrastructure.

In this perspective, there is therefore scope to highlight how a large increase in the impermeable surface in already highly urbanized areas (such as Milan, Monza, Naples and Padua) is a particularly critical element in relation to the adverse effects on the environment. The percentage values obtained should therefore always be considered, for a correct interpretation of the results, together with the absolute values in hectares. The case of Rome is a clear example due to the enormous surface area of the municipality that spreads 33,764 ha of sealed soil (three times that of Milan) in a territory of about 128,000 ha, with an impermeable surface value of 26.3 %. In contrast, 7,127 ha of sealed soil in Turin represent more than half of the municipality area (54.7 %).

Recent surveys (Giudice and Minucci 2011) place Italy in the fourth place at European level for soil consumption with

Fig. 8.10 High-intensity patterns of settlement around Padua (*Source* Google Earth. *Image acquisition* 26 May 2009)

Fig. 8.11 The coast of Tre Fontane in south Sicily (*Source* Google Earth. *Image acquisition* 6 June 2006)

Table 8.4 Sealed areas in 1999 and 2006 in 26 Italian municipalities of different size area

City	Hectares			Percentage	
	Total	Sealed in 1999	Sealed in 2006	Sealed in 1999	Sealed in 2006
Monza	3302	1467	1590	**44.4**	**48.2**
Bolzano	5233	1310	1337	25.0	25.5
Udine	5681	2113	2330	**37.3**	**39.4**
Trieste	8449	2638	2833	**31.2**	**33.5**
Cagliari	8550	2538	2619	29.7	30.6
Brescia	9068	3799	3997	**41.9**	**44.1**
Padua	9285	3545	3855	**38.2**	**41.5**
Prato	9759	2528	2905	25.9	29.8
Florence	10241	3254	3719	**31.8**	**36.3**
Livorno	10479	2101	2297	20.2	22.1
Bari	11620	4171	4501	**35.9**	**38.7**
Naples	11727	7009	7302	**59.8**	**62.3**
Ancona	12323	1685	1735	13.6	14.0
Turin	13017	6993	7127	**53.7**	**54.7**
Bologna	14073	4853	5391	**34.5**	**38.3**
Palermo	15888	5803	6099	**36.5**	**38.4**
Venice*	16014	11265	12472	27.3	30.2
Potenza	17397	2177	2443	12.5	14.0
Modena	18247	3386	3950	18.5	21.6
Milan	18377	10553	11213	**58.0**	**61.6**
Verona	20664	4971	5277	24.1	26.0
Taranto	21750	4256	4727	19.6	21.7
Genoa	24360	4487	4632	18.4	19.0
Parma	26077	4050	4981	15.5	19.1
Foggia	50780	3797	4168	7.4	8.1
Rome	130771	31415	33764	24.4	26.3

In bold, the percentage values above the average (*Source* Munafò et al. 2009)
*Not considering the lagoon areas

a value of 7.1 %. The data expressed as a percentage indicate a significant contribution in terms of soil consumption, which according to data provided by Legambiente (2010c), can be estimated at 21,000 km^2 (Table 8.5).

According to Tempesta (2008), a more accurate estimate of soil consumption in Italy would lead to a value of 7.6 % of urbanized areas on the whole national territory, or 2,350,000 ha (415 m^2/inhabitant). In any case, an element that should be noted is the different contribution of each region to such problem: in the north, there are the most industrialized regions, which lie above the national average, while in the south, there are the regions where the phenomenon of illegal construction is greater.

8.2.2.4 A New Threat of Soil Consumption

In recent years, installation of photovoltaic devices to produce electricity can be considered as a new soil consumption threat. In Italy too, as elsewhere in Europe (Consulente Energia 2011), there has been a remarkable development of photovoltaic installations in recent years and there presumably will be even more in the near future. Photovoltaic devices, in relation to the energy produced, occupy areas of different size (Table 8.3), but they concern almost always the flat areas or the valley floors where soils generally show a higher productive capability (Fig. 8.12). At present, there are no data on soil consumption resulting from installations of photovoltaic systems. However, there are data on the total number of installations that can give an indication on their diffusion (Schito 2011) and highlight how at the end of 2009 in Italy, there were 71.284 photovoltaic installations for a productive capacity of 1,142.4 MW. These data when compared with those for 2008 indicate a 165 % increase in the number of installations and 123 % of productive capacity.

Table 8.5 Soil consumption in Italy in 2010 (*Source* Legambiente 2010c)

Region	km^2	Percentage	
		On the region	Total
Valle d'Aosta	70	2	0.33
Piedmont	1900	7.6	8.84
Liguria	340	6.3	1.58
Lombardy	3400	14.1	15.82
Trentino Alto Adige	390	2.8	1.81
Friuli Venezia Giulia	740	9.4	3.44
Veneto	2100	11.3	9.77
Emilia-Romagna	2000	9.1	9.31
Tuscany	1300	5.6	6.05
Umbria	350	4.1	1.63
Marche	540	5.5	2.51
Lazio	1500	9.1	6.98
Abruzzo	360	3.4	1.68
Molise	70	1.6	0.33
Campania	1450	10.7	6.75
Basilicata	210	2.1	0.98
Apulia	1100	5.9	5.12
Calabria	870	5.8	4.05
Sicily	1900	7.4	8.84
Sardinia	900	3.7	4.19
Italia	21490	7.1*	100.00

*Average

Fig. 8.12 In Italy, large photovoltaic installations have spread more and more in recent years, occupying almost always the areas with the higher agricultural capability in the plains or in the valley floors (*Photos* from personal archive of C. Dazzi)

8.2.2.5 Not Only a Consumption of Soil Surface

The availability of data on soil consumption is very different and does not allow to draw unequivocal conclusions about the past and current dynamics of the soilscapes (Tempesta 2008). In particular, there are few surveys that highlight how the problem of soil consumption does not constitute only a mere subtraction of arable area for agricultural management: it hides more virulent problems related to the fact that in most cases are the most productive soils that are consumed.

In confirmation with this, we can cite the data on soil consumption concerning the Buonfornello Plain, a coastal strip on average 1 km wide and about 18 km long, for a total area of 1,515 ha.

In cross section, the Buonfornello Plain, one of the few flat areas of Sicily, is characterized by:

- the beach, 10 m wide on average;
- a range of dunes, on average 5 m wide and 3–4 m high, that for long stretches no longer exists;
- nearly level or gently sloping surfaces on which evolved the soils that characterize the area: Calcaric Arenosols, Calcaric Fluvisols, Verti-Calcaric Fluvisols and Eutric Vertisols (IUSS Working Group WRB 2006):

Surveys on soil consumption (Dazzi et al. 1997; Asaro 2010) highlighted that in the area, in the period 1955–2010, there has been a considerable soil loss due to urbanization

Table 8.6 Soil consumption over time in Buonfornello Plain soil by type (modified from by Dazzi et al. 1997; Asaro 2010)

Soil type	Soil consumption (ha)					Total
	In origin	In 1955	In 1983	In 1994	In 2010	
Eutric vertisol	966.85	96.6	136.52	144.62	144.93	522.67
Verti-calcaric fluvisol	227.09	15.6	96.75	26.6	39.71	178.66
Calcaric arenosols	106.92	4.4	10.5	39.2	9.64	63.74
Calcaric fluvisol	104.33	7.3	26.5	29.76	14.14	77.7
Other (beaches, dunes, etc.)	109.81	0	0	7.08	0.26	7.34
Total	1515	123.9	270.27	247.26	208.68	850.11

and allowed for the development of a timetable which identifies the soil consumption over the years (Tables 8.6 and 8.7).

While in 1955, the main factors responsible for the process of soil consumption were farms and farmhouses in the service of agriculture, from 1955 to 1983, the main responsible has been the industrial development that has not resulted in a significant economic development of the area but in consuming forever the best soils in their natural use.

In the period 1983–1996 and 1966–2010, we should consider the abnormal development of resorts and residences, as well as seasonal housing that also affected those areas with a fair to very low agricultural potential and that go up to a few metres from the beach (Fig. 8.13).

Ultimately, over an area of 1515 ha, 850.11, that is, 56.1 % have been forever lost from their agricultural use. But, beyond the simple data, in itself impressive, it is dismaying the fact that urban expansion took place at the expense of the best soils of the area.

In fact, Table 8.7 shows that about 75 % of Calcaric Fluvisols, that is, very fertile and productive soil, suited for irrigated agriculture which allows high incomes to farmers, have been forever lost for agriculture use, as well as about 79 % Verti-Calcaric Fluvisols, that is, soils with unimportant or slight limitations that do not compromise the agronomic suitability for irrigated agriculture. Lower percentages were recorded for soils with a gradually decreasing agricultural productivity.

Fig. 8.13 Cranes ready for the construction of new residences in the plain of Buonfornello. The small building at service of agriculture (on the *right* of the photo) is destined to disappear (*Photos* from personal archive of C. Dazzi)

An important aspect is related to the presence in different areas of the plain of "soils" which are not natural (Fig. 8.14) but originated by dumping over time of demolition wastes mixed with other urban wastes and earthy material that have a negative impact on the environment and its quality.

Finally, it is appropriate to point out that the soil consumption determines not only the loss of a vital resource for humans, but also involves other negative impacts on the quality of the environment and the economy of the landscape (EEA 2006a, b).

It is generally believed that an increase in soil consumption corresponds also:

- an increase in traffic (Vance and Hedel 2008), in emissions of CO_2 and particulate (Bart 2009), and in the level of pollution by heavy metals;
- human health problems due to stress originated by driving, to the increase in car accidents and indirectly to the increase in obesity caused by the reduced time available to devote to physical activity (Bray et al. 2005; Ewing et al. 2003; Frumkin 2002).

8.2.3 Soil Contamination

8.2.3.1 Introduction

In the last 50 years, ever-increasing soil contamination is one of the gravest problems existing on the earth and of greatest concern for science and the general public. The occurrence of this phenomenon is correlated with the degree of industrialization and intensity of chemical usage. Industrial activities are the principal cause of soil contamination both by direct introduction of xenobiotic substances in the soil and indirectly by fallout of emissions and spill-out of

Table 8.7 Soil losses in terms of agronomic capability and suitability for irrigation

Soil	Calcaric fluvisols	Verti-calcaric fluvisols	Eutric vertisols	Calcaric arenosols
Land irrigability class	1	2	3	4
Land capability class	1	2	3	5
Hectares in origin	104.33	227.09	966.85	106.92
Total hectares lost	77.7	178.66	522.67	63.74
% of soil lost	74.47	78.67	54.05	59.61

Fig. 8.14 In industrial areas where soil consumption is very heavy, many times it is possible to find "soils" that can be considered "technogenic soil" (*Photos* from personal archive of C. Dazzi)

contaminated water, contaminating soils both locally and diffusely. In all industrialized countries, contaminated sites are the legacy of a long period of industrialization involving unconsidered production or handling of toxic substances and unregulated dumping of wastes. Urban and periurban soils, especially in the most developed areas of the world, are regrettably contaminated by several toxic compounds. Fuel leakages from vehicles are washed away by rainfall and seep into nearby soil. Careless in urban solid and liquid waste management techniques, which are characterized by the release of sewage, is cause of severe soil contamination. Dumps of urban waste scattered everywhere, managed incorrectly or abandoned without any precaution, may represent a dangerous source of soil contamination. Even though there is no precise information about the number of dumps or the total contaminated area in the planet, the issue of soil contamination by urban wastes, especially in recent years, concerns a considerable land surface. The substantial diffusion of contaminated soils drove the World Reference Base for Soil Resources, in 2006, to introduce the new reference group of *Technosols* and two new diagnostic horizons (*Garbic* and *Urbic*) to classify toxic soils contaminated by waste and artefacts (IUSS 2006). The industrialization of agriculture has caused the continuous release of man-made organic chemicals into natural ecosystems. In agriculture, the large use of pesticides and insecticides on the one hand serves its main purpose, but on the other hand leads to deterioration in soil quality, making it contaminated and harmful for human health. Certain agricultural practices cause diffuse soil contamination by both primary and secondary processes. The intensive use, or better said abuse, of nitrogen and phosphorus in the form of fertilizers in modern agriculture caused noticeable problems of soil pollution with transmission and grave repercussions of contamination in all ecosystems. Unfavourable and harmful soil irrigation practices with contaminated water, for example sewage water, may create accumulation of toxic substances especially in areas with poor precipitation and hot climate.

Contaminating substances in soil may be either organic or inorganic. The most prominent group of organic contaminants are hydrocarbons, polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), chlorinated aromatic compounds, dioxins and dioxin-like compounds, detergents and pesticides. Inorganic species include nitrates, phosphates and heavy metals, such as cadmium, chromium and lead, inorganic acids and radionuclides (radioactive substances). Continued contamination with these substances can lead to long-term accumulation in soils (Takei 2010). When the buffering capacity of soil with respect to one or more substances is exceeded, these are released into the environment, becoming non-point pollution source for surface water and groundwater (EMEP/MSC-W 1998). Soil also contributes to air pollution by releasing volatile compounds into the atmosphere. Nitrogen, for example, is released from the soil through ammonia volatilization and denitrification. The decomposition of certain organic materials in soil can release sulphur dioxide and other sulphur compounds, causing acid rain. Heavy metals and other potentially toxic elements are the most serious soil pollutants in sewage. Sewage sludge contains heavy metals, and if applied repeatedly, soils may accumulate heavy metals and consequently become unsuitable to support plant life. In addition, chemicals that are not water soluble contaminate plants that grow on contaminated soils, tending to accumulate towards the top of the food chain (Beccaloni et al. 2010). Contaminated soils are dangerous for human and other animal organism when toxic substances, attached to soil particles, or volatile compounds, trapped in the small spaces between soil particles, may be ingested, inhaled or come in contact with the skin. Moreover, several toxic substances in soil may be naturally transformed or combined into new secondary compounds with a higher potential of harmfulness. Many of these compounds, at high concentrations or following prolonged exposure, produce adverse effects in humans and other organisms, such as acute toxicity, mutagenesis, carcinogenesis, teratogenesis, enzymatic dysfunctions. Other man-made toxic compounds are resistant to physical, chemical or biological degradation and thus represent a persistent harmful environmental issue. This is probably the main aspect making the issue of soil contamination dramatic.

8.2.3.2 Contamination in Italian Soils

A recent report of the European Environmental Agency (EEA) records for Western Europe circa 300,000 potentially contaminated sites. This number must probably be increased because for many EU countries, a complete survey was not possible (EEA 2007a, b). An overview of human activities causing soil contamination (Fig. 8.15) in some Western and Southern European countries (including Italy) shows that industrial production and oil industry activities represent together more than 50 % of the soil contamination sources. Almost a fourth of soil contamination is caused by waste treatment and disposal, both urban and industrial. Other preliminary surveys indicate that for Eastern Europe, one of the main causes of soil contamination may have been instead military activities.

General census of contaminated sites was started by regional authorities since 2000 under the supervision by ISPRA (*Istituto Superiore per la Protezione e la Ricerca Ambientale*), former APAT, aiming to establish proper monitoring activities and to arrange remediation actions. In Italy, circa 12,000 potential contaminated sites were recorded in 2004: circa 5,000 assessed by the regional environmental bureaus and circa 7,000 estimated by the National Environmental Protection Agency (APAT). Even if further investigations suggested that the number is underestimated (APAT 2005a) in terms of contaminated surface, these data correspond to 260,000 ha (almost 1 % of the national area).

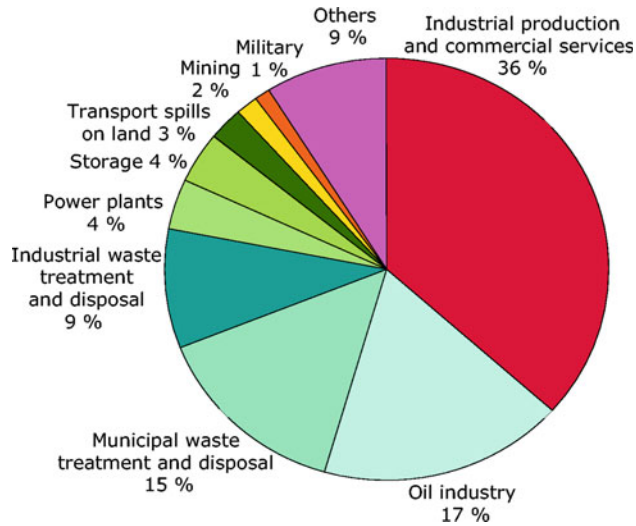

Fig. 8.15 Overview of economic activities causing soil contamination. *Graph* from EEA (2007b)

It must be noted that data refer only to industrially contaminated sites and do not include diffuse soil pollution or areas contaminated by different human activities. Brownfields too are excluded from this evaluation. However, as it happens in the rest of EU, in Italy, a precise quantification of contaminated sites is not so immediate. Still problematic is the quantification of the brownfield area, even if preliminary statistics on major Italian towns indicate that, likely, brownfields surrounding the urban area are twice in size than the old town centre.

Knowledge and perception of soil contamination phenomenon at national or regional level are unfortunately still incomplete. Only recently, regional authorities in charge of environmental protection have started a census of contaminated sites, and only few of these (Piedmont, Lombardy, *Emilia-Romagna* and Sicily) set going regional soil monitoring networks using a common reference methodology. Actually, the lack and eventual inhomogeneity of data prevents a complete overview at national level.

Largest and most contaminated sites, scattered in the whole national territory, are recognized since few years as "Sites of National Interest" (SIN). These areas were identified according to specific characteristics such as size, position, quantity, typology and dangerousness of contaminants produced, risk of impact on human health, on ecosystems and on environmental and cultural heritage. Nowadays, 57 SINs have been identified, concerning a total area of 700,000 ha, and preliminary monitoring activities have been undertaken. Most SINs are large industrial estates, sources of the most harmful toxic substances such as organic compounds, heavy metals and asbestos (APAT 2007b).

A problem which has sensibly shaken the general public in the last years is soil contamination by asbestos. This compound, having carcinogen effects on human health, has been recognized as the cause of many deaths. A recent report on this kind of contamination shows that the area contaminated by asbestos is larger than 75,000 ha (Legambiente 2010a). Contamination due to urban waste dumping reaches also high levels of sensibility in the public opinion. In the last 20 years, many dumps have been closed because of incorrect management. Municipal wastes were buried or burnt without any precaution or any fume cracking for long period, causing direct contamination of soil and diffuse pollution by percolation of water or release of toxic substances (mainly dioxins and harmful gases). In addition, there are many sites where wastes are still dumped illegally (Fig. 8.16). The same has been for industrial wastes with a various range of toxicity. Illegal traffic of toxic industrial wastes is a dark phenomenon involving most of Italian regions and a source of business for criminal organizations (Legambiente 2010b; Caturano 2011).

Soil contamination by heavy metals has received particular attention due to the harmful impact on human health. Heavy metals accumulation in soil may result from several industrial activities and can be the result of fallout of industrial emissions. Several studies have been carried out, mostly in northern Italy, showing the spatial distribution in soils and trying to discriminate the anthropogenic origin from the natural pedogenetic origin. Gerdol et al. (2000) in a survey of heavy metal deposition in the Alps in 1995–1996 demonstrate that metal bioaccumulation in moss samples is statistically correlated with environmental and climatic factors, as well as with bulk depositions and elemental concentrations in the soil. Fe, Ni and Cr, all derived from both by particulate and by anthropogenic emissions in connection with ferrous metal manufacturing, were mostly concentrated in north-western Alps. Cu and Zn, as typical multisource elements, showed rather high concentrations with narrow ranges of variation over the whole area. Cd and Pb, having been transported from long distances, showed the highest concentrations in the regions of highest precipitation, especially in the Eastern Alps. Ungaro et al. (2008) using a geostatistical approach set up a method for the identification of areas affected by anthropogenic As enrichment. Bini et al. (2008) ran a specific research programme aimed at assessing actual chromium accumulation in soils and plants in a tannery industrial district in north-eastern Italy. Results of this study showed (a) large differences in Cr concentration in the area investigated, with a very scattered distribution and (b) most of the investigated sites showed Cr concentrations higher at the subsurface than in subsoil, suggesting local sources of Cr to be responsible for soil contamination. Moreover, data and conclusions of this programme suggest the vulnerability of water and groundwater to contamination by heavy metals in soils, highlighting also the effective hazard for human health through direct contact with soil, ingestion and inhalation. More recently, Bini et al. (2011), assessing background levels of trace elements in 120 representative soil profiles scattered in the whole *Trentino* region, demonstrate that Cu, Ni, Pb, Cd, Zn, Cr, Fe and Mn contents are consistent with currently recorded trace element concentrations of soils from Western Europe. No contamination was recorded in the whole region through natural pedogenetic weathering of parent material. Nevertheless, metal accumulation in surface horizons at some sites may be ascribed to atmospheric input from local agricultural or industrial activities. Adamo et al. (2006) in a study on a representative area in the Campania region, using dedicated geochemical and pedological approach, found that Cr and Cu were the major soil contaminants exceeding the limits set by the current legislation, while Ni, Fe, Zn and Mn total content never exceeded Italian mandatory limits. Assessing the origin of the two exceeding metals, authors conclude that Cr contamination was due to repeated river flooding events and Cu contamination to past intensive agricultural practices. A geographical overview of total concentrations of some heavy metals in topsoil in Italy may be extracted from the geodatabase provided by the Land Management and Natural Hazard Unit of JRC (Lado et al. 2008). Maps of heavy metals for Europe have been generated by geostatistical

Fig. 8.16 Municipal wastes buried into the soil (*Photo* from personal archive of C. Dazzi)

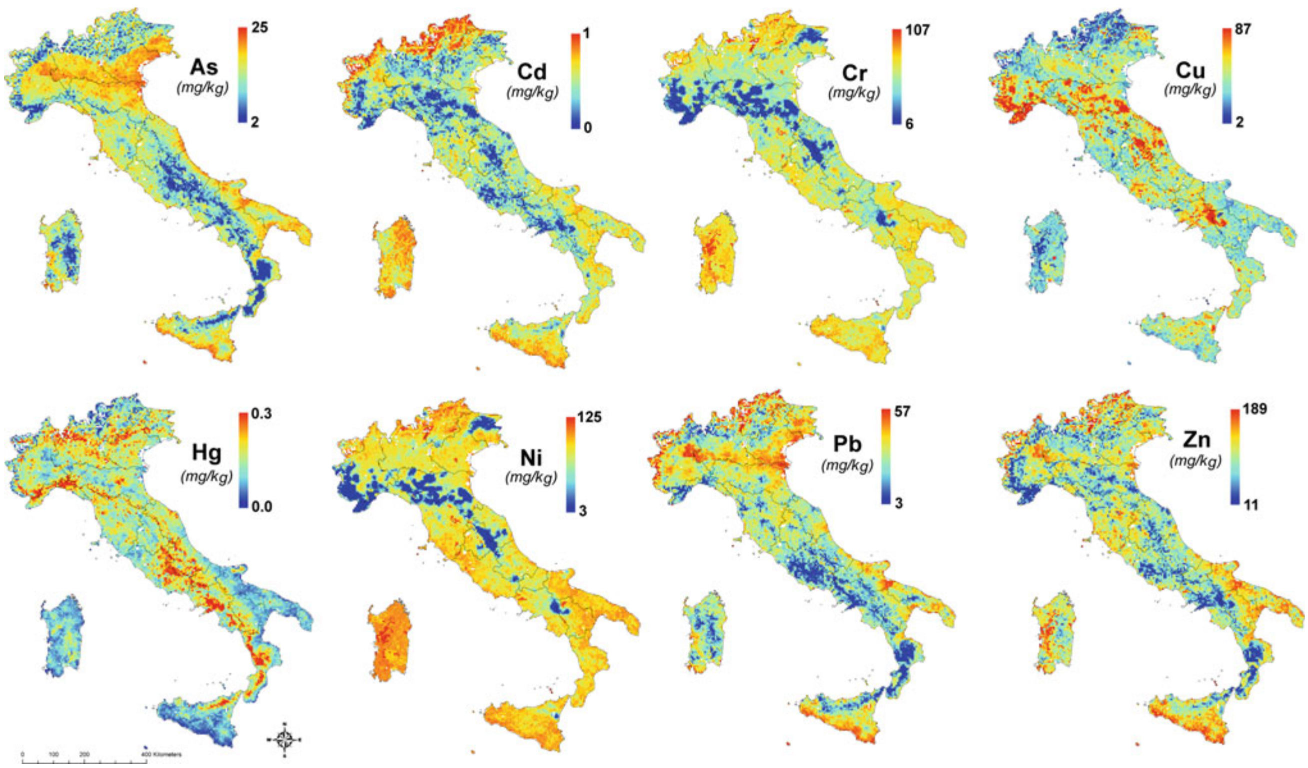

Fig. 8.17 Maps of estimated concentration of heavy metals in topsoil in Italy, extracted from EU maps originated by geostatistical analysis of the FOREGS geochemical database (Lado et al. 2008)

analysis of 1558 sampling points of the geochemical database of EU 26 countries. Maps (Fig. 8.17) could be useful to identify eventual hotspots of higher concentrations in the national area serving also as an ancillary data for a further analysis at national or regional scale.

Italy, as well as most European countries, has been interested by radioactive contamination. The well-known Chernobyl disaster in 1986 caused the fallout of radioactive emissions interesting principally the northern Italian regions. Studies on the fallout and accumulation of ^{137}Caesium in soils show that in Alpine regions, the level of fallout and soil accumulation is higher than plain regions (i.e. Po Valley) and sometimes even higher than in regions of Central Europe (Facchinelli et al. 2002).

Soil contamination by agriculture in Italy involves principally areas with intensive or industrial agricultural settings. Nitrates accumulation represents the most noticeable form of this kind of soil contamination. Nitrates are water-mobile in soil, and when there is an excess of this compound, soil become a source of water pollution. Inputs of nitrates in the soil are organic and mineral fertilizers and mainly the utilization of slurry. When this process reaches a certain level, it may cause eutrophication of aquatic environments and make water toxic for animal organisms. Nitrate contamination has been a remarkable threat to soils in the Po Valley and other flat regions of Italy where the intensity of the modern agriculture is high (Rossi et al. 1991). To limit this phenomenon and its dangerous effects on human health and ecosystems, EU issued the Nitrates Directive in 1991, ratified by Italy in 1999, which set the designation of "vulnerable zones" to nitrate pollution and fixed tolerable limits of nitrates to be applied to the soil. Most Italian regions today have designated vulnerable zones and arranged rules of good soil fertilization, also activating strategies for water and soil monitoring. Reports from regional environmental bureaus confirm, in the recent years, a decrease in nitrate contamination in soil and water (APAT 2005a).

Pesticides and fertilizers, both mineral and organic, may be also dangerous substances for soil contamination and, through the soil, may contaminate water, becoming very harmful for human health. Moreover, these substances may contain high levels of heavy metals which can accumulate over time in the soil. This kind of contamination also occurs in areas with intensive agriculture. However, lack of data actually does not allow a systematic analysis of the phenomenon in Italy, but regional data from water monitoring indicate the presumable severity of soil contamination due to abuse of xenobiotic substances.

8.2.3.3 Conclusions

Even with lack of full information on the status of Italian soils, well-known and presumable levels of soil contamination, both local and diffused, in Italy point out urgent needs for implementation of specific strategies. The EU Thematic Strategy for Soil Protection, with a specific Directive, is pressing member countries to get ready, acquiring much more complete information on the status of their own soils and environments. It is desirable that regions urgently activate soil monitoring networks, acquiring data on soil contamination to allow delineation of a much needed national overview of soil contamination. The results of the first report on "Combating Environmental Illegality", recently issued by the Ministry of Environment and Land and Sea Protection in collaboration with the enforcement agencies, show how in Italy, environmental security forces record, on average, a criminal offence against environment every 43' (Ministero dell'Ambiente e della Tutela del Territorio e del Mare 2010). The main kinds of offences involve contamination of soil and water. Probably, strategies of communication and information on environmental education should be also undertaken, with the aim to pass to the future generations the awareness on the importance of the soil resource.

8.2.4 Soil Salinity

8.2.4.1 Introduction

The size and severity of the processes of salinization/alkalization mean that they should be considered to all effects, as processes of environmental degradation sensu lato, and that cannot be ascribed to a single aspect of agricultural management. From a wider and general point of view, in fact, the problem involves such a wide range of factors and triggers consequences so radical as to affect the ecological–environmental organization of huge landscapes.

Salinity is now widely regarded as a serious threat to the environment as it directly undermines the value and quality of its soil resources and alters the delicate balance of ecological processes (Monteleone 2006). Among the environmental emergencies directly related to the soil salinity, the processes of soil secondary salinization take on particular importance because of their dangerousness. In this regard, we must also consider the potentially saline soils, that is, soils that are not saline at present, but which could reasonably become saline soils (or alkaline soils) due to irrigation or other anthropic activities.

The problem of soil salinity due to irrigation takes on increasing importance from year to year and is not new in world history. It is intended not only to get worse for the increasing competition for water use between cities, industry and agriculture, the overexploitation of groundwater, the use of not suitable water in agriculture, but also as a result of global climate change expected in the near future (IPCC 2007). For the Mediterranean countries, these changes should lead to an increase in the index of aridity that influences the soil humidity regime and the soils salt balance and would eventually lead to a less leaching and to an increase in salinity up to double, in the future, the soilscapes affected by salinity (Barrow 1993).

An estimate projected to 2020 on the development of irrigation and on the consequent secondary salinization (Szabolcs 1998) indicates that trends in the increase in irrigated areas and of saline areas are almost parallel and that landscapes with secondary salinization are larger than the irrigated landscapes. This happen because of secondary salinization influences, in general, a larger area than the irrigated one (Szabolcs 1998).

Particularly prone to the problems of salinization and soil alkalization are the countries bordering the Mediterranean basin, particularly where the climate tends to be hot and dry. In these environments, in fact, the use of water for irrigation can help to reduce the risks associated with soil moisture deficit and to stabilize production and, also, to expand the choice of crops. Over the past 25 years, the irrigated areas in the Mediterranean countries have experienced an increase estimated at 20 % (Pla Sentis 1996). These areas are usually located nearby those with high urban and industrial developments, where most of the good quality water is used. As a consequence, for irrigation purposes, scarce quality waters (mainly saline) from urban or industrial effluents are used. Moreover, it is to mention the overexploitation of the groundwater along the coastal plains, frequently leading to the intrusion of sea waters in the water table and also the excessive use of fertilizers and pesticides that, if used in great quantities in the irrigated agriculture, can contaminate superficial or table waters used for agricultural (and also civil) purposes.

8.2.4.2 Soil Salinization/Alkalization in Italy

In Italy, till today, a detailed map showing the characteristics and the distribution of the different types of saline soil in the whole country is not available. There is only an exploratory survey at national level (Dazzi 2008a), which put in evidence that saline soils appear prevailingly distributed in the low Po Valley, in long stretches of the Tyrrhenian and Adriatic coasts, along the coast in Apulia, Basilicata and Sardinia and in wide stretches in Sicily.

Very recent data on the distribution of salt-affected soils in Italy (National Soil Database—see Chap. 6) allow to

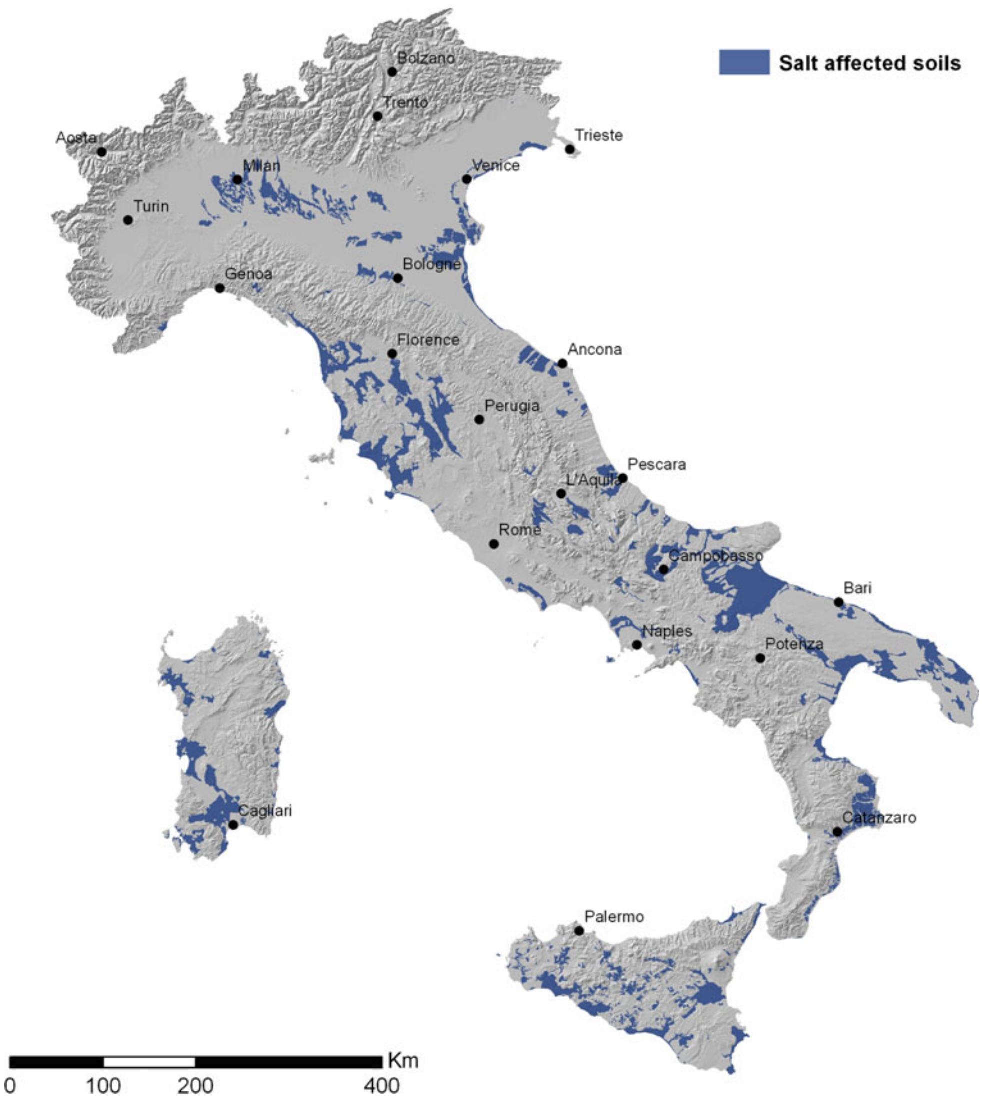

Fig. 8.18 The areas highlighted in *blue* indicate those Italian areas where it is possible to find salt-affected soils

confirm that such soils are particularly widespread in Italy (Fig. 8.18), accounting for some 3.2 million hectares and they are more or less present in almost all the Italian regions with different incidence (Fig. 8.19).

In particular, in Veneto (Giandon and Cappellin 2008), Friuli Venezia Giulia (Michelutti and Barbieri 2008) and Emilia-Romagna (Buscaroli and Zannoni 2010), the saline soils are mainly distributed along the coast and occupy a strip that, depending on the different morphological features and of human influence, ranges from several tens to several hundreds of metres. Their presence is mainly linked to the intrusion of sea water into the groundwater due to the subsidence of the marshes saline soils of the lagoons and nearby-lagoon areas caused, mainly, by pumping groundwater for irrigation or for industrial purposes and for land reclamation.

Some data on conductivity and exchangeable sodium of soils of the coastal strip of the province of Gorizia have shown maximum values of about 12 mS/cm and 2,500 mg/kg, respectively. This leads to decreases in crop production and deterioration of soil structure with formation of surface crusts.

In Tuscany (Gardin and Vinci 2008; Cecchi and Zanchi 2008), processes of soil salinization are widespread along the coast and can go a few kilometres inland. Two distinct situations are reported: the first is related to the saline groundwater intrusion in the coastal plains and in particular in the Albenga Plain, in the province of Grosseto and around the Massaciuccoli Lake; the second concerns the soils that develop on clays of the Pliocene and on argillites of Orcia Valley. The soils that evolve on these substrata are generally free of salts in the "topsoil", but in case of truncation of the soil profile (due to erosion or small mass movements), it is possible to highlight salinity problems in the topsoil that affect, even heavily, crop production. In the case of the Pisa Plain, soil salinity is mainly due to sulphate

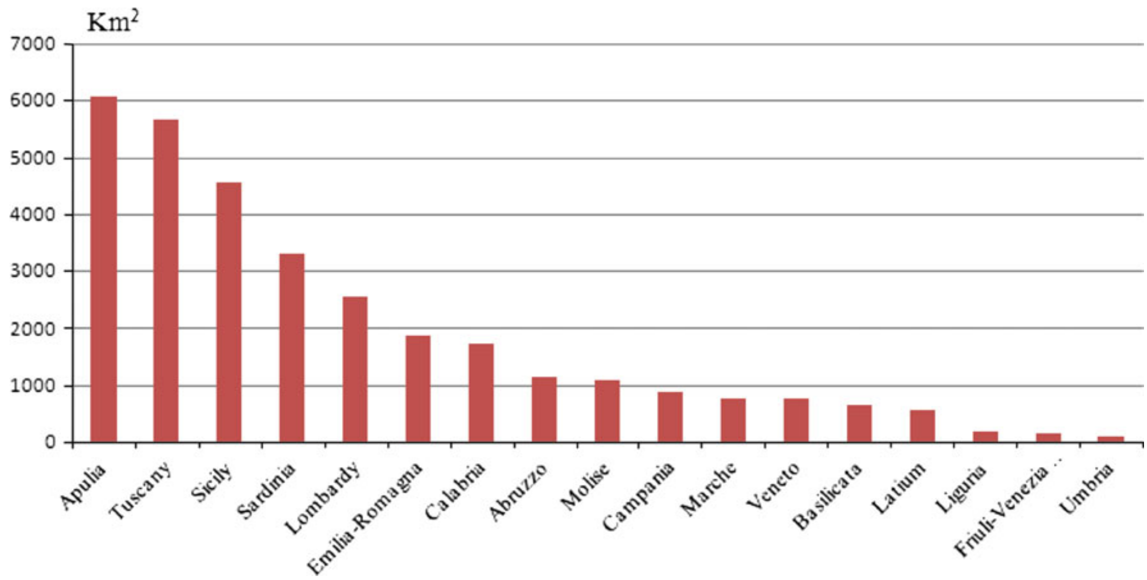

Fig. 8.19 Distribution of salt-affected soil in the Italian regions

dissolved in water and is caused mainly from the ineffectiveness of the drainage network.

In Liguria (APAT 2008), besides some areas of the coast affected by ingression of sea water (the valley of the Magra; the Ceriale coast), there are saline soils due to excessive use of fertilizers, particularly evident in greenhouses where there is no leaching from rainfall. In Marche region (Tiberi 2008), there are saline soils near the coast and also saline and/or sulphide water witnessed by numerous springs and sulphurous mud volcanoes found in soils originated from Plio-Pleistocene and Messinian deposits especially in the provinces of Ancona and Pesaro.

Campania has experienced an increase in areas with salinization problems (D'antonio and Ingenito 2008), not only along the coast where the soil, in direct contact with the water, also exhibit a conductivity of 10 dS/cm, but also in areas where, due to the presence of numerous wells from which water is pumping, there is a strong ingression of sea water.

Apulia, Basilicata, Calabria and Sardinia show saline soils especially along the coastal areas as a result of salinization of groundwater due to marine ingression after its overexploitation (APAT 2008). For example in the Capitanata area (Apulia), a monitoring of groundwater quality (Monteleone et al. 2001) showed that the waters of most of the wells surveyed show a worrying level of salinity in summer with values that exceed 6–7 dS m^{-1}.

In Sicily, the problem due to soil salinity is particularly widespread (Dazzi 2006). Currently in the island, about 10 % of the total area, roughly 250,000 ha, is characterized by salt-affected soils (Dazzi and Fierotti 1996). Their distribution is partially due to the presence of the Gessoso-Solfifera Formation and partially induced by irrigation; the first are particularly present in the provinces of Caltanissetta and Agrigento, that is, in the central and southern zone of the island, where are to report peculiar processes of secondary salinization that lead to the formation of Gypsisols even on not-gypsiferous substrata (Dazzi et al. 2005). Also in Sicily, as well as in southern Italy, soilscapes affected by secondary salinity due to irrigation are found mainly in coastal areas, where irrigation practice has continued in the long term and causes accumulation of soluble salts in the soil that leads to the sharpening of particularly intense social and environmental problems. These are to be related not only to the nature of the soils present, but also to the quality of water available for irrigation. These waters many times show a low quality and often give rise to serious apprehensions for the quality of the soils, above all if they are put in relation to the injurious effects of the exchangeable sodium on the physical characteristics of the soil that, in many cases, are characterized by a clayey texture.

Where the smectitic clays predominates, the structure of the soil shows severe degradation problems already with waters showing adjRNa[2] values higher than 9; where the illites and the vermiculites prevail, the structure degrades with adjRNa values higher than 16, while the kaolinitic or sesquioxide-rich soils begin to show a structure degradation with adjRNa values higher than 26. Consequently, the alkalization process, also in these environments, is more severe than salinization. Nevertheless, often the two forms of salinity coexist (Fig. 8.20).

[2] adjRNa: adjusted sodium adsorption ratio (Ayers and Westcot 1994).

Fig. 8.20 In many cases, irrigation with saline water determines strong soil degradation (*Photos* from personal archive of C. Dazzi)

In south Italy's irrigated soils with a loamy or tendentially loamy texture where the movement and the free drainage of the water are more or less good, the dangerousness of salinization is notably reduced, and very often, the few winter rainfalls are sufficient to assure a good leaching of the salts.

Different is the case of the Vertic Xerofluvents or of the Typic Haploxererts, clayey soils with a very difficult drainage in which the management of irrigation water is very difficult. These soils which are very diffused in all the irrigated landscapes of Sicily should be excluded in the irrigation projects, mostly if the waters show a low quality. Nevertheless, in peculiar environments, like the Sicilian one, where most of the soils of the plains and those of the low hills are made up just by these soil types, their destination to irrigation is an almost inevitable event. For these soils, more than for others, it is necessary to keep into account the limits posed by their low permeability, their high water capacity, their structure degradability and all factors that, singularly or in synergy, create an environment not really suitable for the normal development of the plants.

The dangerousness of the use of saline waters and their considerable influence in the processes of soil's secondary salinization are evident especially in coastal areas where groundwater (from wells) is used for irrigation. It has been observed (Indorante et al. 2001) that soils used for protected crop evolve in saline soils (becoming Solonchak) and/or alkaline soils (becoming Solonetzs) even in the short time of a season. Moreover, when dry periods follow each other for several years, as happens with increasing frequency, it triggers a chain reaction in which the problems of physical and chemical degradation of soils heavily affect the crop production and this, in turn, has a strong influence on economic and social fabric of all areas.

Finally, we wish to emphasize an almost always neglected aspect of secondary salinization of soils that is related to the spreading of salt on roads and motorways in the anti-freeze function. In the area of influence of the main roads in environment with cold winter, NaCl or $CaCl_2$ is spread for personal safety while driving. Sodium chloride is used both in the prevention and in the removal of the blanket of snow; with temperatures below −5° C or in the presence of heavy snowfall, so with high relative humidity, a 27 % solution of calcium chloride is used. One of the consequences on soils adjacent to the areas affected by the spreading of salt is that during the formation of ice crystals, there is the extrusion of solutes, which accumulate at the fringe of freezing. Being fairly constant the position of the limit of this fringe in soils, the trend is the chronic accumulation of solutes at the same depth. In these "horizons", always superficial, the salt concentrations also get to be 2–3 orders of magnitude higher than in the soil as a whole.

8.2.5 Soil Organic Matter Decline

8.2.5.1 Introduction

Organic matter is the most active and vital component of the soil because of its role in the chemical, physical and biological processes. Its main functions in soil concern nutrient supplying, pH buffering, increasing water-holding capacity, improving soil structure and porosity, limiting of erosion and compaction, reducing surface crusting, degrading and filtering pollutants. SOM plays also a fundamental role in sustaining soil biodiversity by providing a source of energy and nutrients for soil microorganisms. Organic matter is a reservoir for nutrients including nitrogen and phosphorous that can be released gradually to the soil through the mineralization process supplying nutrients to crops. Increasing soil organic matter generally results in increased soil productivity, but on many soils, suitable soil physical properties occur at relatively low levels of organic matter (2–4 %). A level of organic matter higher than required to produce suitable physical properties is beneficial, but it does not contribute directly to soil productivity. Increasing soil organic matter levels can reduce atmospheric CO_2 that contributes to climate change. In the last years, this aspect has received huge attention in the world, since some estimates reported that the amount of soil organic carbon in the planet is circa triple of the vegetation carbon stock and almost twice of the carbon in the atmosphere. Soil have been recognized as one of the best planetary systems for carbon sequestration for its high sink capacity (more than half of the global capacity), for its high stability of some organic matter components, for its relatively low cost functioning and for its associated positive environmental impacts and benefits for productivity (Lal et al. 2004). Preservation and restoring of SOM are therefore fundamental affecting several critical functions and can be addressed though appropriate land uses and soil management.

The decline in the content and stock and/or quality of organic matter represents a serious soil threat causing a deterioration or loss of one or more important soil functions. Loss of organic matter determines the decline in soil productivity and soil degradation and accelerates others degradation processes such as erosion, compaction and biodiversity loss. More than 50 % of soil carbon was reported to have been lost within a decade in various regions of the planet (Feller and Beare 1997; Tilman et al. 2002; Lemenih et al. 2005; McLauchlan 2006; Rumpel et al. 2006; Solomon et al. 2007; Tittonell et al. 2007) with greater losses under tropical climatic conditions (Spaccini et al. 2002). Conversion of natural ecosystems to agriculture and anthropogenic perturbations through continuous cultivation and land tillage cause an immediate and rapid loss of carbon and quality deterioration of SOM (Davidson and Ackerman 1993; Giardina et al. 2000). In agricultural settings of tropical and arid and semiarid Mediterranean regions (which are more sensitive to decline in SOM), the removal of crop for feed causes a more rapid loss due to reduced carbon returns to soil (Lal 2006). To limit these effects, many practices are available and have been adopted: reincorporation of straw; applying of farmyard manures and organic fertilizers; cover crops; crop rotations including grass in the cycle; adopting minimum or no tillage systems; returning to natural pastures or forest where possible. Manure and organic fertilizer applications have to be carefully evaluated under the nitrates regulations. Building up soil organic matter is a long-term process even when management practices that conserve soil organic matter are adopted.

8.2.5.2 Status and Trends of SOM in Italian Soils

While measuring the organic carbon of a soil sample in a laboratory is quite immediate and relatively cheap, assessing the carbon stock at national or regional level, even sometime at farm level, is quite difficult and expensive due to the great variability of SOM in the 3D space. Therefore, monitoring actions to assess changes in SOM require time and are expensive and affected by high levels of uncertainty. Trends assessed using historical data may be affected by additional bias caused by changes in methods for SOM determination and bulk density measure. Moreover, methods that use data from long-term field experiments are often affected by differences caused by changes in land use during the period of observation. Laboratory and field tests in the last decades have shown the relationships between organic carbon balance and evolution and other influencing factors such as pedogenetic factors, soil temperature and moisture regimes, erosion, land uses, tillage and crop management. However, assessing the trends of SOM still remains affected by great uncertainty as most of the factors are mutually dependent. A decline in SOM is therefore not unequivocal to assess.

First experimental results in the last years suggest that most European soils are out of equilibrium as regards soil organic matter contents (Smith et al. 2005), as they have been affected by land management practices and land uses typically responsible for SOM decline. Jones et al. (2005) calculated that 0.6 % of soil carbon in European terrestrial ecosystems is lost annually. Recently, the Land Management & Natural Hazards Unit—Joint Research Centre on behalf of EU Commission produced a map of organic carbon content of European soils derived from the European Soil Database in combination with associated databases on land cover, climate and topography (Jones et al. 2004, 2005; Panagos et al. 2008; Panagos et al. 2012). This map shows the organic carbon contents in percentage of the topsoil (upper 30 cm) in a spatial resolution 1 × 1 km, and it is finalized to support the EU soil strategy in line with the global policy for agricultural greenhouse gas mitigation arisen from the Kyoto Protocol to the 1992—United Nations Framework Convention on Climate Change (UNFCCC)—and its subsequent elaboration to the Marrakech Accords. Data extracted for Italy (Fig. 8.21) indicate that almost 23 % of Italian soils have less than 1 % of organic carbon. These areas are concentrated mostly in Sicily, Sardinia and Southern regions, with some very large areas in the Po Valley. Data calculated from the European map considering values of bulk density show that soil carbon stock in Italy comes to 2 Pg. In spite of the coarse resolution and a certain high grade of uncertainty, this map points out those areas that could be more sensitive to SOM decline due to the presence of low contents of organic carbon.

Data from USDA-NRCS global soil organic carbon map show for Italy a stock value equal to 3.9 Pg (Schils et al. 2008).

In Italy, some experiences on assessment of soil organic carbon stock from soil map were undertook in some regions such as *Emilia-Romagna* (Calzolari and Ungaro 2005; Ungaro et al. 2010), Piedmont (Petrella and Piazzi 2005; Stolbovoy et al. 2006), Lombardy (Solaro and Brenna 2005; Cerli et al. 2009), *Veneto* (Garlato et al. 2009a), *Trentino* (Garlato et al. 2009b) and Sicily (in progress).

Recently, organic carbon stock maps at national level have been produced for three different period, aiming to evaluate the variation in the organic carbon in the last decades in Italian soils (Fantappiè et al. 2010). Organic carbon and bulk density values for the surface layer (up to 50 cm) were extracted from the national soil geodatabase (BADASUOLI) for dated survey points. Georeferenced points were grouped in three periods (1979–1988, 1989–1998 and 1999–2008), and values of bulk soil organic carbon were harmonized and interpolated by geostatistical

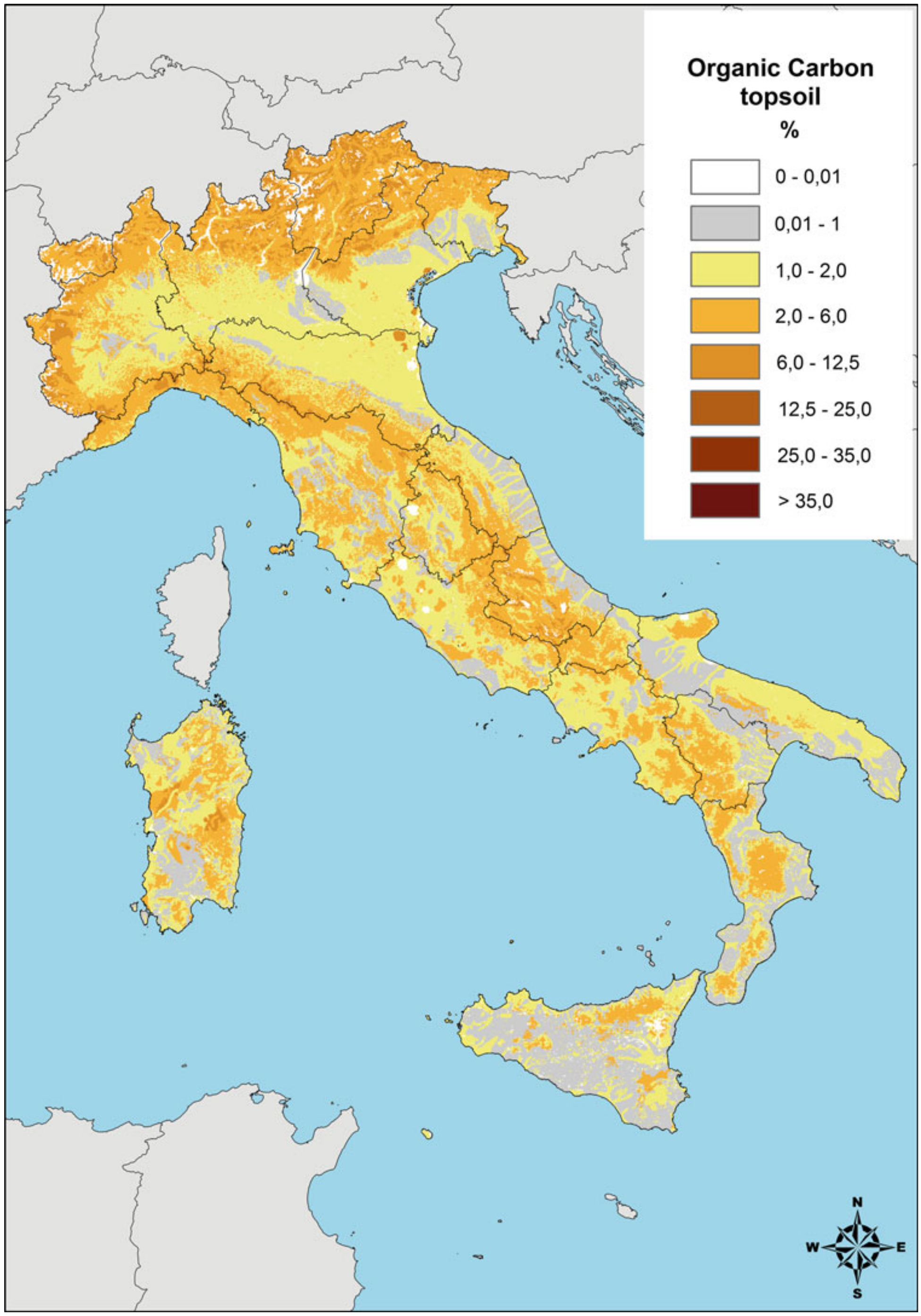

Fig. 8.21 Organic carbon content in % in the topsoil (0–30 cm) in Italy. Map extracted from the European soil organic carbon map (Jones et al. 2004)

inference techniques using climatic, topographic, lithological, pedological and land use derivatives as covariables in the model. Results (Fig. 8.22) of this project were three different maps showing the organic carbon stock estimated for Italy in the past three decades till to 2008.

Soil organic carbon stock is 3.32 Pg in the period 1979–1988, 2.74 Pg in 1989–1998 and 2.93 Pg in 1999–2008. Highest values of organic carbon are in the soils of Alps, Apennines and Sardinia, principally in forest soils, while lowest values are in soils of hilly and plain areas with intensive agriculture. National trend shows a decrease in the second decade, probably caused by intensification of agricultural settings, followed by an increase in the third decade. This most recent estimated increase could be attributed to the change in European Agricultural Policy in the 1990s which promoted in Italy the adoption of agri-environmental actions oriented towards the environmental protection of rural areas, fixing among targets a positive

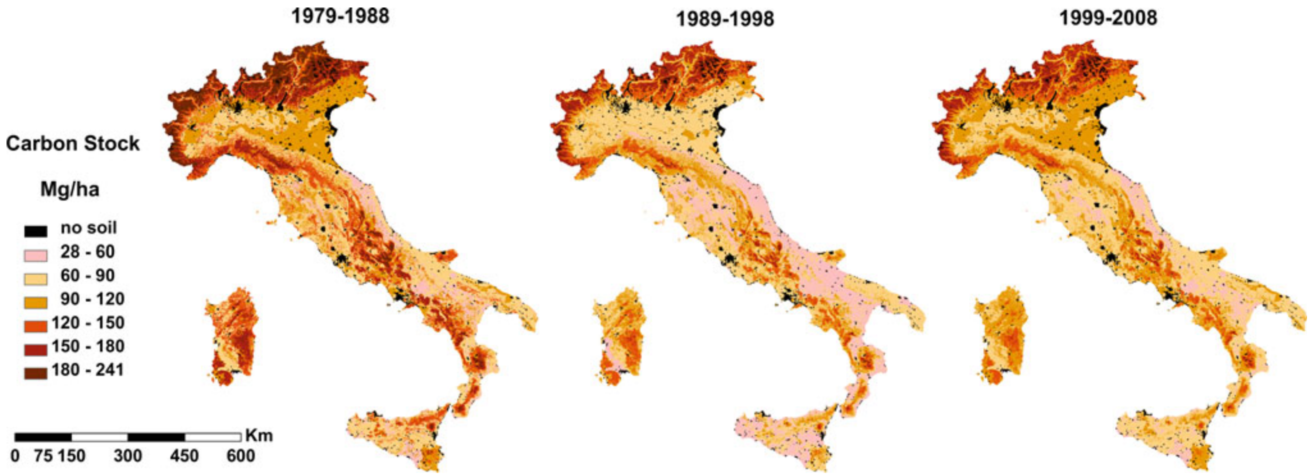

Fig. 8.22 Organic carbon content in % in the topsoil (0–50 cm) in Italy (Fantappiè et al. 2010)

effect on soil organic sequestration. In short, preservation and restoration of natural environment, forest and land uses led to increase the soil organic carbon stock in Italy. Highest positive and negative values of change estimated in time are widely distributed in Po Valley and in hilly and plain areas of central and southern Italy. These areas are probably the most sensitive to variation in soil organic carbon (Fantappiè et al. 2010).

More recently, estimate of organic carbon stock for Italian soils has been carried out exclusively for cropland (Chiti et al. 2011). Soils in cropland are estimated to be the largest biospheric source of carbon loss and therefore more sensitive to SOM decline (Janssens et al. 2003). Estimate was carried out using data from SIAS database (*Sviluppo di Indicatori Ambientari sul Suolo*) and regional soil databases; croplands were extracted from CORINE land cover map 2000. The total amount of carbon in the upper 30 cm of all cropland soils resulted to be 490 $\pm$ 121.7 Tg, representing about 17 % of the total stock estimated by Fantappiè et al. (2010) in the upper 50 cm of all soils of Italy. Most of this carbon ($\sim$70 %) is stocked in soils of "arable land" and "agro-forestry" CORINE land use classes. Some authors indicate that for Italian cropland soils dynamics near to the equilibrium over time, excluding noticeably negative variations at national level when keeping the actual agricultural management (Morari et al. 2006; Gardi and Sconosciuto 2007; Lugato et al. 2010), although permanent meadows and pastures seem to have been significantly affected by the climate change of the last decades (Fantappiè et al. 2011).

8.2.5.3 Conclusions

According to recent data and trends of SOM stock at national level, even if affected by a certain level of uncertainty, decline in SOM in Italian soils seems not to be worrying. However, loss of organic matter could be a relatively rapid process when anthropogenic factors such as incorrect soil management and land use changes may be adopted or when the process is linked to other uncontrolled degradation processes such as accelerated erosion and compaction. On the other side, restoration of SOM on suitable levels is possible with a proper land management, although it can need long periods, especially in most arid Italian regions. Thus, EU soil protection and national policies for optimizing soil organic matter and maintaining soil quality should be formalized and adopted as a permanent strategy at farm regional level together with setting of a suitable SOM monitoring network capable of reducing the level of uncertainty of current statistics.

8.2.6 Loss of Pedodiversity

8.2.6.1 Introduction

In these last decades, besides the threats that traditionally affect the soils more or less everywhere in the world, a new soil threat is becoming more and more evident. This is linked to the loss of soil diversity that has driven pedologists to consider a new soil process due to anthropic action that in origin was called "entisolization" (Dazzi 1995; Fanning and Fanning 1989) but that nowadays is better known as "anthrosolization" (Bockheim and Gennadiyev 2000). Such term indicates a collection of geomorphic and pedologic processes resulting from human activities that include deep working, intensive fertilization, additions of extraneous materials, irrigation with sediment-rich waters and wet cultivation. Effectively, in the 1990s with the constant improvement of scientific knowledge in soil science, the concept of "diversity" has been extended from the kingdom of Biology to the kingdom of Pedology and the term "pedodiversity" has been introduced by Ibañez et al. (1990). In those years, the concept of pedodiversity started to be diffused in the scientific literature not only from a philosophical point of view, highlighting how the depletion of soil diversity can be seen as a sort of "genetic erosion" of the soil systems (Dazzi 1995), but mainly from a pragmatic one, with several surveys on the different aspects related to pedodiversity (Costantini et al. 2002; Dazzi and Monteleone 1999; Guo et al. 2003a, b; Ibáñez et al. 1992; Krasilnikov 2001; Phillips 2001; Phillips and Marion 2004, 2005, 2007; Saldaña and Ibáñez 2004, 2007; Tan et al. 2003).

8.2.6.2 The Facets of a New Soil Threat

The problem linked to the loss of pedodiversity cannot be simply ascribed to population explosion, but is mainly caused by consumerist lifestyles that give nearly one billion people benefits but cause excessive pressures on the biosphere (Rifkin 2000; Amundson 2006). Consumerism, in its turn, is linked to the increase in technological knowledge and in energetic resources that allow us to use and abuse even greater quantities of natural resources (European Environment Agency 2005). Every year, large portions of productive land from an agricultural point of view are sealed with buildings and concrete, and our landscapes are disfigured by excessive amounts of sometimes polluting or highly toxic wastes. Natural areas are deeply ploughed and transformed, even if, in the best of cases, most of them are not useful for agriculture.

As a rule, the anthropogenic soil-forming processes related to long-term agricultural use influence the soil properties over a few hundred or thousand years. In case of soils affected by land use changes in large-scale farming, the anthropogenic processes can be extremely fast-acting (Dazzi and Monteleone 2007). From a pedogenetic point of view, the destruction and/or the construction of soil through their physical and mechanical manipulation are catastrophic events that bring up the soils to time zero, and the area of newly created anthropogenic or technogenic soils is often as large as the area of well-developed soils that have been destroyed (Fanning and Fanning 1989). These are the most remarkable effects of the housing, construction of roads and motorways, or of the burial of various kinds of waste. There are, however, examples which are less striking, but just as dangerous for the protection of pedodiversity such as the case of anthropogenic soils created by land use change in large-scale farming (Dazzi et al. 2008).

Land use change and changes in soil management often occur together (Halvorson et al. 2000), resulting in changes in soil quality, including soil physical features (Wang et al. 2006), soil biology (Kennedy and Papendick 1995) and soil nutrient contents (Kong et al. 2006). Modification at soilscape levels can also lead to an increase in soil aggregate breakdown, in soil organic matter losses and in soil erosion rates (Brandt and Thornes 1996; Drake and Vafeidis 2004) and all in all, to a diminishing of pedodiversity due to the consequent creation of man-disturbing soils. Over the last few years, such processes have marked out several vine-growing areas of Mediterranean Europe, where the capital income deriving from vineyard cultivation is substantial (Dazzi et al. 2004; Pla Sentis et al. 2004; Costantini and Barbetti 2008).

A significant example of the consequences that the creation of anthropogenic soils can have on pedodiversity decrease—and on the total quality of the landscape—comes from a survey carried out within the administrative boundaries of the municipality of Mazzarrone, a town in south–east Sicily (Italy) (Dazzi and Monteleone 2007; Dazzi et al. 2009). The landscape of Mazzarrone in the decade between 1970 and 1980 has experienced a rapid transformation which led to a significant increase in the per capita income of its inhabitants. In particular was widely grown table grapes, so that, currently, most of the land use of the landscape was, and still is, made by vineyards. Wine growing diffused rapidly during the 1970s when everyone started cultivating "Italia" vine. Vineyards grew up with a frequency not easily measurable and with a consistent and evident transformation of the landscape. Such landscape transformation was achieved through excavations, earth levelling and trenching. Arable lands, almond yards, olive grove and natural grazing were replaced by vineyards. In many cases to gentle the morphology, large amounts of soils were spread over the land by trucks, a very expensive operation. In few years, all the surfaces that did not place limits to the use of mechanical tools for vine cultivation, also the steeper areas, have been affected by an intense process of anthropogenesis which resulted in the almost total annihilation of the pedodiversity of the Mazzarrone's soilscape (Lo Papa et al. 2011).

Different types of soils on variable morphologies and with very different characteristics (Calcic, Inceptic, Mollic e Typic Haploxeralfs, Calcic, Humic e Typic Haploxererts, Entic Haploxerolls, Typic Xerorthents) were so deeply and intensely reworked to be destined to vineyards, that no longer it is possible to distinguish in them any fragment of the original horizons.

Dazzi and Monteleone (2007) estimated that such process, only in Sicily (Italy), has affected some 20,000 ha in western Sicily (mainly for orchard cultivations), some 25,000 in central Sicily and some 15,000 in eastern Sicily (mainly for vineyards cultivation). This means that in Sicily, such anthropogenic soilscapes account for about 60,000 ha on 1,281,655 ha of the total farming area (i.e. about 4.7 %). This enormous pressure exerted on soil ecosystems leads to other kind of disorders: the soil, raped so deeply, remains defenceless to erosion (Fig. 8.23).

Under these vineyards, in fact, every year, tons of soil are blown away by winds or are carried to plains, through big erosion furrows which are filled with soil material

Fig. 8.23 Deep gully erosion in anthropogenic soils under vineyard (*Photos* from personal archive of C. Dazzi)

transported from other places where soils still present their peculiar configuration. In such conditions, it is clear that soil resilience, namely the soil ability to counteract stress and alterations, is very low and in some cases even null because energy fluxes, after human action, overcome largely any critical thresholds.

Next to these aspects, there are those which come from the use of plastic films and pesticides. Plastic films used to cover vineyards, even if law imposes recycling, are often abandoned in the environment and then burned and release toxic compounds as, for example, dioxin, while to maintain grapes on the plants for a long period, farmers use massive quantities of pesticides which also persist in the environment.

8.2.6.3 Conclusions

The potential negative effects of various human activities on soils have been an important topic of concern for soil science in these last two decades as testified by the many research papers on pedodiversity that continue to be published in the international literature. In the above-reported case study, all the surfaces that did not limit the use of machinery to set new plants for vine cultivation, including also areas where morphology tends to be steeper, have been involved in an intense anthropic process causing, in the

Table 8.8 Forest fires in the different Italian regions (Italian Forest Corps 2009)

Region	Number of fires	Wooden area (ha)	Not wooden area (ha)	Total burned area (ha)
Valle D'Aosta	13	2	5	7
Piedmont	117	286	87	373
Lombardy	138	268	128	396
Trentino Alto Adige	48	4	1	5
Veneto	99	30	24	54
Friuli V. G.	73	198	156	354
Liguria	332	1489	1155	2644
Emilia-Romagna	86	69	102	171
Tuscany	549	1407	431	1838
Umbria	56	44	11	55
Marche	19	38	25	63
Lazio	325	1802	726	2528
Abruzzo	34	104	55	159
Molise	49	75	111	186
Campania	903	4881	1321	6202
Apulia	277	1527	2831	4358
Basilicata	142	651	390	1041
Calabria	716	4114	3087	7201
Sicily	762	1801	6815	8616
Sardinia	684	12270	24834	37104
Total	5422	31060	42295	73355

Table 8.9 Summary of the effects of fires on the soil properties (from Certini 2005)

Physical, physico-chemical, and mineralogical properties
Water repellence the natural water repellence of soil often increases because of the formation of a continuous water-repellent layer, a few centimetre beneath the surface. It implies limitations in soil permeability and thus increased run-off and erosion
Structure stability complexity decreases as a result of the combustion of organic cements
Bulk density increases because of the collapse of aggregates and the clogging of voids by the ash and the dispersed clay minerals; as a consequence, soil porosity and permeability decrease
Particle-size distribution does not change directly, but the increased erosion can remove selectively the fine fraction
pH in non-calcareous soils increases, although ephemerally, because of the release of the alkaline cations (Ca, Mg, K, Na) bound to the organic matter
Mineralogical assemblage changes, but only at temperatures higher than 500 °C
Colour darkens, due to charring, and reddens, due to formation of iron oxides
Temperature regime changes temporarily because of both the disappearing of the vegetable mantle and the darkening of ground (decreased albedo)
Chemical properties
Quantity of organic matter decreases immediately after fire, but in the long run, generally exceeds the pre-fire level
Quality of organic matter changes remarkably, with a relative enrichment of the fraction more recalcitrant to biochemical attack. This is due to both selective burning of fresh residues (leaves, twigs, etc.) and due to neoformation of aromatic and highly polymerized (humic-like) compounds. Charred material, an exclusive product of incomplete combustion, shows residence times of centuries or even millennia
Availability of nutrients increases, often remarkably, but ephemerally
Exchange capacity decreases proportionally to the loss of organic matter
Base saturation increases as a consequence of the prevailing release of bases from the combusting organic matter
Biological properties
Microbial biomass decreases; the recovery of the pre-fire level depends chiefly on promptness of plant recolonization
Composition of microbial community changes as a consequence of the selective effect of fire on some groups of microorganisms and the modification imposed to vegetation; generally, fungi diminish more than bacteria
Soil-dwelling invertebrates biomass decreases, but less than that of microorganisms: thanks to the higher mobility of the invertebrates
Composition of soil-dwelling invertebrates community changes, and the time of recovery of the pre-fire assemblage differs highly among the various phyla

short period, the genesis of anthropogenic soils. This, interpreted strictly under the light of the diversity, allows for the conclusion that there was an increase in soil diversity in the soilscape but hides the effects concerning the soilscape pattern change. Farmers, in fact, in most cases, aim mainly at increasing economic profits, and the higher they increase, the more they exploit natural resources, particularly the soil. In such conditions, it is clear that soil resilience, namely the soil ability to counteract stress and alterations (Szabolcs 1994) is very low and in some cases cancels out, because soil exogenous energy fluxes, after human action, overcome largely all critical thresholds.

Many studies should be undertaken to verify how the transformation of natural soils into anthropic ones leads the transformation of the system including aspects related, for example, to the soil biodiversity, pollutants and environmental sustainability. The prediction of what reasonably can happen in the future allows for a better comprehension of the phenomena linked to land use change and must be used to stimulate local stakeholders and land managers towards a safe and sustainable land use of the soilscape.

8.2.7 Other Soil Threats: Forest Fires and Landslides

Forest fires and landslides are to be considered other threats that contribute to decrease or to alter the soil fertility and capability.

8.2.7.1 Forest Fires

Forest fires are a recurrent phenomenon in Italy and are mainly of anthropic origin. According to recent data (Italian Forest Corps 2009) in 2009, there were a total of 5,422 forest fires that involved 73,355 ha of which 31,060 wooded and 42,295 non-wooded (Table 8.8). Campania is the region that in 2009 recorded the highest number of fires (903), followed by Sicily (762), Calabria (716) and Sardinia (684). The latter region has had the largest wooded area covered by fire (12,270 ha), followed by Campania (4,881), Calabria (4,114), Lazio (1,802), Sicily (1,801) and Puglia (1,527).

Important causes that originated forest fires include escaped fires associated with agricultural practices, such as

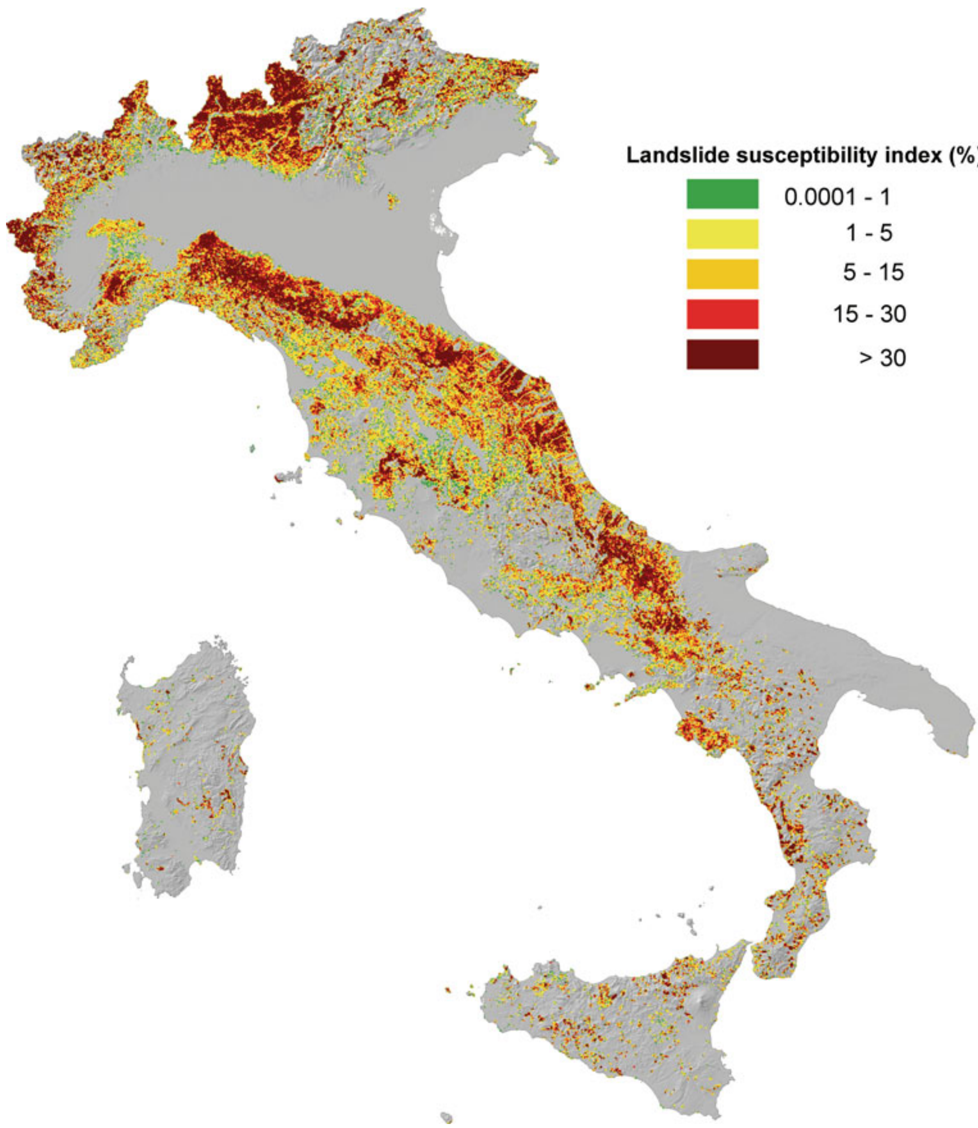

Fig. 8.24 Landslide susceptibility map of Italy (*Source* APAT 2007a)

straw or shrub burning, forest debris burning or pasture renewals, careless use of recreational fires and cigarettes. Despite the human origin, fire ignition and the subsequent spread are mainly driven by the presence of fuels and the meteorological conditions that determine the dryness of the fuels. Moreover, fire ignition and spread are both enhanced by cumulated drought, high temperature and low relative humidity and by the presence of wind (EEA 2010).

In any case, soil properties experience fire-induced changes, depending chiefly on severity and frequency of fires, and post-fire climatic conditions. The most intuitive change soils experience during burning is the loss of organic matter, but many other soil properties could be affected and/or modified by fires (Certini 2005). Considering that a plethora of scientific works has investigated what type of modification selected properties of forest soils undergo following fire, we prefer to summarize these effects in Table 8.9.

8.2.7.2 Landslides

Landslides represent one of the major threats to human life, buildings, infrastructure and soils in all the mountainous and hilly regions of Italy. In our country, landslides are mainly associated with heavy and/or prolonged rainfalls, coupled with soil erosion on mountain and hilly slopes. Other important triggering factors include snow melt and slope toe erosion by rivers and man-made activities such as slope excavation and loading, land use changes (EEA 2010).

In Italy, (EEA 2003), landslides increased substantially during the second half of the 20th century, mostly because of urbanization and agricultural land abandonment. It is estimated that as many as half of Italian cities are at risk from such events. The following map shows the Italian areas that can be considered prone to the occurrence of landslides (Fig. 8.24).

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9 Italian Soil Management from Antiquity to Nowadays

Giuseppe Corti, Stefania Cocco, Giorgia Brecciaroli, Alberto Agnelli, and Giovanna Seddaiu

9.1 Introduction

Soil is the product of the cumulative action of matter and energy fluxes on a parent material, whose primary minerals are progressively transformed into secondary constituents (Chadwick and Chorover 2001; Cornu 2005; Samouëlian and Cornu 2008). Topographic relief, living organisms including humans and climate modify fluxes of mineral, organic matter and energy over time. Agriculture is an important human soil activity as the human practices strongly affect physical, chemical and biotic soil properties and processes (Yaalon 2007). As expressed by Dudal (2004), human and humankind activities must be considered as soil-forming forces able to induce *anthropo-pedogenetic* processes (Richter 2007). In the past, some of these processes, actuated for prolonged time, were able to degrade soil so as to contribute to the failure of past civilizations like those Mesopotamian and Greek (Diamond 2005; Montgomery 2007; Brevik and Hartemink 2010). In fact, the first human civilizations unintentionally interfered on soil formation processes through deforestation by means of fire, vegetation changes, relief modifications, excessive tillage, irrigation, excess of animal trampling and changing of the parent material by transport and dumping of new substrata (Dudal 2004; Goudie 2006). Doing this, they favoured erosion and salinization (Brevik and Hartemink 2010). The first soil management practices were concocted as there was the raising consciousness that soil degradation determined reduction in food quantity and diversity, which is nowadays known to be caused by erosion and alteration of microbial population, nutrient and soil organic matter cycles (Matson et al. 1997; Guo and Gifford 2002). These problems, together with the demographic pressure and the genetic improvement of most crops that increased sensitivity to fertilizers, are those that in the last 60 years have induced the introduction and the even higher use of fertilizers and pesticides (e.g. Lobry de Bruyn 1999).

Nowadays, agriculture approximately interests 40 % of Earth's land surface (FAO 2003; Kareiva et al. 2007). Because of this, human activity is even more driving soil evolution and landform modification by soil redistribution processes due to water erosion (Hairsine and Rose 1992a, b; Legout et al. 2005) and tillage erosion (Lindstrom et al. 1992; Govers et al. 1994, 1996; Van Oost et al. 2003a, b), which are mainly controlled by topography and, to a lesser extent, farmer activities.

As agricultural soils are subjected to degrade and man has been (and is) the main force governing occurrence and intensity of degradation and rehabilitation, it is mandatory to know and develop techniques able to preserve soil and its functions for the future generations. Soil management is intended as the total of agricultural practices and operations that are finalized to minimize soil degradation and improve soil performance in the agro-ecosystems. Because of this, soil management is also much implicated in the soil carbon sequestration and in the mitigation of global warming (Lal et al. 2007).

In Italy, many types of physiographic regions can be recognized, each one resulting from the interaction of many factors like geology, geomorphology, climate, vegetation and land use (Costantini et al. 2004). In this context, the human factor differently operated through the time. Soil modifications were induced in early times by vegetation changes caused by fire, but the use of soil increased after the advent of agriculture. The human impact became bigger with increasing population, and when lithic tools evolved into iron ploughshares, coulters and spades that in turn

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made place to heavy tillage machinery (Dudal 2004). From a pedological point of view, by agriculture, man is a forming force that may cause soil changes through direct interventions such as manuring, liming, ploughing, fertilization, and through indirect interventions such as relief and drainage modification that change moisture regimes, reclamation of natural soils after their deforestation, irrigation (Dudal 2004).

The climate variability was also an important driving factor for the soils evolution in Italy. Information obtained from archaeology records and classical geographic documents of antiquity suggest that, in the Mediterranean basin, the climate should have been moister in Roman times than nowadays. The widespread presence of aqueducts, bridges and thermal baths built around 2,000 years ago in areas that are currently facing desertification processes and the historical documents written by many Greek and Roman authors support this hypothesis. After the downfall of the Roman Empire, Middle Ages represented a dark hole in the human civilization, and in the development of agriculture as well. Because of this, forests expanded, re-occupying former cultivated soils that, in turn, had been obtained from deforestation. During the Medieval Warm Optimum (about 950–1250 A.D.), forests occupied even soils of high altitude, but in general, they declined again because of a strong demographic increment that occurred around the eleventh century. Between about 1300 and 1870 A.D., there was a period, called Little Ice Age, during which Europe and North America were subjected to much colder winters than during the previous and successive centuries. Winters were bitterly cold and prolonged, reducing the growing season of several weeks. These conditions led to widespread crop failure, famine and, in some regions, population decline. During this period, as obvious, soil temperature and moisture regimes changed.

A comprehensive understanding and managing of actual soil functionalities requires the knowledge of soil management evolution from its pre-agricultural to current state. Thus, as Italian agriculture dates back thousands of years, it is difficult to recollect all the climatic, cultural and technological changes the soils faced, although soil management has been driven and defined by many of these changes. For all these reasons and because of a high variability of soil types, the Italian territory is one of those with a major diversity of soil uses in the Mediterranean basin. This condition can be established giving a look from the top of the Alps to the African shelf islands of Sicily and the small others. Such a territory covers a vast gradient of climates and habitats that includes mountains, hills, plains, but also volcanic apparata, islands, marshes, lacustrine environments, all with a great variety of parent materials.

The aim of this chapter is to present an overview of the soil management practices through the time and in the different Italian physiographic districts, analysing their effects on soil conservation and fertility.

9.2 General Concepts of Soil Management

Processes of soil degradation or reduction in the soil fertility can reduce the ecological state and the productive capacity of the soil. Degradation can result from inappropriate farming practices such as unbalanced fertilization, excessive use of groundwater for irrigation, improper use of pesticides, use of heavy machinery and overgrazing. Other causes of soil degradation include the abandonment of certain farming practices (Cannell and Hawes 1994). Soil management is the harmonious whole of agricultural practices, operations and treatments that farmers adopt in each context to minimize soil degradation, obtain the relatively highest quantitative and qualitative production of food and fibres and preserve the soil and agro-ecosystem functions. As a matter of fact, in the various agro-ecosystems, the soil management and the local environmental conditions are the main factors involved in the conservation of the soil from the various types of degradation that threaten it. From this statement derives that, if soil management is not well harmonized with the environmental conditions, soil is prone to degradation, which proceeds because of erosion, soil sealing, compaction, salinization, pollution, and often deals with some of the soil properties like drainage, decline of organic matter and nutrient supply, so reducing the soil fertility. Here below, we report a brief description of the main soil threats; however, for an exhaustive coverage of the matter, see Chap. 8 of this book.

9.2.1 Erosion

Erosion is a natural process consisting in the removal of soil particles by the action of water or wind. With respect to soil degradation, most problems about erosion are associated with accelerated erosion. In fact, conversely to the "geological erosion", which removes the soil at nearly the same rate the soil is formed, accelerated erosion causes a loss of soil at a faster rate than it is formed. This process is a product of unwise human activities such as overgrazing or unsuitable cultivation practices that leave the soil vulnerable to the action of water or wind. In fact, during rainfall or windstorm, soil may be detached, transported and deposited elsewhere. In particular, in the hilly lands, the strong mechanization and the abandonment of land set-up systems for soil and water conservation have triggered erosion processes (Bazzoffi and Jakab 2006; Bazzoffi et al. 2011) producing loss of soil, fertility and biodiversity.

Worldwide, 16 % of land was estimated to be vulnerable to erosion hazard, and water erosion is considered one of the major causes of soil degradation (FAO 2000). In Europe, 12 % of the land is estimated to be subject to soil erosion (CEC 2006), whereas 30 % of the Italian soils are affected by a risk of potential erosion greater than 10 Mg of soil per ha per year mostly because of geomorphic reasons and soil erodibility.

9.2.2 Soil Sealing

The covering of the soil surface with impermeable materials as a result of urban development and infrastructure construction (OECD 1993; Gentile 1999) or a change in the soil properties leading to impermeability (Jones and Montanarella 2001) is known as soil sealing. Practically, sealing is the separation of the soil from atmosphere and above-ground biosphere. This problem occurs mainly in metropolitan areas, where high is the soil surface covered by constructions, industrial and commercial infrastructures and roads. However, also cultivated soils may develop subsoil compaction because of inappropriate use of machinery and intensive agriculture (Jones and Montanarella 2001). The soil sealing generates an impoverishment or a loss of soil ecological functions and affects the water cycle and flow patterns of the surrounding agro-ecosystem. In fact, the main effect of the soil sealing is the reduction in water penetration into the soil and the increase in run-off that, in turn, can trigger erosion processes.

During the last decades, in Europe, the urbanized areas increased about 20 % with a population growth of 6 % (APAT 2007). Further, the global economical crisis have favoured the abandonment of obsolete industrial plant that occupied wide sealed surfaces (brownfields), so producing a shifting of population towards new growing areas that are often developed over natural or agricultural land (Blum et al. 2004; Burghardt 2006). In Italy, Lombardy, Veneto and Campania regions have the relative largest sealed surfaces, with values between 8 and 10 % of their regional territories (APAT 2007).

9.2.3 Compaction

Soil compaction is the result of the rearrangement in a denser way of soil aggregates and/or particles induced by heavy machinery or passage of animals. The orientation, size and shape of soil aggregates are signs of soil compaction, which produces a typical soil platy structure (aggregates with one side much longer than the other and in a horizontal way). Compaction modifies soil temperature and moisture regimes, produces changes in the biological activity, porosity and permeability, reduces water infiltration capacity and increases erosion risks by accelerating run-off. All agricultural soils in developed countries display a certain degree of compaction. In arable land with annual ploughing, compaction of both topsoil and subsoil is possible as tillage operations may cause the formation of pan-layers (Castrignanò et al. 2004), which are poorly permeable for roots, water and oxygen. In Italy, the formation of a pan-layer occurs commonly in the alluvial plains intensively cultivated (especially monoculture), where it is responsible of drainage reduction and consequent soils submersion.

9.2.4 Pollution

Soil contamination is the occurrence of pollutants in soil above a certain level, so as to cause deterioration or loss of one or more soil functions. The soil contamination is defined "diffuse" when the origin is not easily identifiable or "local" if it derives from a specific source. The diffuse soil contamination, recognized as a threat of the soil quality by the Thematic Strategy for Soil Protection of the European Commission (CEC 2006), affects wide areas, and it is due to agricultural practices (use of fertilizer, waste materials as amendments and pesticides) and diffusion of pollutants produced by industrial plants, traffic and other human activities. The main effects derived from the diffuse contamination are accumulation in soil of nutrients, heavy metals and persistent organic molecules (Tremolada et al. 2008). With time, when the buffering capacity of soil with respect to a certain substance is exceeded, the substance can be released to the environment, causing impairment of groundwater and/or surface water. This is the case of nitrogen and phosphorous over-fertilization: when application of fertilizers is beyond plant necessities and soil retaining capacity, the excess is leached, eroded or washed off into groundwater and/or surface waters so inducing eutrophication of the water bodies. Besides over-fertilization, accumulation of nitrogen can be caused by wet and dry nitrogen depositions (Fabietti et al. 2010). Further, the use of fertilizer such as superphosphate and calcium nitrate has been associated with heavy metals soil accumulation (Lopez-Mosquera et al. 2005).

The local soil contamination affects specific areas subjected to high degree of industrialization, and usually arises from the percolation of contaminated surface water to subsurface strata, leaching of wastes from landfills, direct discharge of industrial wastes to the soil, application of pesticides and damages to underground storage tanks. The most common chemicals involved in soil contamination are petroleum hydrocarbons, solvents, pesticides and heavy metals.

Areas with local soil contaminations are the "brownfields", abandoned industrial areas whose reclaiming is often hampered by the contamination of the site. A problem that implies soil pollution in many places of the Italian territory is represented by the abusive waste landfills, which is a sordid behaviour in which are involved criminal organizations known as *camorra*, *mafia*, *'ndrangheta*, *sacra corona unita*, as well as non-organized criminals. In a report of the National Forest Corp (Corpo Forestale dello Stato 2002), in the year 2002 in the Italian territory (excluding the regions of Sicily, Sardinia, Val d'Aosta, Trentino-Alto Adige and Friuli Venezia Giulia, which are regulated by a Special Statute), there were 4,866 abusive waste landfills of any nature, with a rather diffuse incidence in all the territory. The major problems of soil pollution due to this aspect occurred in regions such as Campania, Calabria, Apulia and Abruzzo, where criminal organizations have been more active and buried waste of industrial origin. However, in Tuscany, Emilia-Romagna, Veneto and Lombardy, the number of abusive landfills are relatively high as, in the last two decades, parts of these regions have become terrain of conquest and settlement of more or less organized criminal conspiracies.

9.2.5 Salinization and Sodicization

Salinization and sodicization are among the major degradation processes that affect southern European soils. These processes are among the main soil threats identified in the Thematic Strategy for Soil Protection of the European Commission (CEC 2006). Sodic soils become less permeable to water and air, and more prone to erosion. Saline and alkaline (or sodic) soils are characterized by excess salts that modify their chemical and physical properties. If carefully managed, saline soils can maintain a suitable structure and permeability to water and air. Sodic soils, on the contrary, are affected by clay dispersion and structural instability, are less permeable to water and air, and display scarce workability. Degradation of the soil structure also increases soil erodibility. In terms of field operations, the increased energy requirements due to reduced trafficability and workability and the increasing compaction damage are the most important consequences of soil salinization and sodicization (Spugnoli et al. 2002).

In the Mediterranean soils, salt accumulation is a natural process favoured by the ecological conditions in the region governed by the water balance of the area (Zalidis et al. 2002), but human activities may modify this water balance and cause salt accumulation under limited drainage conditions so as to accelerate land degradation. Further, in many coastal areas, the groundwater contains high concentrations of NaCl and the continuous use of this saline–sodic water for irrigation leads to soil salinization and yield reduction (Lal and Stewart 1990; Oster 1994; Shalevet 1994; Aragüés and Tanji 2003).

Globally, 20 % of irrigated lands suffer salinization, which is induced by the increase in salts due to irrigation (Wood et al. 2000). In Italy, one of the main problems of the coastal alluvial plains, which are used intensively for agriculture and industry, is that the groundwater is affected by sea water intrusion due to natural and man-induced subsidence (Pagliuca 2004).

9.2.6 Decline of Organic Matter

Among the main causes of soil fertility decline, the loss of organic matter is one of the most relevant causes. Soil organic matter is made up of heterogeneous mixtures of both simple and complex substances containing carbon. Most of the soil organic matter is found in the upper 10–20 cm of soil, and its amount and quality in the topsoil is often used as indicator of soil quality and productivity (Allison 1973; Bauer and Black 1994; Davidson 2000).

The annual rate of organic matter loss varies depending on cultivation practices, type of plant/crop cover, soil drainage status and weather conditions. A decline of organic matter is caused by the reduced presence of decaying materials or the increase rate of decay, which may occur as the result of changes in natural (climate, land cover and vegetation, topography) or anthropic (land use, soil management and degradation) factors (Davidson and Janssens 2006). The loss of organic matter can limit the presence of available nutrients (Loveland and Webb 2003), so reducing crop yields and soil biodiversity. The depletion of organic matter may also deteriorate structure and, therefore, reduce water infiltration capacity and available water content, so leading to an increased run-off and erosion and, under semi-arid climate, even to soil drying up or desertification (Costantini et al. 2009). As it is predicted that global warming speeds up the decay of soil organic matter with release of greenhouse gases and increasing climate change, it is expected that the major decline of organic matter should occur in the areas under cold and wet climatic conditions. Consequently, in Italy, soil degradation might progressively affect mountain soils from south to north (Costantini and L'Abate 2009).

9.2.7 Decline of Soil Fertility

Soil fertility is defined as “the quality of a soil that enables it to provide nutrients in adequate amounts and in proper balance for the growth of specified plants or crops” (SSSA 1997). Although soil fertility does not consider the significance of physical and biological properties of soil for crop productivity, it is a useful simplification to understand the importance of nutrient balance. Decline of soil fertility can be due to nutrient depletion (larger removal than addition of nutrients), nutrient mining (large removal of nutrients and no inputs), acidification (decline in pH and increase in exchangeable Al), loss of organic matter and increase in toxic elements (Hartemink 2006). Concerning with nutrient depletion, it is a matter of fact that, at the harvest, the nutrients (N, P, K, Mg …) taken up by crops are removed from soil, and this removal may result in a decline of the soil fertility if replenishment with inorganic or organic fertilizers is inadequate.

Soil fertility decline, although it has not received the same attention as soil erosion, is considered as an important cause for low productivity of many soils (Foley et al. 2011). Soil fertility is preserved by applications of manure or other organic materials, inorganic fertilizers, lime, appropriate rotation and cropping systems, or a combination of these.

9.3 Soil Quality Rating: A System to Evaluate Soil Management

Through the time, farmers have always “fought” against climate and environment to obtain yields optimization, but sometimes their efforts were not sustainable and induced soil quality decline (Lal 1993, 1994; Pimm 1984; Blum and Santelises 1994; Eswaran 1994; Sombroek 1994; Szabolcs 1994a; Herrick and Wander 1998). To understand the environmental sustainability and the impact of a certain soil management on a given soil and avoid mistakes, it is mandatory to evaluate *ex-ante* and *ex-post* the effects of the soil management on the soil quality (Herrick 2000). Soil quality reflects the capacity of a soil to sustain plant and animal productivity, to maintain or enhance water and air quality and to promote plant and animal health (Doran and Parkin 1994; Doran et al. 1994). However, soil quality is affected by soil management, which may modify physical, chemical and biological properties of soil (Caravaca et al. 2002). Fromm et al. (1993) found that soil management can affect biological soil quality more than soil type does.

As physical, chemical and biological properties of soil interact among themselves, and the soil quality can be considered as the outcome of these interactions (Bloem et al. 2006; Marzaioli et al. 2010), a proper assessment of the soil quality requires considering many soil indicators such as texture, thickness, infiltration index, bulk density, water-holding capacity, pH, electrical conductivity, microbial biomass C and N, mineralizable N and microbial activity (Duiker 2006). Evaluating soil quality by means of these indicators is evidently a scientific approach, but it is undoubtedly time-consuming and expensive. Because of this, less scientific but quick (even though subjective) field approaches have been developed to rate soil quality so as to establish sustainability of a certain soil management. Examples of soil quality determination are those of Duiker (2006) developed for Maryland, Oregon and Pennsylvania soils, and the visual soil assessment (VSA) developed by Shepherd (2003). In the first case, the indicators taken into consideration are the following: surface cover, soil structure, soil colour, soil erosion, soil compaction, water infiltration, presence of earthworms, amount and morphology of seedlings and spontaneous plants. The second approach generally takes into consideration indicators such as soil texture, soil structure, soil colour, soil porosity, number and colour of soil mottles, earthworms, potential rooting depth, surface bonding, surface crusting and cover, soil management, with some difference that depends on the crop to which is applied. In fact, at the moment, the application of VSA method has been developed for the following nine different cultivations: wheat (Shepherd et al. 2008a), vineyards (Shepherd et al. 2008b), olive orchards (Shepherd et al. 2008c), annual crops (Shepherd et al. 2008d), orchards (Shepherd et al. 2008e), pastoral grazing and cropping (Shepherd 2009a), pastoral grazing on hill country (Shepherd 2009b), corn (Shepherd 2010a) and pasture (Shepherd 2010b). The reiterated application of one of the soil qualities evaluating systems is able to give information on the sustainability of a certain soil management after few years, but always before that major damages may occur.

In agricultural systems, soils are subjected to a range of stresses that may affect physical and biological properties of soil and, at extreme consequences, compromise soil functionality. How the soil responds to stresses both initially and over time defines the concepts of resistance and resilience, respectively (Lal 1993; Kay et al. 1994; Seybold et al. 1999), and both are key factors to establish sustainability of soil management. For example, soil resilience studies often monitor a particular soil property or function prior to, during and following imposition of a stress. Soil physical resilience has been evaluated through monitoring pore volume (O’Sullivan et al. 1999; Zhang et al. 2005; Kuan et al. 2007) and strength (Munkholm and Schøjnning 2004; Gregory et al. 2007) during and after compaction, by measuring stability and size distribution of soil aggregates to wet–dry cycles (Grant et al. 1995; Denef et al. 2001), and by measuring vertical soil movements after compaction (Tobias et al. 2001). Soil biological resilience has been assessed by measuring changes in the dissolved organic carbon (Merckx et al. 2001), catabolic function (Degens and Harris 1997), specific microbial function groups (Tobor-Kaplon et al. 2005; Wada and Toyota 2007; Wertz et al. 2007), size and activity of the microbial biomass (Franco et al. 2004) and rate of plant residues mineralization (Griffiths et al. 2000; Kuan et al. 2007) in response to disturbance. Orwin and Wardle (2004) offer an interesting discussion on how to convert measured soil properties into resilience indices: "Using soils from long-term controlled field experiments, where management practices have been in place for 45–160 years, Gregory et al. (2009) found large differences in biological and physical resilience to stress between arable, grassland and forest soils. Total organic matter varied markedly between the soils and management practice, with arable soils having the smallest amounts. Strong positive relationships were found between organic matter and many soil resilience indices. In the grassland soils, greater particulate organic matter probably enhanced elastic recovery from the physical compression stress. The resistance to heat and copper stresses in grassland soils may also be enhanced by greater organic matter, as well as microbial diversity. Between the different experimental sites, clay content had a large impact on soil resilience".

9.4 The Italian Soil Management: A Historical Overview from Protohistory to Nowadays

In Italy, soil management has a long history since the story of land use is as old as the occupation of this country by different people. In the different Italian agro-ecosystems, all the soil threats have been experienced, and the agriculturists have been refining various soil managements so as to avoid degradation and maintain or improve the capability of soil to produce food or fibres. This means also that the history of the progression or the innovations that were realized in the course of time in terms of soil management depends on the difficulties the people encountered in the various places they settled and on the human history. Because of this, the history of the Italian soil management will be presented according to the following historical sub-divisions: (1) *Protohistory*, meaning the time spanning from the beginning of agriculture (Neolithic Age, about 9,500 years before present (YBP)) to the foundation of Rome (773 B.C.), hence including the Iron Age; (2) *Classic Age* (or Classical Antiquity), which is conventionally taken to begin with the foundation of Rome and that roughly coincides with the first recorded Olympiad (776 B.C.), while the end is considered to coincide with the collapse of the western Roman Empire, in AD 476 (the abdication of Romulus Augustus, the last emperor of the western Roman Empire); (3) *Middle Ages*, which spans from AD 476 and is considered to end in 1401 (contract for the building of the north doors of the Florence Baptistery) or 1453 (the Turkish conquest of Constantinople) or 1492 (the Christopher Columbus's voyage to America); (4) *Renaissance*, which started in the late Middle Ages and is considered to span till the beginning of sixteenth century, and *Modern Age*; (5) *Risorgimento* from the end of the Modern Age to the Italian unification, and (6) *from the Unification of Italy* (1861) *to nowadays*. However, it is usually hard or impossible to find information about soil management for many historical periods, consequently some information is inferred from the dietary habits, which have been often reconstructed thanks to archaeological studies.

9.4.1 Protohistory

Italian landscape is changing since the Protohistory when man ceased to be nomadic and became able to create small niches within which he managed to cultivate the land through the use of fire and primitive cutting tools. The first signs of agricultural impact in the late Mesolithic, namely about 8,500 YBP, were detected by the occurrence of cereal pollen which showed that the principal cultivated cereals in Italy were hulled six-rowed barley (*Hordeum vulgare* L.), emmer (*Triticum dicoccum* Schübler), spelt (*Triticum spelta* L.) and broomcorn millet (*Panicum miliaceum* L.). During the Iron Age (about 3,100–2,500 YBP), in addition to these species, also naked wheat (*Triticum aestivum* L.) and foxtail millet (*Setaria italica* L.) were cultivated (Schmidl et al. 2007). The diet was supplemented by protein-rich seeds of broad bean (*Vicia faba* L.), pea (*Pisum sativum* L.), lentil (*Lens culinaris* Medik.) and picked berries such as mulberries, strawberries, and the fruits of sloe (*Prunus spinosa* L.) and European cornel (*Cornus mas* L.).

Many pollen studies were also conducted in village remains that represent the sign of a cultural settlement named *Terramara* or *Terramare*, which diffused from 3,700 to 3,150 YBP mainly in the Po plain and other parts of Italy (Bertolani Marchetti et al. 1988; Mallory 1997; Nisbet and Rottoli 1997; Rottoli 1997; Menotti 2004; Cremaschi et al. 2006; Mercuri et al. 2006). These villages were made of houses built upon piles and were surrounded by trenches and earthworks (*vallum*) or by an earth wall, whose traces in some cases survived till nowadays. The most studied *Terramara* villages are those found in Emilia-Romagna, Lombardy, Trentino (Perini 1984), on the shores of Lago di Mezzano, near Rome (Follieri et al. 1977; Sadori et al. 2004) and in the area of Longola–Poggiomarino, near Naples (Cicirelli et al. 2006). The economy of this society was based on agriculture (mainly cereals) and pastoralism, while hunting and fishing were occasional. The species cultivated were six-rowed barley, emmer, spelt, rye (*Secale cereale* L.), chickling vetch (*Lathyrus cicera* L.), broad bean and common flax (*Linum usitatissimum* L.). In addition, they also consumed hazelnuts (*Corylus avellana* L.), acorns (*Quercus* sp.) and many berries. Pastures were created for sheep and goats, but they also raised bovines and pigs, while horses were considered of less importance. The *Terramara* people were somehow aware that soil was subjected to reduce its fertility probably thanks to the empiric observation that production declined with time. Because of this, to improve soil fertility, they were use to incorporate ash and wood into the soil by means of a plough made with deer's antlers. Nonetheless, cultivation, picking and rearing of all these species and a quick demographic increment induced an intense impact on the environment in terms of deforestation and declining of soil fertility. The cause of the abandonment of the *Terramara* villages is not entirely known but, together with the decline of the amber market thanks to which they have flourished, the intense exploitation of soil and forests, and the incoming aridic climate period have probably played a role in their collapse (Bernabò Brea et al. 1997; Cremaschi et al. 2006; Mercuri et al. 2006).

9.4.2 Classic Age

The first important transformation of Italian soils, from natural to cultivated, dates back to the Greek civilization, which was followed by those Etruscan and Roman. The people of these three big civilizations were profoundly tied to soil, which represented a precious resource for their agricultural economies.

During the II millennium B.C., Greek people were already aware about the importance of soil (Krupenikov 1992; Brevik and Hartemink 2010). Around 3,000 YBP, some places of southern Italy became Greek colonies, and the main modification of the colonizers imposed to the Italian landscape was the diffusion of the viticulture, so that the Greeks called the southern Italy *Οινωτρια* (Oinotria), namely the land of the vines supported by stakes. Thus, during the eighth and seventh centuries B.C., Greeks colonized much of the southern Italian Peninsula (Cerchiai et al. 2004), which they called *Μεγάλη Ελλάζ* (Megálē Hellás), namely the Great Greece. Greeks were successful in choosing crops suitable for the soils of their colonies, and from eighth to third century B.C., the Greeks philosophers/scientists (Hesiod, Xenophon, Plato, Aristotele) recognized differences among soils, described soil profiles, improved the knowledge on the crops most suitable for a given soil and devoted literature to agronomy, soil classification, soil management practices and ability of soils to store water (Hillel 1991; Krupenikov 1992; Brevik and Hartemink 2010). Further, they also realized that the soil supplies nutrition to plants (Sparks 2006). The lands of the Italian-Greek colonies were much exploited mainly for the cultivation of trees like vine (*Vitis vinifera* L.), olive tree (*Olea europaea* L.), oleaster (*Olea europaea* L. var. *sylvestris* Brot.) and fig tree (*Ficus carica* L.), but they also sparsely cultivated walnut (*Juglan regia* L.), pistachio (*Pistacia vera* L.), apple (*Malus* sp.) and pomegranate (*Punica granatum* L.). Greeks also introduced in the Italian colonies chestnut (*Castanea sativa* Miller), which was firstly cultivated along the slopes of the Etna volcano and in other areas with sub-acid or pyroclastic-derived soils (Conedera et al. 2004). Usually within the tree rows, but also in open field, they cultivated barley (*Hordeum vulgare* L.), wheat (*Triticum aestivum* L., *Triticum turgidum* L.), broad bean (*Vicia faba* L.), chickling vetch (*Lathyrus cicera* L.) and pea (*Pisum sativum* L.). In addition to these widely cultivated species, Greeks also used vegetable gardens such as cabbage (*Brassica* sp.), onion (*Allium cepa* L.), garlic (*Allium sativum* L.), lentil (*Lens culinaris* Medik.) and chick pea (*Cicer arietinum* L.). In many places, they also cultivated herb gardens like sage (*Salvia officinalis* L.), mint (*Mentha* sp.), thyme (*Thymus* sp.), savory (*Satureja* sp.) and oregano (*Origanum vulgare* L.). The cultivation of all these species had a strong impact on the soil. In summer season, many of these cultivations needed irrigation which were made by means of bucketful of water filled into wells and rivers, but also by irrigation ditches and conduits. The Greeks also devised the *Triptolemos ard* (Fig. 9.1) one of the first examples of wooden plough used to work the soil (Glob 1951) and perceived that soil needed a sort of rest. Because of this, they introduced the practice of fallow, which allowed the soil to be unexploited one year over two. They tried to establish a triennial fallow introducing legumes into the rotation, but this practice did not become popular possibly because of the poor soil quality. In fact, the Greeks did not use manure but introduced the practice of green manure thanks to the plough they had invented.

They also created pastures mainly for sheep, which were reared for milk and cheese, but a number of animals were reared as follows: pigs, goats, bovines, horses, dunks and mules (Carter 1987). Forests of highlands were denudated by goats and for the production of charcoal. In spite of the

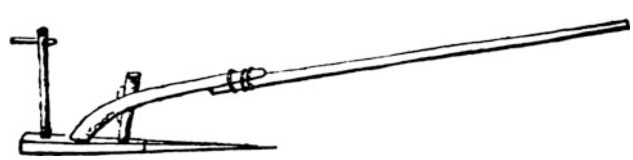


Fig. 9.1 Scheme of *Triptolemus ard*, the wooden plough devised by the Greeks. Modified from Loudon (1825)

strong soil exploitation, the Greeks did not conceive specific techniques to combat the erosion, which caused soil quality decline (Brevik and Hartemink 2010). Hence, as well as they had caused soil denudation and formation of badlands in Greece (van Andel et al. 1990), it is assumed they made the same in the southern Italy, where the intense soil exploitation and the soil-forming factors (semi-coherent sedimentary pedologic substrates, warm and aridic climate, hilly morphology) should have favoured soil erosion. This may explain why in southern Italian regions such as Calabria, Basilicata and Apulia (most of the ancient Great Greece) there is the diffuse perception that the vast badlands area "has always existed".

However, for some aspects, Greeks also paid particular attention to soil quality as they began to drain large areas of marshland and floodplain so as to increase agricultural productivity (Smith 1976). The reclamation of floodplain has been continued by Etruscans and Romans in southern as well as in other parts of Italy so as to arrive to nowadays, as in the case of the agronomic drainage systems that are still under process in the area of central Italy known as Maremma.

To obtain cultivable soil in very steep slope areas, Greek farmers made little terraces that were surrounded by drywalls to protect the crops from animals and thieves. The terraces were planted with olive trees and vines that, because of the hydric competition of the grasses and the good drainage of the artificial soil, had to be irrigated by means of ditches and conduits. With this landscape modification, Greeks unwittingly reduced incidence of erosions in the terraced areas.

Greeks landscape organization included subdivision of cultivated soil into geometric fields, which were ploughed with the *ard* according to regular stripes. Because of this, properties had irregular borders but with geometrically subdivided fields cultivated with crops under rotation, orchards and isolated tree fruits, drywall terraces, pastures, small woods and a net of ditches and conduits with sparse wells. This man-made landscape tessera is actually denominated *Mediterranean garden* (Sereni 1986) and was rather diffuse in southern Italy.

In southern Italy, the Greek influence lasted over centuries until the end of the later Byzantine Empire (middle of fifteenth century). In the meanwhile, the Etruscans inhabited the central and northern Italy (their land was labelled as *Etruria*), and Romans extended their dominium in Italy and subsequently in many other countries.

Etruria extended in central-northern Italy (Fig. 9.2), and its rural landscape consisted of hills covered by dense woods typical of environments with abundant precipitation. In the southern part of their settlement (the actual Latium), all alongside the hills, there were lakes of volcanic origin surrounded by mountains. The Etruscans settled in this country around 3,000 YBP and gave an important input to the local agriculture of that time by cultivating barley, emmer (*Triticum dicoccum* Schübler), wheat (*Triticum aestivum* L. *Triticum turgidum* L.), einkorn wheat (*Triticum monococcum* L.), spelt (*Triticum spelta* L.), lentils, broomcorn millet (*Panicum miliaceum* L.), broad beans, faba beans (*Vicia faba* L. var. *minor*), chickling vetch (*Lathyrus sativus* L. and *Lathyrus cicera* L.) and chickpea. The cultivated vegetable gardens were garlic, onion, chard (*Beta* sp.), turnip (*Brassica* sp.) and wild leek (*Allium ampeloprasum* L.). Some fruit trees were also cultivated as follows: vine, olive tree and fig tree. The Etruscan also consumed hazelnuts (*Corylus avellana* L.) and elder (*Sambucus* sp.) fruits (Keller 1999; Camporeale 2004; Bagnasco Gianni 2005). The emmer was particularly suitable for the hilly environment dominated by silt loam to loamy silt soils, moderately fertile but often with sufficient to abundant precipitations able to give good harvests. Etruscans were aware of the damages due to soil erosion and, before seeding, prepared soil with hydraulic techniques able to regulate the outflow of run-off. The *Etruria* land also abounded of pastures, but the Etruscans further enlarged them by clearing of the woods so as to increase the livestock rearing. The most common species reared for food were cows, pigs, sheep and goats, but they also raised horses and beefs to be used for food, work and battle animals (Keller 1999; Camporeale 2004).

Fig. 9.2 Greek and Etruscan territories during eighth century B.C. (our reconstruction from many sources)

Contacts with the Greek culture brought the cultivation of vine in Etruria during the seventh century B.C. This cultivation became so popular and widespread that in turns of a century, Etruscan wines were exported throughout the Mediterranean sea (Haynes 2005). Starting from the fifth century B.C., Etruscans also started the cultivation of olive tree and, after a century, the olive oil begun to be exported (Haynes 2005). The pictures on the Etruscan vases, discovered in numerous tombs in Tuscany, revealed how this culture used and regarded both the olive tree and its oil. Etruscans also introduced the crop rotation with the aim to produce food while preserving soil. At that time, the Etruscan territory was famous for its fertility, which was due to the geological characteristics and the man's interventions such as manuring, ploughing and irrigation or reclamation of marsh areas (Pallottino 1975; Barker and Rasmussen 2000). In fact, the Etruscans were capable of valuable works of civil engineering such as excavation of aqueducts in the rock, change in the river course, drainage of marsh areas surrounding the riverbanks of the major rivers (Chiani, Ombrone and Po), forming a dense network of canals and conduits for irrigation and shipping. Ship channels were diffused mainly in the Po plain and Maremma (Rodenwaldt and Lehmann 1962; Carandini et al. 2002). This means that, like Greeks, Etruscans heavily exploited the soil, but the territory of these latter received more precipitations than that of the former, and this was probably the reason why soil degradation was less in Etruria than in the Great Greece. Yet, in Etruria too, there were semi-coherent and sedimentary plio-pleistocene parent materials that made soils prone to catastrophic erosion. The presence of badlands in central Italy would be residual erosion forms developed in aridic conditions by degradation of soils with silt, silt clay or silt loam texture (Rodolfi and Frascati 1979; Mazzanti and Rodolfi 1989), when submitted to deforestation (Dramis et al. 1982; Ricci and De Sanctis 2004). Because of this, the badlands in the territory of the ancient Etruria probably formed during one of the two warm periods occurred in the last 3,000 years (Alley 2000; Sicre et al. 2008): the Roman Warm Period (250 B.C.–250 A.D.) or the Medieval Warm Optimum (950–1250 A.D.). The first one was in the same period the Etruscans prospered in their territory and, consequently, with their intense soil and forest exploitation they could have been responsible for the beginning of a catastrophic soil degradation that brought to the formation of badlands. The second warm period occurred in correspondence with a strong demographic increment (especially in the cities of Tuscany and Emilia-Romagna, which were part of the ancient Etruria) that entailed deforestation of hills and mountains to get wood as building material or for commerce (il Glabro 1991; Fisher and Pedrotti 1997; Cardini and Montesano 2006). Because of this, it is possible that much of the badlands territory of the central Italy formed during this period rather than during the Etruscan civilization.

Roman society overlapped and succeeded that of the Etruscans and improved the rural land organization. According to Krupenikov (1992), the agricultural and soil knowledge of the Romans was initially developed under the influence of the Greeks because of the contact with colonies of the Great Greece. However, it was also thanks to Roman scientists/writers such as Marcus Porcius Cato, alias Cato the Elder (234–149 B.C.), that the Roman territories were introduced of hedgerows, drywalls and ditches to separate countryside properties. Another roman scientist, Marcus Terentius Varro, known as Varro Reatinus (116–27 B.C.), defined farming as a science. He considered soil as one of the most important components of farming, developed a soil classification system and advocated methods for the improvement of soil fertility (Krupenikov 1992). Under the first Emperor Gaius Iulius Caesar Octavianus Augustus (known as Augustus), from 27 B.C. to 14 A.D., the Romans also began to terrace steep slopes to reduce soil erosion (Troeh et al. 2004) and obtain soil to cultivate. For the same reason, a strong deforestation interested all the remaining planitial forests for the double aim to get timber and soil to cultivate or transform in pasture. In fact, the planitial forests that occupied deep soils with a high content of organic matter and a good availability of water were made of oaks (*Quercus* sp.), elms (*Ulmus* sp.), limes (*Tilia* sp.), hornbeams (*Carpinus betulus* L. and *Ostrya carpinifolia* Scop.), maples (*Acer* sp.), ashes (*Fraxinus* sp.), poplars (*Populus* sp.), alders (*Alnus* sp.), with a great variety of understory. Where the soils were shallow and/or with a lesser waterholding capacity, vegetation was represented by the association known as *Macchia Mediterranea* (Celant 2002; Di Rita et al. 2010). The fact is that the Roman people had a so high level of consumptions and experienced a so strong demographic increment that any pocket-handkerchief plot of the Italian territories of the Roman Emperor had to be cultivated. As a support of this statement, one has to consider that the Rome of Augustus had about 1,000,000 inhabitants (Castiglioni 1878; Abbate 2004). Because of the high demographic increment and of their style life, Romans imported huge amounts of food and fibres from the colonies, but they also needed to cultivate intensively the Italian soils. Under Augustus, Rome was able to import each year as much as 350,000 t of wheat mainly from Egypt, Asiatic and African provinces, Sicily and Sardinia, but importation activities also included metals, animals, wine, olive oil, cheese, dried fruit, wood, pitch, wax and many other products from any Empire angle (Moss 1980). The scientist Gaius Plinius Secundus, known as Pliny the Elder (A.D. 23–79), argued about soil fertility decline under cropping (Pliny the Elder 1855). In the same period, Lucius Junius Moderatus Columella (A.D. 4–70), a Roman soldier and farmer, wrote a manuscript titled *De re rustica*, which was composed of twelve books devoted to furnish a simple practical classification of soil aimed to help farmers. According to the Columella's method, to understand the type of soil, one had to dig a hole into the soil and then to fill it up with the extracted material. On the basis of the behaviour of the filling soil material, the soil could be ranked into three classes as follows: the soils of the first class (fat soils) were those whose extracted material was overfilling the hole; the soils of the third class (poor soils) were those whose extracted material was not sufficient to fill the hole; the soils of the second class (moderate soils) were those in between. This is one of the first examples of soil classification based on soil properties (Nortcote 1986). However, at the end of the Roman Empire (fifth century), there was a soil classification that included considerations of mineral grain size, colour, density, structure and fertility of the soil, and had some recommended tests for determining soil properties and fertility (Tisdale et al. 1993; Winiwarter 2006).

At the beginning of the first century A.C., a wide variety of tillage tools were available, ranging from a simple digging stick to a paddle-shaped spade or hoe that could be pulled by men or animals. The Greek *Triptolemos ard*, which have been used even by Etruscans, was implemented into the *Roman plough* (Fig. 9.3) which was provided of an iron share and was described by Virgil in A.D. 1 (White 1970; Fowler 2002). This tillage implement was thought to "nourish the earth" and to "break the drought". This plough was then widely used in all Europe till the fifth century, and it was further implemented into a soil-inverting plough around the eighth to tenth century (Lerche 1994).

Romans were used to organize the territory of the new Italian settlements by subdividing the countryside into square blocks of an area of about 50 ha each, sufficient to transform a soldier and his family in agricultural businessmen. This type of countryside organization was called centuriation (*centuriatio*) from the name of the Roman legions (*centuria*) as the blocks were usually assigned to retired soldiers. The boundary of the blocks was occupied by roads, hedges, canals or aqueducts, while the agricultural surface was occupied by a great variety of crops. This land organization in many places substituted the Mediterranean gardens and survived for long time even after the agricultural organization has changed. In fact, even nowadays, it is possible to observe large portions of centuriated territory in the Bergamo, Padua, Modena, Bologna, Cesena, Lucca, Florence, Caserta, Naples and Potenza provinces (Fig. 9.4).

The soil working to prepare seedbed was made by the Roman plough drawn by a pair or more oxen, donkeys or mules, which were guided by a ploughman. It is expected that thickness of ploughed soil should be of about 15 cm. This practice allowed Roman farmers cultivating cereals like wheat (*Triticum aestivum* L. *Triticum turgidum* L.), spelt, barley, broomcorn millet and oat (*Avena* sp.), but also legumes such as broad beans, pea (*Pisum sativum* L.), lupins (*Lupinus* sp.), lentils, chickling vetch (*Lathyrus sativus* L. and *Lathyrus cicera* L.), wild artichoke (*Cynara cardunculus* var. sylvestris Lam.) and many other vegetable-garden species. They also cultivated forage plants such as clover (*Trifolium* sp.), alfalfa (*Medicago sativa* L.), common broom (*Cytisus scoparius* (L.) Link.) and fenugreek (*Trigonella foenum-graecum* L.). Large surfaces were also devoted to the cultivation of fibre crops like common flax (*Linum usitatissimum* L.) and hemp (*Cannabis* sp.) (Mercuri et al. 2002). Romans also cultivated a great variety of fruit trees, mainly represented by vine, olive tree and, only after the first century A.C., chestnut (*Castanea sativa* Miller); this latter species was diffused mainly in the north (the former Insubria region, between Italy and Swiss) and in the south, the Calabria region (Conedera et al. 2004), everywhere there was neutral to sub-acid soils with large availability of water during the vegetative season. Romans farmers already knew apricot tree (*Prunus armeniaca* L.) and citrus trees such as citron tree (*Citrus medica* L.), lemon tree [*Citrus limon* (L.) Burm.] and sweet orange tree [*Citrus*

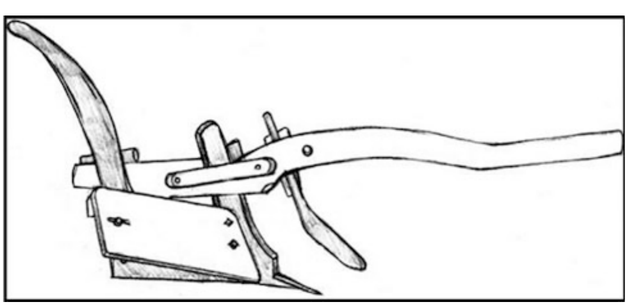


Fig. 9.3 Scheme of the Roman iron share plough. From Lal et al. (2007)

Fig. 9.4 Image of an actual landscape maintaining the signs of the centuriation. Nearby the city of Cesena. Courtesy of Emilia-Romagna region

sinensis (L.) Osbeck], but the cultivation of these trees will become popular in Sicily only during the Arab invasion.

Ligneous crop were also cultivated, generally at the margin of the fields, to produce baskets and ties and poles for olives and vines. These trees were mostly represented by willows (presumably *Salix viminalis* L. and *Salix rubra* L.), poplars (*Populus* sp.) and elms (*Ulmus* sp.). However, ligneous crop were also cultivated for other reason. In fact, Roman farmers cultivated the vine supported by poplars, elms, and maple (*Acer* sp.), so favouring accumulation of organic matter in the vineyard soil. The vine inter-row were often cultivated with cereals (Sereni 1986) to exploit the acquired soil fertility, but also to reduce the vine luxuriant by means of the hydric competition induced by the cereals themselves.

Romans reared many animals such as pigs, sheep, goats and birds for food, bovines, donkeys, mules and horses for work and battle animals. In addition to these animals, farmers also practised bee-keeping and someone raised snails (Loudon 1825; White 1970; De Martino 1979; Buck 1983).

Romans were well aware the soil may decline in fertility, especially if it was intensively exploited. For this reason, they practised crop rotation and introduced leguminous species in the rotation. Further, according to Winiwarter (2006) and Krupenikov (1992), Romans soil specialists were well aware of the use of manure, the fertilizing effects of leguminous plants and the fertility increase that arises from fallow. In particular, the use of green manure was a step further with respect to the Greek idea of soil fertility. Fallowing was a universal practice among the Romans, and animal manuring was held in high esteem. For this reason, animal dung was ranked into three classes as follows: good (that from poultry and donkeys), moderately good (from sheep, goats, horses and man) and bad (from cows) (White 1970). Pigeon dung was preferred over the others, but the mixture of human ordure and urine also got great consideration. In addition, human dung mixed with sawdust and urine was applied to the roots of vines and olives to help them to establish in the soil. Thus, trees, twigs and stubble were burned to feed the soil of the nutritive element coming from the ash, while lime was added to the soil to be implanted with vines and olives. Studies on palaeo-Andisols close to ruins such as those at Pompeii have demonstrated that volcanic soils were preferably devoted to vineyards (Jashemski 1973) or fruit trees, and that these soils were rather fertile thanks to the addition of manure (Foss et al. 2002; Inoue et al. 2009).

9.4.3 Middle Ages

After the fall of the Western Empire and the barbarian invasions of the Italian territories, it came down the long period of Middle Ages, also called "dark ages" by many historians as much of the previously acquired knowledge was lost. In Western societies, like the Italian one, this period was characterized by a strong dominance of religion and the absence of a thriving science community. The repression for science included soil knowledge that had been gained during the classic age (Brevik and Hartemink 2010).

A counter-tendency was experienced in many parts of the former Roman Empire thanks to the Arabs conquest. In the conquered territories, in fact, the Arab culture brought new (or forgotten) knowledge in the field of art, medicine, technology and science, including agriculture (Lo Jacono 2004). In Italy, Sicily was the only region massively occupied for about three centuries (from the beginning of nineth to the end of twelfth century) by the Arabs. In that period, Sicily island became an Arab Emirate, while in other southern regions such as Calabria, Campania, Apulia and Sardinia, the Arabs committed incursions and never built a real settlement; because of this, the Arab culture never pervaded in these regions. Only exceptions were the small Emirate of Bari and that of Taranto (Apulia), whose extensions were those of the respective urban area and something nearby. In Sicily, the Arab culture introduced the cultivation of crops till then unknown in all the Italian territory: cotton (*Gossypium* sp.), artichoke [*Cynara cardunculus* subsp. *scolymus* (L.) Hegi], sugar cane (*Saccharum officinarum* L.), eggplant (*Solanum melongena* L.), spinach (*Spinacia oleracea* L.), rice (*Oryza sativa* L.) and mulberry (*Morus* sp.) for the rearing of silkworms (*Bombys mori* L.). The Arab dietary also included the use of numerous spices; many of these such as cinnamon (*Cinnamomum* sp.), nutmeg (*Mystica fragrans* Houtt.), clove (*Eugenia caryophyllata* Thunb.), cardamom (*Elettaria* sp. and *Amomum* sp.) and ginger (*Zingiber officinale* Roscoe) were imported from the near and far East, while saffron (*Crocus sativus* L.) begun to be cultivated in the well-drained soils of Sicily and then it expanded in all Italy. Trees such as citron tree, lemon tree, sweet orange tree and apricot were already known in Sicily, but their cultivation was almost absent. Arabs introduced new varieties of these trees and improved their cultivation, which expanded mainly on volcanic or in well-drained soils equipped with irrigation. Also plantation of mulberry diffused in all islands as the use of silk clothes (and consequently silk production) rapidly diffused in all Sicily and in other southern regions (Sereni 1986). Within one century from the arrival of the Arabs in Sicily, cultivation of mulberry diffused in the rest of Italy and, in the twelfth century, the country was the major European silk producer. This primacy lasted till the nineteenth century, and this is why mulberry is still nowadays widespread in all Italy, restricted to the margins of fields or to the irrigation ditches mainly in neutral sub-alkaline soils of plain and hilly environments, even though the Italian silk production stopped after the

World War II. Some historians have defined the agricultural modification occurred in Sicily at that time as the "Arab Agricultural Revolution of the Middle Ages", meaning that the implementation of cultivations was of high level (Watson 1974; Di Pasquale et al. 2004). In effect, the Arabs developed a scientific approach to agriculture based on advanced systems of crop rotation, irrigation techniques and the cataloguing of a large variety of crops according to season, type of land and amount of water they required (Watson 1974). Arabs also developed a system of cultivation that combined orchards and vegetable garden known with the Spanish word *huerta*. Each *huerta* was organized with trees [citrus, apricot, laurel (*Laurus nobilis* L.), myrtle (*Myrtus communis* L.), etc.] that shadowed vegetable cultivations and was all manured and irrigated so as to have more harvests during the year. In wide extensions of good soils, many *huertas* were made one close to the other, so as to take advantage from irrigation and fertilization. This sort of landscape organization is known as "the Islamic garden" (Fairchild Ruggles 2008) and was diffused in all the Sicilian plains where there was a certain availability of water to irrigate. The famous *Conca d'Oro* (golden basin) in which the city of Palermo grew is a fertile valley once organized as *huertas* (Bresc 1972; Lombard 2004). To have an idea of how attractive and useful was the *Conca d'Oro*, Palermo was called *Gennai al-rad*, namely the *Paradise on Earth*. The hilly environments made of heavy soil with relatively high water retention were cultivated with durum wheat. As this wheat contains less gluten than the soft one, it was not milled to have flour for bread but to have a coarse flour known as semolina (from the Arab *semoules*) used to make couscous.

The rest of Italy, submitted to a long period of anarchy and barbarism, faced population decline and landscape change. Roman centuriated territory almost disappeared and in many places pasturage was preferred to tillage. Agricultural and human activities focused around castles and fortified villages where the peasant population residing in the countryside could find protection in case of enemy attack. Agriculture survived in little "kitchen gardens" within the city walls and in religious buildings possessions that were considered as respected territories; here, the lands were cultivated by servants under directions of the priests. Since the food products derived from in-wall agricultural activities, some practices were developed to increase crop productivity, which, however, did not avoid famine crisis. Among all, the old Roman plough was improved and a new heavy plough equipped with a mouldboard that allowed reversing a thicker slice of earth was devised. Also there was the introduction of a three-year crop rotation, the small agricultural areas on which agriculture persisted were divided into three plots and in each plot winter cereals, annual legumes and fallowing succeeded. The soil fertility was enhanced thanks to animal manuring and human ordure (Anderlini 1981). Far from the cities, a general lack of care for agriculture raged and, consequently, during early Middle Ages, soils experienced a fertility decline that obliged the farmers to cultivate poor cereals like oats (*Avena* sp.), millet (*Panicum miliaceum* L.), sorghum (*Sorghum* sp.) and barley (*Hordeum vulgare* L.), while olive tree and vine were cultivated close to the cities. Along the Apennines chain, also chestnut (*Castanea sativa* Miller) was rather diffused. Orchards were mainly concentrated around the great lakes of the north as well as of central Italy, while lemon and sweet orange trees were diffused in the south (Kleinhenz and Barker 2004).

As a further demonstration of the lack of care for agriculture, in the first centuries of Middle Ages forests and swamps expanded re-occupying former cultivated soils that, in turns, had been obtained from deforestation and drainage. Further, Italy, as all the north Atlantic and North America regions, experienced a warm climate known as Medieval Warm Optimum, which lasted from 950 to 1250 (Grove and Switsur 1994; Mann et al. 2009). In these 300 years, forests re-occupied areas of higher altitudes but, in general, the soils faced a fertility decline because of the strong demographic increment that occurred around the eleventh century.

During thirteen to fourteenth century, viticulture and oliviculture almost disappeared, surviving only in monasteries, convents, churches and within the wall of the city-states such as Florence and Siena. Since twelfth century, Po plain marshes were reclaimed by Chiaravalle Monks that transformed waterlogged soils into productive soils. In this period, in fact, they began water-meadow cultivation that endured until recent times. Thanks to the monks, cultivation of rice began in the hydromorphic soils since fourteenth century, and rice became one of the most characteristic cereals of the Po plain for centuries. Chiaravalle monks were considered expert hydraulic engineers and practised irrigation from the eleventh century.

The soil drainage and reclamation of the southern Po plain began in the tenth century and continued until the second half of the twentieth century. In the early part of the fourteenth century, the inhabitants of southern Italy were ignorant of the vine cultivation while Florentines traded wine with England and France. Because of the lack of manuscripts about agriculture of this period, the most important instrument to understand land organization is pictures which often represented agriculture and pastoral activities. Forests and hunting scenes were generally depicted in a wild landscape with extended marshlands and without particular soil organization (Sereni 1997).

9.4.4 The Age of Communes

Social and policy evolution has often conditioned soil management and organization. After the Middle Ages, the age of municipalities began and agriculture flourished again out of the city walls. Large extensions of marsh soils were reclaimed and ploughed, while agronomists like Pietro De' Crescenzi with his book *Trattato della Agricoltura* (Estate Cultivation) suggested instructions to save deforested slopes from erosion using trees and bushes especially in the central Italy. In the Po plain, meadows and fields of cereals were delimited by ditches and tree rows. Depicted country landscapes of this period show a new organization of enclosed plots of land all around the cities which generally rested at the top of the hills. On the slopes, pastures and woods extended where stock-breeding and hunting were practised.

The discovery of the Americas was a major "revolution" that brought a variety of benefits for the Western man. The occupation of the Americas provided the Western societies of new varieties or new species to be imported in Europe, such as maize, potato, tomato and beans. All these crops were rapidly introduced into the rotations.

9.4.5 Renaissance and Modern Age

In the sixteenth century, a period of scientific thinking and approach to natural resources began. The scientific study encompassed many disciplines including agriculture. The farmer improved drainage systems to eliminate excess water, land fertilization and the terracing of steep terrain. During this period, the greatest agricultural improvements in Italy took place in Tuscany, Lombardy and Veneto. The first excelled in vine and olive culture, while in the others two rice, maize (*Zea mays* L.), vineyards and cattle breeding abounded. Pastures were widespread in plains with suitable climate conditions, good soils and abundant water for irrigation. The agricultural landscape of this period was represented as very attractive by many painters, and intellectuals like Leonardo da Vinci gave an important contribution to engineering progress with drainage and irrigation projects in Arno and Adda rivers and in the Po plain. In the same period, however, the south of Italy was less involved in the agricultural progresses, and the landscape was characterized by Mediterranean gardens and "starze", a sort of enclosed orange and olive trees plantations.

During the Renaissance, farmers started to cultivate forage crops so as to feed the livestock during the winter months. The property of alfalfa (*Medicago sativa* L.) and clover (*Trifolium* sp.) to restore soil fertility enabled farmers to reduce or eliminate the practice of fallow to replenish the soil. Alfalfa, which had been cultivated as a forage crop in ancient times and fell out of use in Italy during the Middle Ages, reappeared in Italy around the year 1540, after the rediscovery of Columella's writings. Alfalfa was mostly cultivated in northern Italy, sometimes along with rice. During this age, farmers put fences around their fields to separate them from pasture or open areas.

The northern cool districts were devoted to pastures, the hills of central Italy hosted olive trees and vines, and the plains were cultivated with maize (*Zea mays* L.). The Po plain soils in Lombardy and part of Piedmont were enclosed with hedges of different plants (willow, mulberry) and ditches, or with open water courses for irrigation. Forage crops were cultivated for cattle, and the trees were common in the hedgerows. Cultivation of pear (*Pyrus* sp.) and apple (*Malus* sp.) trees was common, while olive trees were planted on declivities with southern exposure. In central Italy, Tuscan climate was esteemed as the best of Italy with the exception of that of Maremma, the malaria-affected region on the seacoast. Irrigation was practised in Lombardy in every plain, where the fields were generally surrounded by ditch planted with poplars and vines or by rows lengthways made of mulberry, maple or manna ash (*Fraxinus ornus* L.), also interspersed with vines. In the arable lands of the plains, three- or five-year crop rotations were adopted.

9.4.6 Risorgimento

In the first decades of 1800, agriculture dominated the Italian economy and the type of farming varied from north to south (Chapman 2008). In the north of Italy, Lombardy and Veneto regions, farmers cultivated rice, maize and flax in the fertile soils of the Po plain and produced wines and silk; in central Italy, farmers cultivated the hilly land with vines, olive trees and cereals, while in the southern regions *latifundia* abounded of cash crops such as tobacco and wheat in the plains and olive trees on the hills of the warmer areas. Different situations required different soil management. In fact, the soils of the northern Italy needed drainage and hydraulic land settings because of the abundance of water, the hilly soils of central Italy needed land set-up systems to prevent erosion, whereas the southern soils, affected by aridity, needed a careful water conservation management.

In 1853, one of the most efficient and, for the time, large irrigation systems was built in the rural area of Vercelli (northern Italy). The complex infrastructure was upgraded in 1866 with the construction of the *Gran Canale Cavour* (Fig. 9.5), a canal that allowed the distribution of water of the Po, Dora Baltea, Sesia, Ticino rivers and Maggiore lake

Fig. 9.5 Works for the building of the *Gran Canale Cavour*. Around to 1864. From Romeo (1969)

in an area of approximately 400,000 hectares (Romeo 1969).

In other parts of northern Italy (Piedmont region), the abundance of water in territories with soils hosting fragipan horizon rather close to the surface (Ajmone Marsan et al. 1994) was taken as an opportunity for rice cultivation. This combination of factors (abundance of water and presence of fragipan) favoured the cultivation of rice in many others sites of the Po plain as well as in other parts of Italy as in Tuscany, along the plains of Merse river where in ancient alluvial plain fragipan developed (Scalenghe et al. 2004).

During the second half of 1700 and in the first decades of 1800, central Italy was interested by a strong demographic increment, with a consequent increase in cereals demand. The need of new space to devote to food production brought to the clearing of forests and the transformation of natural areas into intensively cultivated lands; this transformation of the landscape caused the trigger and/or an increase in erosion processes. Because of this, in Tuscany, large areas of internal valleys were rapidly transformed from woodlands in badlands. Many agronomists of that time tried to solve the problem and the first important ideas to reduce incoming erosion were proposed by Giovan Battista Landeschi, who pointed out the importance of a canal net all around the badlands to avoid their enlargement (Landeschi 1995). The fight against erosion was carried on also by the prestigious institution named "Accademia dei Georgofili" (funded in Florence in 1753), which spread the new acquisitions so as to preserve soil. In 1819, the agronomist Francesco Chiarenti published the results of his studies dealing with soil conservation in areas vulnerable to catastrophic erosion where he proposed the abolition of the tillage along the maximum slope gradient for a more preserving "edge system". Around 1830, Cosimo Ridolfi published in the agricultural journal titled *Giornale Agrario Toscano*[1] many articles dealing with a new important land set-up called *colmate di monte* (filling in mountain) which was considered even more able to preserve soil. This system differed from the *colmata* (an agricultural hydraulic system, see below in this chapter) as the *colmata di monte* consisted in reducing the relief of hilly terrain and expanding level land by inducing cycles of erosion and sedimentation (Lami 1938). In the same period, Agostino Testaferrata devised another land setting useful for areas with high risk of potential erosion, the so called *unita a spina* (see below, in this chapter), which has characterized Tuscan landscape till nowadays (Landi 1984, 1989).

9.4.7 From the Unification of Italy (1861) to Nowadays

At the time of unification, as reported by Zamagni (1993), Italian regions showed different control on watercourses and organization on soil reclamation: the Po plain showed a good land organization that favoured agriculture especially in Piedmont and Lombardy and part of Veneto regions; the Maremma area, in Tuscany, which consisted of 245,000 hectares of marshlands, swamps and wild vegetation, was infested by malaria; the rural area around Rome and the Agro Pontino (208,000 and 20,000 hectares, respectively), in the Latium region, were often submerged by water; in the south of Italy, plains were *quasi* deserted and uncultivated, course of rivers was wild and people ploughed deforested soils on the hills and mountains favouring erosion.

In the 1882, more than 400,000 hectares of land started to be reclaimed using drainage pumps in Ferrara, Modena, Rovigo and Ravenna provinces; the reclamation of these lands ends up with the World War I. In other areas of Italy, economic problems discouraged these kinds of projects.

Between 1900 and 1914, plains and mountains of Basilicata, Calabria and Sardinia were interested by a great programme of land reclamation and drainage (Serpieri 1948). During this period, viticulture recovered surfaces and continued to increase thanks to a certain economic and politic stability. Afterwards, two plagues threatened the vine survival in Italy as in Europe: meldew (around 1850) and phylloxera (1880–1890). Because of this, in the successive decade's vineyard surface decreased considerably but, with the diffusion of the American rootstocks, during the 1930s the viticulture regained surfaces reaching a maximum of expansion in the 1950s (about 3,700 km^2). Although it is difficult to estimate the amount of surface devoted to vineyards during the Roman Empire or the Renaissance, it is assumed that the expansion reached in the

[1] The papers were published in the journal from 1828 to 1830 and have been republished by the Giovan Battista Landeschi Association in 2006 (Ridolfi 2006).

1950s was the maximum reached in the Italian viticulture history (Corti et al. 2011a). Thus, a surface reduction started and it persists till nowadays when a surface of about 8,000 km^2 has been reached.

At the beginning of 1900, different physiographic situations and land organization along the peninsula still caused different levels of technological advances in north, centre and south Italy. In the north, there were born "farmers associations" and peripatetic agricultural instructors who provided farmers with selected seeds, fertilizers, pesticides and machinery, while in the south, these figures were introduced later. In the same period, the adoption of chemical fertilizers was accompanied by an increase in the production especially in the Po plain (Zamagni 1993).

In the first decades of the twentieth century, the main soil management revolution was the reclamation (*bonifica integrale*) of waterlogged soils and marshes, which took place in several Italian areas such as Bassa Friuliana in Friuli Venezia Giulia, Agro Pontino in Latium, coastal plains of Ferrara in Emilia-Romagna, Catania plain in Sicily, Arborea in Sardinia and others. In these areas, this reclamation allowed malaria diffusion to be almost solved and agriculture developed (ITPA 1970). Contemporarily, a great technological effort was made to expand the irrigated areas by the construction of water pumps, ditches, canals, etc. These new infrastructures had a big impact in the agricultural soil use and management by increasing the cultivation of maize and rice mainly in northern Italy, flowers in Liguria, fruit and horticultural crops in the Po plain and in the south. In order to increase the national wheat yields and to become autonomous for wheat flour production, the Italian government launched in 1925 the so called "Battle for Grains" (*battaglia del grano*), which consisted of an increased use of chemical fertilizers (Fig. 9.6) and the substitution of fruit and vegetables production with wheat in many areas. As a result of this campaign, Italy did increase grain production, but the fruit and vegetable production declined (ITPA 1970).

In Italy, farm mechanization started in the 1930s, and it encouraged agricultural intensification and progressive crop specialization that favoured nutrients, pesticides and heavy metals soil loading. Hedgerows and sparse vine rows almost disappeared. The intensification of agricultural practices also influenced soil physical characteristics such as structure and drainage, and modified the organization of the soil horizons so as to lower variability and diversity of soil microflora and microfauna (Gray 1987; Haynes et al. 1995).

The availability of electric pumps allowed the drainage of vast areas, especially along the shores of the lagoons. Rice cultivation was widespread and different stages of cultivation (land preparation, planting and flooding, weeding and rice harvest) required a lot of manpower. Above all, the manual removal of weeds and harvest, until the 1950s

Fig. 9.6 Advertising poster produced in the first years of 1900 for Magni & C., an Italian (Vicenza) agricultural supply company. The motto says "by fertilizing we cultivate the plenty". *Location* Science Museum, London

brought into paddy fields 260–280 thousand people in late spring and autumn. The practice of transplantation in order to exploit the soil with other crops, then abandoned, required a great number of highly skilled workers.

During this period, Italian soil management profoundly changed by neglecting most of the previously developed soil management, so improving incidence of landslides and run-off. In addition, soil management in the last decades has been led by the numerous European directives, as reported in the following paragraph.

9.5 Effect of European Directives on the Soil and Land Management

Soil management has been frequently driven by technological innovations (Schneeberger et al. 2007) and social and cultural changes (Antrop 2005; Mattison and Norris 2005), but also by policies such as laws and regulations (IEEP 2007; Osterburg et al. 2010) and economic instruments like subsidies and taxes (Aviron et al. 2009; Stoate et al. 2009). The European Union (EU) policy instruments have always played a crucial role in shaping agricultural systems and, among them, the Common Agricultural Policy (CAP) contributed particularly to the increase in cropping systems productivity through agricultural intensification and farm specialization (Tappeiner et al. 2003; Stoate et al. 2009; Acs et al. 2010). In fact, when it was introduced in 1962, the CAP's original goal was to expand production in order to reduce dependence on imported food as well as to cut down the EU import requirements in energy, raw materials, etc. The growing intensification of production caused several problems such as persistent products surpluses associated mainly to decline of demand and population falling and ageing, asymmetries between the kind of products available or their quality and what consumers wanted, and a range of environmental threats. For example, greater specialization towards arable farming systems had frequently meant the end of traditional cropping systems and the use of green manure that helped restoring the content of soil organic matter. In some Italian areas, these factors have induced farmers to develop cropping systems and forest management practices not fully harmonized with the local environmental conditions, so causing land degradation (INEA 1999a).

The CAP reform in 1992 (the so called MacSharry reform) was designed to reduce production (e.g. setting aside farmland), to encourage greater attention to the environment and to the use of land and to decrease prices. The subsidies favoured the cultivation of some crops (wheat, oil seeds, etc.) even under unsuitable ecological conditions. Example of this is the cultivation of sunflower under rainfed semi-arid Mediterranean conditions, which became a rather common practice in all the southern regions of Italy. In fact, farmers received subsidies just because they followed sustainable agricultural practices, no matter they produced or not! At the same time, the CAP was not always fully in accordance with other European directives, leading to contrasting impacts on land use compared to the intended goals. For instance, Roggero and Toderi (2002) observed a greater adoption of the agro-environmental measures under the Regulation 2,078/92 in the farms characterized by a predominant incidence of already low-input cropping systems (i.e. alfalfa meadows, vineyards) than in the farms receiving the CAP-coupled subsidies to grow mainly wheat and oilseeds. This lack of coordination between CAP and 2078/92/EC schemes limited the achievement of the agro-environmental objectives to induce the more intensive cropping systems to be converted into low-input or even organic farming systems.

It is important to highlight that among the major threats to the ecology of agro-ecosystems, both intensification in some regions and concurrent abandonment in others are key of the soil state and of the biological diversity in agricultural landscapes (Stoate et al. 2009). The last CAP reforms have put a greater emphasis on environmental concerns by introducing accompanying measures such as agro-environmental schemes and by making direct payments to farmers conditional on meeting the cross-compliance requirements (Aviron et al. 2009; Stoate et al. 2009). Despite the increased attention towards environment-friendly farming practices, soil protection was not so far a specific objective of EU legislation, but it is cited in some policies as a secondary objective. For instance, the Nitrate Directive (91/676/EEC) and the Water Framework Directive (2000/60/EC) could contribute to some extent to soil quality, although not always effectively (Louwagie et al. 2011). Other directives, such as the Sewage Sludge Directive (86/278/EEC), the Birds Directive (79/409/EEC) and the Habitats Directive (92/43/EEC) are expected to have beneficial effects on soil quality, but to a lesser extent owing to a more focussed set of objectives. The EU Commission is still discussing on the opportunity to develop a specific Soil Framework Directive [COM(2006)232] targeted to soil conservation and sustainable use of soil, proposed within the Thematic Strategy for Soil Protection [COM(2006)231].

Nevertheless, the EU policies have been evaluated only to a limited extent for the achievement of their, even secondary, soil quality goals. The assessments were restricted to specific policy measures (Alliance Environnement 2007; Hudec et al. 2007) or considered only one soil degradation process (Rodrigues et al. 2009). Moreover, target levels of soil quality were not often clearly defined, the uptake of many measures for soil protection was low also due to limited awareness-raising and technical advice efforts, and the coordination between existing measures focused on soil protection is missing at the EU level (Louwagie et al. 2011). However, some initiatives at national and local levels exist. Another problem is the lack of data from a monitoring network on soils and in relation to the adopted management system at territorial scale (see, for example, Rusco et al. 2009). For a comprehensive assessment of the role of EU policies to address soil degradation processes linked to agricultural systems, we suggest the chapter of Louwagie et al. (2011).

9.5.1 Set-Aside

Agricultural set-aside schemes were introduced by the CAP in the late 1980s to reduce the large and costly surpluses produced in Europe, and it should also favour the restoration of self-sustaining plant successions by taking soil out of production. In 1993, thanks to the MacSharry reform, set-aside became obligatory for any farmer receiving European Economic Community subsidies, whose main goal was to decrease rates of cereal production. The reform included a set-aside programme requiring farmers to take certain

Table 9.1 Evolution of the obligatory seat-aside quota

Campaigns	Obligatory set aside quota (%)	Calculated on the surface cultivated with
1993/1994 and 1994/1995	15	COP
1995/1996	12	COP
1996/1997	10	COP
1997/1998 and 1998/1999	5	COP
from 1999/2000 to 2003/2004	10	COP
2004/2005	5	Crop land
2005/2006 and 2006/2007	10	Crop land
2007/2008	Temporary suspension	
2009	Definitive abolition	

Source Orèade-Brèche (2002), Areté and DEIAgra (2008)

percentages of their arable land out of production. Roughly 5–15 % of arable land cultivated with COP (cereals, oilseed crops and protein-rich-plants) was expected to become rotational set-aside (Table 9.1).

From 1995, farmers increasingly dedicated set-aside to non-food plant production, in particular renewable resources (ENCA 2008). According to Henke (2004), only after 2003, set-aside assumed the role of regulating environment equilibrium. In fact, as reported by Lenucci (2005), after the year 2003, the objectives of set-aside changed from productive to protective purposes. After 2006, energy crops (such as oilseed rape) were increasingly sown. In 2008, the EU-wide set-aside obligation was suspended and a large proportion of set-aside land was re-cultivated with the exception of Switzerland (Albrecht et al. 2007; ENCA 2008; Oppermann et al. 2008; Aviron et al. 2009).

Van Buskirk and Willi (2004) assessed that five years under set-aside favoured agro-ecosystems conservation biodiversity and erosion control, while annual set-aside interruptions exerted a positive effect on soil fertility (Hodge et al. 2006; IEEP 2008; Hodge et al. 2003; Van Buskirk and Willi 2004). The policy had different environmental impacts due to the various climatic, environmental and economic conditions of Europe. Generally, set-aside promoted rehabilitation of soils previously submitted to intensive cultivation, so favouring detoxification and microbiological activation of arable soil horizons because of an increase in organic matter (Dalal and Mayer 1986). In fact, different methods of set-aside have been proposed to restore the fertility of a soil after a long period of agricultural use. In southern Europe, where soil erosion represents a primary environmental concern for agricultural land (Morgan 1987, 2005; Arrúe and López 1991; Lasanta et al. 2000; López-Bellido and López-Bellido 2001), re-establishing vegetal species represented one of the best ways to restore the soil to condition of biological functioning. This management strategy of "guided" set-aside had the advantage of addressing more rapidly the successions of microbial and vegetal communities to a natural stable ecosystem (Buckley 1987). Boellstorff and Benito (2005) applied modelling approaches to study the impact of set-aside on soil erosion in central Spain and showed that the rates of erosion risk increased because of the particular climatic conditions characterized by relatively high mean air temperature and low mean annual precipitation with a concentration of storm events in late summer and autumn. These results are very similar to those observed in southern Italy, where few of these studies have been carried out. However, in southern Italy, the contributions to support farm income have contributed maintaining an extensive management of vulnerable and semi-natural agro-ecosystems, especially those in less-favoured or marginal areas (IEEP 2007; Alliance Environnement 2007), so increasing land degradation because of increment of landslides, denudation rate and erosion in badlands environment.

In central Italy (Castelporziano, Rome), Trinchera et al. (1999) assessed that set-aside soil was characterized by slower organic carbon turnover with a better humification with respect to arable soil. In central-west of Italy (Peccioli, Pisa), Masciandaro et al. (1998) compared an unseeded set-aside system converted since three years with an undisturbed native soil and an intensively cultivated soil. They observed that the soils under set-aside conditions had the lowest humification index, an intermediate value of the mineralization index and the highest value of "metabolic potential" demonstrating the spontaneous recovery of a soil degraded by cultivation practices after only three years since conversion. In north–east of Italy (Legnaro, Padua), Giardini and Borin (1996) studied the impact of bare and energy (sunflower) set-aside on the nitrates content in the shallow water table. In their climate conditions characterized by frequent leaching rainfalls, bare set-aside was found to lead to higher median nitrates concentration so as to reach dangerous peak values, while the energy set-aside seemed to be more conservative.

The introduction of set-aside in Italy had also a great impact on the land use. In fact, when this measure was voluntary, it arose a good degree of adoption, especially in southern districts, as farmers were allowed to get rid of unproductive lands, improving their incomes. This marked a historical change in attitude in Italy, where, in the past, the need of land caused the reclamation of many marginal soils. After the MacSharry reform, the adoption of set-aside became annual and compulsory, so involving all the farmers also in northern Italy and in the most productive lands, with the consequence to reduce the average income for the best producers (Amadei 1994).

9.5.2 Subsides to Cultivate Durum Wheat

On 30 June 1992, the European Economic Community promulgated the Council Regulation number 1765/92, which concerned with the subsidies to cultivate some priority crops. In central and southern Italy, this regulation was mainly devoted to the production of durum wheat (first on production basis, then on cultivated area basis). Owing to the promised greater economical advantages, the regulation favoured the reclamation of soils with silt, silt clay or silt loam texture of bushy lands and badlands for durum wheat cultivation, and exacerbated the already existing tendency to the mono-succession and simplification of the agro-ecosystems, so increasing diffusion of erosion phenomena. In Basilicata region, agricultural soils underwent continuous degradation because of erosion during the last century, but erosion was accelerated in the last 30 years (Rendell 1986; Sonnino et al. 1998). These authors ascribed the acceleration of the erosion processes to the effect of the introduction of the Regulation, particularly to the over-use of the wheat mono-succession. As a matter of fact, in Basilicata as in the rest of central-southern Italy, the increased erosion due to agricultural intensification had further decreased the soil water-holding capacity, which in the last 50 years diminished of about 30 % at a national level (Pagliai 2008), so favouring the activation of a negative feedback consisting of an increase of the erosion that decreases the water-holding capacity, and so on.

9.5.3 Cross-Compliance

The EU's CAP comprises two main elements: market price support and direct income payments (Pillar 1), and incentive payments targeting rural development (Pillar 2). Cross-compliance belongs to both pillars and is compulsory since 2005 [Regulation (EC) 1782/2003 repealed by Council Regulation (EC) 73/2009]. It plays an important role in the protection, conservation and/or improvement of soils. Farmers' receipt of the single farm payment and payments for rural development measures [Rural Development Regulation (EC) 1698/2005] are conditional on their compliance with a set of statutory management requirements (SMRs) as set out in annex II of Regulation (EC) 73/2009 (Table 9.2), and on the maintenance of the land in good agricultural and environmental conditions (GAEC) in line with the annex III of the same regulation (Table 9.3). Cross-compliance also defines the reference level for voluntary agro-environmental measures within the rural development plans. SMRs gradually became applicable from January 2005 to 2007. Member States have some discretion when translating the SMRs into farm-level measures. This flexibility has resulted in a high diversity of farming practices to address the environmental goals among Member States and Regions within each country (Louwagie et al. 2011).

Jongeneel et al. (2007) assessed the level of compliance with environmental SMRs in seven European countries including Italy. These authors found a high degree of compliance, with few exceptions, with the Birds and Habitats Directives, the protection of groundwater with the Sewage Sludge Directive, while the achievements within the Nitrates Directive were not always satisfactory.

Piorr et al. (2009) carried out an integrated assessment of the impact of CAP policies on land-use patterns in a German agro-forestry system and in an Italian agricultural area (Mugello, Tuscany). The Italian case study was characterized by an extremely heterogeneous territory with small mixed crop-livestock farms engaged mostly in the cow–calf line farming. Under the cross-compliance scenario and decoupled single farm payments scheme, an extensification

Table 9.2 Statutory management requirements (SMRs) relevant to soil quality

Environmental directives	
Birds Directive	Council Directive 79/409/EEC of 2 April 1979 on the conservation of wild birds. Articles 3(1)(2)(b), 4(1)(2)(4), 5(a)(b)(d)
Groundwater Directive	Council Directive 80/68/EEC of 17 December 1979 on the protection of groundwater against pollution caused by certain dangerous substances
Sewage Sludge Directive	Council Directive 86/278/EEC of 12 June 1986 on the protection of the environment, in particular of the soil, when sewage sludge is used in agriculture. Article 3
Nitrates Directive	Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources. Articles 4 and 5
Habitats Directive	Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. Articles 6, 13(1)(a)
Directives for Public, Animal and Plant Health	
Plant Protection Products Directive	Council Directive 91/414/EEC of 15 July 1991 concerning the placing of plant protection products on the market. Article 3

Source Council Regulation (EC) 73/2009, Annex II. *See* Louwagie et al. (2011)

Table 9.3 Common framework for defining standards for keeping land in good agricultural and environmental condition (GAEC)

Issue	Standards
Protect soil from *erosion* through appropriate measures	Minimizing the areas with bare soil Appropriate land management reflecting site-specific conditions Retain terraces
Maintain *soil organic matter* levels through appropriate measures	Standards for crop rotation where applicable Arable stubble management
Maintain *soil structure* through appropriate measures	Appropriate machinery use
Ensure a proper level of habitats maintenance	Retention of landscape features (hedges, ponds, ditches, field margins, etc.) where appropriate Protection of permanent pastures Avoiding the encroachment of unwanted vegetation on agricultural land Minimum livestock stocking rates or/and appropriate regimes

Source Council Regulation (EC) 73/2009, Annex III

of the land use was simulated, with a significant decrease in cultivated areas, an increase in arable lands in hilly areas, and an increase in traditional crops such as alfalfa and spelt replacing cereals. In this context, a marked reduction in the average soil erosion risk was also estimated. At the same time, the cropping pattern of the arable farms with soils of medium to good quality was found to evolve towards a reduction in the spatial crop diversity. This is also because the payment entitlements may be transferred to more favourable areas which would be kept in agricultural use anyway or which can be maintained more easily with the extensive use of machinery (Gay and Ostenburg 2005). On the contrary, less-favoured and high-nature-value lands may lose entitlements. In fact, although the recent CAP reform would lead to more extensive agricultural land use, it is doubtful whether this will have positive consequences for already existing low-input systems (Strijker 2005).

Extensive grazing could be another option for land maintenance, for example, on land difficult to maintain with machinery. However, the fulfilment of GAEC standards would be more difficult on grazed land compared to mulching, as “unwanted vegetation” could encroach (Gay and Ostenburg 2005).

A trend towards an increasing extensification due to reduction in intensive crops was also simulated at regional scale by Povellato (2004). In this study, the cross-compliance was found to decrease the durum wheat cultivation in central-southern Italy and increase the threat of land abandonment because of the concentration of cultivated land in the most efficient farms and more fertile areas. Moreover, it was expected that the average cost of respecting the GAEC measures for non-marginal farms in the more fertile plain areas will also encourage, even at a smaller extent than the marginal ones, abandonment of farm production.

The impact of cross-compliance on erosion control in the future of the hilly and mountainous olive groves in Portugal was analysed by de Graaff et al. (2010). They found that cross-compliance obligations could be quite effective in reducing erosion, but at the same time would depress income as a result of higher abandonment and lower percentage shifts towards intensive systems. The same results are expected for southern Italy, where soil conditions and economy linked to cultivation of olive trees are similar to that of Portugal.

The research findings have thus highlighted that the CAP policy have been usually well intended to address soil protection issues, but sometimes they were badly designed leading farmers to take farm management decisions that reduce soil quality rather than accomplishing the objectives for which the policy was conceived. For instance, Martínez-Casasnovas et al. (2010) observed that the influence of the CAP on land morphology in vineyard areas of north–east of Spain was to increase the terracing rates, with consequent increase in huge land movements. In fact, bad design of terraces of newly planted area involving the use of heavy machinery has led to the collapse of benches and borders. This example questions the effectiveness of the EU policy for vineyards in all hilly and mountainous Mediterranean areas.

A more comprehensive analysis of the impacts of cross-compliance on Italian soil was recently published within a special issue of the Italian Journal of Agronomy (Bazzoffi 2011).

9.5.4 Agro-Environmental Directives

In order to reduce the negative impacts of agriculture and to offer new income alternatives to marginal agriculture, since the beginning of the 1990s, the European Economic Community promulgated some directives that were expected to have direct or indirect effects on soil quality in all the Member States. In particular, with the MacSharry reform, two schemes were envisaged specifically to integrate the environmental objectives in agricultural policies: the Council Regulation 2078/92 referring to agro-environmental measures and the Council Regulation 2080/92 concerning (re)afforestation. Other relevant EU environmental directives dealing with soil are the Council Directive 91/676 known as Nitrates Directive and the Council Regulation 60/2000 known as the Water Framework Directive.

9.5.4.1 Council Regulation No 2078/92

The Regulation 2078/92 provided for programmes to encourage farmers to carry out environmentally beneficial activities on their land. Among the promoted land management activities, the most relevant measures that could have had impacts on soil protection were as follows:

- reversion of intensively exploited land, such as arable or grass for silage, to extensive grassland;
- reduction in the use of nutrients (low-input farming practices);
- reduction or suppression of pesticides use (e.g. organic farming);
- creation of natural zones taken out of production;
- maintenance of landscape features that are no longer agriculturally viable.

In Italy, the most adopted measure was that supporting the low-input farming systems (almost 50 % of the overall subsidies), followed by the organic farming measure (about 25 %), while the measure aiming to promote the conversion from arable to extensive grassland systems received around 6 % of the total incentives (INEA 1999a). With few exceptions, most of the cropping systems that benefited of the subsidies were rather extensive such as vineyard and temporary or permanent pastures (INEA 1999a). For instance, in Sardinia, the 80 % of areas converted to organic farming was previously interested by forage crops cultivated following agricultural management practices very similar to the traditional ones (INEA 1999b). The same pattern was observed by Roggero and Toderi (2002) in the Marche region. Thus, more intensive cropping systems, which were the main target of the Regulation, were less interested by the agro-environmental schemes application. Because of this, we may assume that the effects of the Regulation 2078/92 on changing soil management practices were negligible in all countries. In terms of reduction in nitrate pollution, considered one of the main goals of the 2078/92 prescriptions, Roggero and Toderi (2002) found that the application of the agro-environmental measures in many cases had improved soil nutrient balance. At the same time, when considering the nitrate concentration in water run-off, it was often above the legal threshold, in particular immediately after the first autumn rainfalls, and it was on average higher in less-diversified agricultural landscape. Further, the high nitrate concentration in the water run-off was only partially related to nitrogen fertilization, and was mainly attributed to organic matter mineralization occurring when soil was bare and the rain precipitation overcame soil water-holding capacity. Nevertheless, the spatial and temporal cropping system diversification was not taken into account by the directive, and no measures were specifically designed to promote it.

9.5.4.2 Council Regulation 2080/92

The 2080/92 Regulation has been the first comprehensive scheme of EU intervention in the forestry sector. The Regulation was directly carried out by the Italian regions by means of specific operative programmes that in the 1994–1999 period contributed directly to (re)afforest about 80,000 ha (INEA 2000a; Cesaro and Povellato 2001). The most active regions were Lombardy, Sicily and Sardinia. The afforestation of agricultural land was mainly concentrated in the plains and in the areas with the most intensive agriculture, with about 48,000 ha of arable crops converted to woodlands, while only 10,000 ha of grasslands from hill and mountain areas was converted. Fast-growing plantations (i.e. poplars) and, in general, broad-leaved trees were mostly used for the afforestation (INEA 2000b). At European level, the actual role of the conversion of agricultural land to forest as an eligible measure to achieve mitigation of climate change and biodiversity protection is a very debated argument. A pan-European assessment of the impact of the afforestation programmes promoted in EU, highlighted that the initial expectations have mainly not been fulfilled and the planted areas were below the initial targets (Zanchi et al. 2007). The report on the Regulation 2080/92 confirmed that the potential role of afforestation in agricultural areas was considerably over-estimated in the 1980s since environmental, economic, social and legal constraints were not taken into account. In this context, Zanchi et al. (2007) questioned whether the estimated emission reduction targets of 14 $MtCO_2$ from (re)afforestation in the EU-15 could be considered as realistic.

9.5.4.3 Council Directive 91/676

The Nitrate Directive was adopted with the aim to protect water quality by preventing nitrates from agricultural sources polluting ground and surface waters and by promoting the use of "good" farming practices (European Commission 2002). The Nitrates Directive forms part of a comprehensive framework of the EU framework legislation to protect the environment. In this case, the EU was forced to focus its efforts on water for human consumption (Goodchild 1998) because of sanitary problems induced by nitrates diffusion such as "blue baby syndrome" (Shortle et al. 2001) and stomach cancer (Harrison 1996). Agriculture was considered a significant source of nitrogen for ground and surface water pollution (e.g. Heathwaite et al. 1996; Yadav et al. 1997; Carpenter et al. 1998; Hadas et al. 1999), in some cases strongly associated to eutrophication of surface and marine waters (Carpenter et al. 1998; Rejesus and Hornbaker 1999). Under this directive, all Member States have to analyse their waters nitrate concentration levels and trophic state and drawn up action programmes to cut nitrate pollution. An expanding European monitoring network is demonstrating a trend towards steady or falling nitrate concentrations. Overall, the 2004–2007 report indicated good progress towards more healthy water.

However, the Nitrates Directive has been considered one of the most controversial and unsuccessful directives ever made in the EU on environmental matters, because of the slow and difficult implementation by the Member States and because of the unsuccessful results of its prescriptions (Grossman 2000; Sonneveld and Bouma 2003) or less satisfactory than expected (Agence de l'Eau Adour-Garonne 2004; Belhouchette et al. 2011). An *ex-ante* assessment of the impact of Nitrates Directive in the Midi-Pyrenees region (France) by using a bio-economic model to analyse farm income and three environmental indicators (nitrate leaching, erosion, water consumption) showed that nitrogen leaching at the farm scale did not change significantly, while the overall water consumption increased and soil erosion decreased mainly because of modifications in cropping patterns and soil management. In a nitrates vulnerable zone in central Sardinia, with an intensive double-cropping silage maize–Italian ryegrass rotation on a loamy sand soil, Urracci et al. (2010) observed that the nitrates concentration in the soil percolation water was highly variable and occasionally above 300 mg L^{-1}. Moreover, the directive prescriptions for the allowed organic fertilizer rates (170 kg ha^{-1} $year^{-1}$ of N from organic sources) did not show a substantial reduction in nitrate concentration in the percolation water. In an agricultural watershed of the Po plain located in the Ferrara Province and representative of a vulnerable zone for Nitrates Directive, nitrates concentration in efflux water exceeded occasionally the maximum level permitted by the directive (Ventura et al. 2008). By calculating a soil balance, total N outputs and inputs were found of similar magnitude, indicating that crop and soil management (and especially N fertilization techniques) have reached good level of ecological sustainability under Nitrates Directive application.

9.5.4.4 Council Regulation 60/2000

The Water Framework Directive (WFD) aims to prevent and reduce water pollution, to protect and improve the status of the aquatic environment, to mitigate the effects of floods and droughts and to promote the sustainable use of water. Its general goal is to establish a "good status" for all waters by 2015.

Hudec et al. (2007) analysed the institutional settings surrounding soil management in ten European countries with the main objective to study the role of some EU directives, including the WFD, on soil protection issues. These authors demonstrated that the majority of the policy measures were not focused mainly or exclusively on soil conservation but had another or a broader set of objectives, nonetheless affecting soil management. For the WFD, as well as for many EU directives, the closest link between soil quality and water quality was with measures aimed at controlling water pollution, particularly from local and diffuse nutrients contamination. Soil erosion was considered as a key factor affecting water quality, whereas decline in soil organic matter and soil compaction were recognized as negative factors only in few cases. Other aspects, such as salinization, soil biodiversity and landslides, were not cited among the soil degradation processes connected to water quality (Louwagie et al. 2011).

9.5.5 Good Agricultural Practices

Good agricultural practices consist of "practices that address environmental, economic and social sustainability for on-farm processes, and result in safe and quality food and non-food agricultural products" (FAO-COAG 2003). Principal objectives are soil and water protection. Appropriate soil management favours soil productivity by improving the availability and plant uptake of water and nutrients, replenishing soil organic matter and soil moisture, and minimizing losses of soil, nutrients, and agrochemicals through erosion, run-off and leaching into surface or ground water. Good practices related to soil include the following:

- maintaining or improving soil organic matter through appropriate crop rotations, manure application, pasture management and other land-use practices, rational mechanical and/or conservation tillage practices;
- maintaining soil cover to provide a conducive habitat for soil biota, minimizing erosion losses by wind and/or water;
- application of organic and mineral fertilizers and other agro-chemicals in amounts and timing and by methods appropriate to agronomic, environmental and human health requirements.

Agriculture carries a high responsibility for the management of water resources in quantitative and qualitative terms. Good practices related to water include the following: (1) maximization of water infiltration and reduction in unproductive efflux of surface waters from watersheds, (2) managing ground and soil water by proper use, (3) improving soil structure and increasing soil organic matter content, (4) preventing soil salinization by adopting water-saving measures and re-cycling where possible, (5) enhancing the functioning of the water cycle by establishing permanent cover, or maintaining or restoring wetlands.

9.5.6 The Soil Thematic Strategy

The Thematic Strategy for Soil Protection consists of a Communication from the Commission of the European Union to the other European Institutions of a proposal for a framework directive (a European law), and an Impact Assessment. The Communication COM(2006)231 of the year 2006 explained why further action is needed to ensure a high level of soil protection, sets the overall objective of the Strategy and explains what kind of measures must be taken (European Commission 2006). It establishes a ten-year work programme for the European Commission. The proposal for a framework directive COM(2006)232 sets out common principles for protecting soils across the European Union. Within this common framework, the Member States will be in the position to decide how best to protect their soils and how to use it in a sustainable way on their own territory. Moreover, Member States would have to establish risk reduction targets and adopt appropriate measures for reaching those targets. The implemented measures and strategies would vary in response to the severity of the degradation processes, local conditions and socio-economic issues. The national programmes could be shaped taking into account measures already implemented in national and community contexts, such as cross-compliance and rural development under the CAP. The adoption of the proposed Soil Framework Directive would achieve an EU-wide coordination between the different Member States-specific legislation on soil protection. Such coordination would allow dealing with soil degradation processes at multi-scale (from global and regional to local) and would trigger alignment of regional approaches with supra-national requirements, that would be particularly relevant for transboundary soil degradation processes (Louwagie et al. 2011).

The proposal for a Soil Framework Directive to become operative is still under discussion.

9.6 Soil Management and Land Set-up Systems for Soil and Water Conservation

Soil degradation processes represent a direct threat to both biomass and economic yields worldwide. The need to put under control the environmental impact of agricultural activities limiting soil structure decay is one of the main aims of soil management.

Soil structure is one of the most important properties affecting crop production, because it determines the depth that roots can penetrate, the amount of water that can be stored in the soil and the movement of air, water and soil fauna (Hermavan and Cameron 1993; Langmaack 1999). Soil quality is strictly related to soil structure and much of the environmental damage in intensively cropped lands such as erosion, desertification and susceptibility to compaction, originate from soil structure degradation. Moreover, soil functions strongly depend on the quality of soil structure, with optimum structure defined as soil having the widest range of possible uses (Dexter 2002). The adoption of intensive monocultures without application of farmyard manure to the soil instead of traditional farming rotations has compromised soil structural stability (Lal et al. 1994) so reducing the effect of chemical fertilizers, and increasing soil particles and nutrients transport with the consequent risk of surface water pollution. The introduction of new agriculture practices to increase production has often changed land systems from complex to homogeneous (Borselli et al. 2006; Busoni and Colica 2006; Ramos et al. 2007), so modifying soil porosity (Pagliai et al. 1995), hydrologic characteristics (Ludwig et al. 1995) and, finally, landscape structure (van Oost et al. 2000).

The land set-up systems, both for plains and hilly environments, were ideated to exploit new areas for agricultural uses and, at the same time, to maintain or improve the soil quality together with landscape structure and heterogeneity. Many of these systems are today obsolete because of the advent of mechanization and the costs, in terms of work and money, for their maintenance. However, the knowledge of the land set-up systems, each one shaped for specific soil type, geomorphology and climate, may help adopting the soil management most respectful for the soil and most sustainable for the agro-ecosystem.

9.6.1 Land Set-up Systems

The agricultural hydraulic land settings were developed to improve physical, chemical and biological soil conditions and reduce hydraulic erosion.

In Italy, the agricultural systems are particularly important because of the occurrence of (1) large bare arable areas with respect to the naturally covered lands (woods and pasture); (2) climatic regimes characterized by intense and concentrated precipitations; (3) common fine-textured soils with low permeability; (4) hilliness of most of the agricultural soils; (5) lack of a sufficient height to discharge the water in excess from the plain soils. As a consequence of the many physiographic areas present in the country, many systems were elaborated for both plain and sloping surfaces.

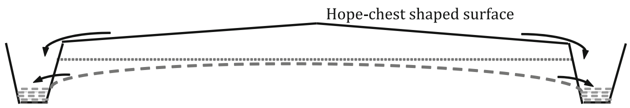


Fig. 9.7 Effect of the excavation of trenches on the removal of the superficial water and on the level of the groundwater table

9.6.2 Flat-land Agricultural Hydraulic Land Settings

In the case of the plain soils, draining of the excess of water can be hindered by two main and often concomitant causes: low soil permeability and insufficient height of the field with respect to the natural discharge collectors. These facts produce an excess of humidity in the soils and, in some cases, winter waterlogging.

The negative effects of an overabundance of water in soil are as follows:

- insufficient gas exchange between soil and atmosphere and low oxygen availability for plants and microorganisms;
- reduced absorption of nutrients due to a lower efficiency of the roots and leaching of soluble compounds;
- limited root development with depth;
- slowing down of the aerobic microbial processes, such as humification and nitrification, and increase in the nitrogen losses by denitrification;
- increase in the diseases and attacks from parasites;
- higher developments of weeds which often have lower oxygen needs than the crops;
- lower soil temperature as wet soil warms slowly because of the water thermal inertia and part of the solar energy are spent for water evaporation;
- limited aggregation degree due to reduced wetting–drying cycles.

The depth of the groundwater table controls the soil agricultural use, since each crop needs a minimum soil thickness free of water to produce at its best. For example, a soil depth of 40–60 cm is required for cereals and pastures; 60–80 cm for alfalfa, beet and sunflower; 80–130 cm for arboreal crops (fruits, vine, olive tree).

Two kinds of solution are usually adopted to reduce the amount of water in the soil: the creation of a deep draining system made of drains, or a superficial network of discharging trenches. The groundwater removal can be achieved with both drains and trenches, while for the removal of the superficial water drains are not the best solution, in particular when the soil has a fine texture. On the contrary, trenches appear more efficient because the water can reach them by superficial flow (in case, favoured by the shape of the field) (Fig. 9.7); further, thanks to the wide section of the trenches the removal of the water is rapid with little slopes, and they can also act as water reservoir when the discharge is hindered. In Italy, trenches are fundamental elements of the plain agricultural systems whose soils derived from fluvial, marine or fluvio-marine sediments and have a fine texture, although in the case of arboreal crops also drains are often present to assure the best soil hydraulic conditions.

The mean volume occupied by the trenches of the plain agricultural systems ranged from 100–150 m^3 ha^{-1} in the well-drained soils to 200–400 m^3 ha^{-1} in the poorly drained soils (Ferrari 1976).

The following descriptions are related to the traditional systems (Oliva 1948), diffused throughout Italy until about 1950. With time, these systems underwent modifications to satisfy the requirements of the modern agriculture and allow mechanization of the agronomic operations.

9.6.3 Proda

This agricultural system was common in the plains of central Italy and, mainly, in Tuscany (Chiana, Arno, Elsa and Ombrone valleys) and Umbria region where soils have a fine texture and penetration is slow. The fields were about 1,000–2,000 m^2, with dimensions of 60–80 m long and 15–30 m wide (depending on the soil permeability), limited by 60 cm deep lateral trenches with roughly rectangular section and grassed rim. Along the field borders, a vine row supported by wood stacks or trees (maples and ashes) placed at about 0.8–1 m from the trenches creates a sort of strip called *proda* (Fig. 9.8). The fields surface had a hope-chest shape (*baulatura a basto rovescio*), thicker in the middle part than close to the vine rows thanks to the soil material obtained from the excavation of the trenches and as a result of the tillage. The hope-chest-shaped fields allowed a better removal of the superficial water towards the vine rows and lateral trenches.

This kind of systems has been almost abandoned to favour the mechanization of the agronomic practices and for the costs required to maintain the system, in particular for the annual cleaning and renewing of the trenches.

9.6.4 Piantata

The *piantata* (Fig. 9.9) was a system diffused in the plain lands of the northern side of Reno valley (Emilia-Romagna region) and, in particular, of the Mantova, Ferrara, Reggio Emilia and Modena provinces, where soils are mostly fine loamy and thick. The fields were 60–80 m long and 30–35 m wide (1800–3000 m^2), with a hope-chest-shaped

Fig. 9.8 *Up* schematic representation of the *proda* system with the fields seen in section; *down* picture of the *proda* system adapted to a gentle slope with a silt loam soil. The Ridolfi's Meleto farm, municipality of Castelfiorentino, Tuscany. *Photo* by Giuliano Corti

surface with a maximum high of 30–70 cm. Between one field and the other, a hope-chest-shaped strip 4–5 m wide, called *piantata*, hosted a row of trees, made generally by vines supported by maples or mulberries. This system did not require excavation of trenches, and the water was removed along the depressions between the *piantata* and the fields. Along the shorter sides of the fields (head), there was a track (*cavedagna*) at lower height than the field, about 4 m wide and with a slope of 1–3 %, which gathered the water from the fields to the major collectors.

The *piantata* system has been adapted to the modern mechanized agriculture by removing the tree rows and levelling the fields; further, the fields have been widening by removing the *cavedagna*.

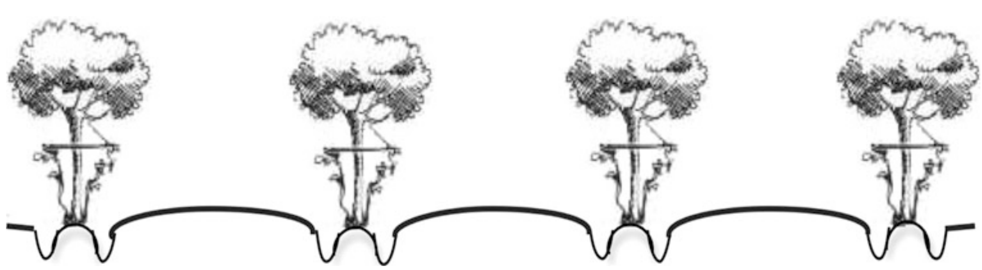
9.6.5 Cavalletto

The *cavalletto* is the typical system for the plain lands of the southern side of Reno valley (Emilia-Romagna), in areas of the Bologna and Ferrara provinces, and in the Comacchio valleys, in the presence of clayey soils. The fields were 80–100 m long and 30–36 m wide (2400–3600 m^2), with a hope-chest-shaped surface with a maximum high of 60–70 cm. Between one field and the other, a hope-chest-shaped strip 4–6 m wide, called *cavalletto*, hosted a row of vines supported by maples, planted along the row 4–6 m one from the other (Fig. 9.10). At both side of the *cavalletto,* there were two trenches, 50 cm deep and 60 cm wide at the surface and 35 cm at the bottom. As for the *piantata* system at the heads of the field, there was a track (*cavedagna*) that was grassed and with a slope of 1–2 %. The soil of this system was deeply ploughed, reaching the depth of 30 cm (manually) or 50 cm (mechanically). The large area occupied by the trenches in the *cavalletto* system, other than the deep tillage, assured a rather good hydraulic regime to these plain clay soils; on the other hand, wide areas were subtracted to the crops.

In modern times, the *cavalletto* was adapted to the new requirements of mechanization with the removal of the tree rows and *cavedagna*.

Fig. 9.9 Schematic section of the *piantata* system

Fig. 9.10 Schematic section of the *cavalletto* system



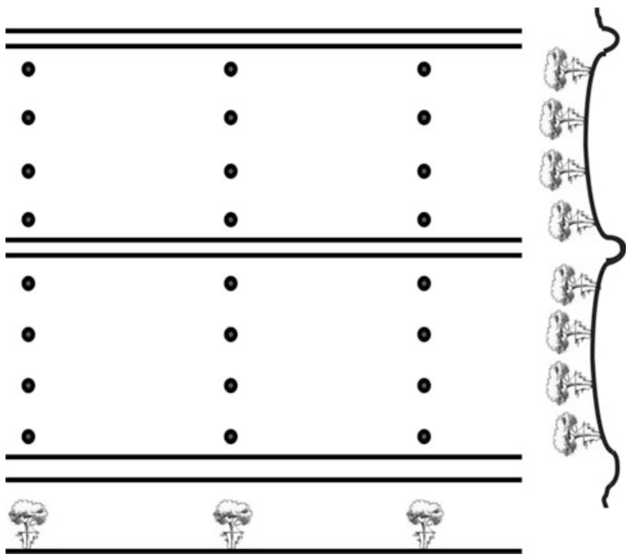


Fig. 9.11 Schematic representation of the *cavino* system with the fields seen in section

9.6.6 Cavino

This system was common in the Veneto region, in the north-east part of Italy, and in particular in Padua province, where soils have fine texture and low penetration. The fields were 60–100 m long and 35–50 m wide (2400–4000 m^2), with the ridge of the hope-chest-shaped surface perpendicular to the long side of the field and 1–1.5 m high with respect of the original surface (Fig. 9.11). The fields were separated by 4–5 m wide strips hosting a row of trees. A trench (*cavino*) ran along the long side of the fields, sometimes substituted by a track 2.5–3 m wide. The system was not very efficient in the water removal, and in particular in the areas closed to the heads of the fields, where the crops suffered for the slow draining due to the standing water in the *cavino*. Another inconvenience of this kind of system was the onerous works to maintain the hope-chest shape of the field surface and to ensure the accessibility and efficiency of *cavino* and track.

This system was adapted to mechanization through the removal of the tree rows and, sometimes, joining the fields.

9.6.7 Larghe

Larghe was a common system for the drained lands in northern (Ravenna, Ferrara, Po river delta) and central Italy (Ombrone river, near Grosseto), characterized by the absence of tree rows (Fig. 9.12). Soils of these areas have fine to very fine textures and had a shallow natural height to discharge the water in excess that had been increase thanks to artificial drainage systems. The fields were 200 m long and 40 m wide

Fig. 9.12 *Up* schematic representation of the *larghe* system with the fields seen in section; *down* picture of the *larghe* system taken at the Ridolfi's Meleto farm, Municipality of Castelfiorentino, Tuscany. *Photo* by Giuliano Corti

(8,000 m^2), with a hope-chest-shaped surface. Along the long side of the fields, the water was collected by trenches that, in turn, were connected to bigger trenches running along the head of the fields and parallel to the track.

This system was easily adapted for the requirements of the modern agriculture without particular modifications.

9.6.8 Hilly Agricultural Hydraulic Land Settings

The hydraulic land settings in the hilly lands, other than to consider the problems related to mechanization, soil thickness and fertility, exposition and precipitations regime, are fundamental to control the erosion processes, through reducing the run-off and favouring the infiltration of water. The maintaining and improving of the hill and steep sloping surfaces systems are addressed not only towards the optimization of the agricultural production, but can be considered as important environmental issues. Indeed, they are responsible for soil and slope stability conservation, which influence the development of human settlements and activities in these disadvantaged areas and, finally, the safety of the communities living in the downstream plain regions.

Several systems were developed to these aims through the construction of agricultural systems and the use of specific practices addressed to enhance the effects of the systems. These latter taken into consideration (Chisci and Zanchi 1980; Landi 1984):

- tillage (reducing the soil refinement and harrowing the fields at 90° with respect to the direction of maximum slope);
- organic amendment of the soil (favouring the aggregation degree);
- choice of the crops in the rotation (inserting multiannual crops and avoiding to leave bare soils during the critical periods).

The hydraulic land settings for hill and steep sloping surfaces tends to (1) interrupt the slope length by digging trenches perpendicular to the slope direction and (2) reduce the declivity by the construction of steps or terraces (Bonciarelli 1989).

9.6.9 *Girapoggio* (Circling the Hill)

This is an extensive system, typical of the hilly lands with moderate slope (Fig. 9.13). It is realized by the excavation of trenches, 20–30 cm deep and 30–50 cm wide, that run along the contour lines with a slope of about 1.5–3 %. The slope of trenches depends on the soil erosion susceptibility, higher the susceptibility lower the slope and vice versa. These ditches discharge the water in natural collectors generally maintained vegetated with willows (Salix sp.), poplars (Populus sp.), maples, giant cane (*Arundo donax* L.). Often, the downstream rim of the trenches is reinforced by little dykes to prevent water overflowing in case of intense rainfall. To avoid the run-off water acquires a high velocity, the drop between one trench and the successive is about 4 m in elevation; so, the field's width is a function of the slope (for example, with a slope of 10 % the distance of the trenches will be 30–50 m).

9.6.10 *Cavalcapoggio* (Straddling the Hill)

This system (Fig. 9.14) is common in central Italy on rocky areas with slope lesser than 35 %. The construction of the *cavalcapoggio* system begins from the lower part of the slope with the digging of a trench (*piegaia*) that is filled with the lithic material excavated through the tillage of the upstream surface for building up a little dry stone wall, 60–150 cm thick and 60–100 cm high. The walls, 8–15 m distant one from the other, were perpendicular to the slope and 40–80 m long. The fields were not flat and maintained their natural downstream slope and two opposite lateral slopes. Sometimes, tree rows were present, planted on a drainage system and at 50–60 cm from the walls. With time, the walls were filled by earthy material and, every 40–50 years, they had to be removed and re-build.

9.6.11 *Unita a spina* (Set to a Herringbone Layout)

This system was born in Tuscany at the beginning of the nineteenth century to intensify cultivation in hilly land with less than 30 % slope having not stony soils rich in clay. This system (Fig. 9.15) was an evolution of the *girapoggio*. The first step of the construction of this system was the modelling of the slope, which were achieved by removing the irregularity of the surface through the run-off produced by the rainfall. This operation also allowed to recognize along the hillside the watershed lines (*punti di spina*) where the trenches (with a section of 0.2–0.3 m^2) were dug alongside with a slope of 2–3 %. The trenches were often associated to drained tree rows, and connected to larger ditches that run along the maximum slope.

Fig. 9.13 Picture of vineyards planted according the *girapoggio* system on the volcanic soils of the Colli Euganei. Municipality of Arquà Petrarca (Veneto). *Photo* by Agnelli

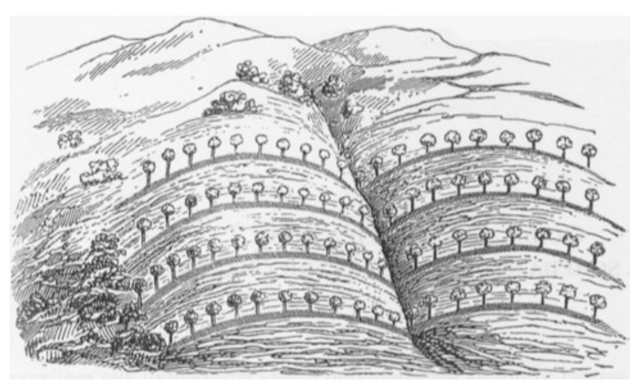


Fig. 9.14 Schematic representation of the *cavalcapoggio* system (from Caruso 1898)

Fig. 9.15 Picture of *unita a spina* system (foreground) taken at the Ridolfi's Meleto farm, Municipality of Castelfiorentino, Tuscany. *Photo* by Giuliano Corti

9.6.12 *Rittochino* (Along the Maximum Slope Gradient)

This is a common system in many Italian regions like Marche (where this system was born), Tuscany and Umbria, where the cultivated land is on hilly environment with moderate slope and characterized by silt and clay-rich soils. The *rittochino* system (Fig. 9.16), in which the tillage is made along the maximum slope, allows a rapid water removing and a lower power requested to tractors and other machines. As a consequence of the one-way tillage, the machines have to do an empty run to go back to the head of the field. The fields are 50–80 m long and are generally separated along the long side by trenches and drained tree rows that discharge the collected water in larger ditches perpendicular to the slope.

The *rittochino* system, functional for an extensive agriculture with scarce mechanization, after the advent of the intense agriculture, is a soil management able to favour activation of erosion processes. Further, higher the slope, lower the penetration of water into the soil, so in slopes of about 15 %, the trees are subjected to summer water stress. One of the possible solutions for maintaining this type of system and, at the same time, reducing the erosion is the minimum or no tillage or, in case of vineyards or other orchards, green-mulching (Landi 1989).

9.6.13 *Gradonamento* (Step System)

The *gradonamento* is an extensive system that can be found in the steep slope of hills and low mountain rocky areas of the central and southern Apennines, where it is functional to the creation of small plain surfaces for the pasture and/or wheat cropping. The steps (*gradoni*) are made with the lithic material excavated from the same soil and

Fig. 9.16 Schematic representation of the *rittochino* system (from Caruso 1898)

approximately follow the morphology of the slope. The hydraulic control systems, both at surface and in deep, are absent.

9.6.14 *Ciglionamento* (Step System)

This system is commonly adopted on slopes that do not exceed 40 % and where the soils have loamy-sand or sandy-loam texture, such as those derived from pliocene or plio-pleistocene marine sandy sediments, volcanic tuffs, windblown sands, moraines and sandstone parent material.

The *ciglionamento* (Fig. 9.17) is analogous to *gradonamento*, but does not need lithic material to design steps (*ciglioni*), which maintain a rather good coherence thanks to the coarse texture and the presence of a grass cover. Hence, a good distribution of precipitations, especially during the summer season, is needed to ensure stability of the system. For these reasons, the *ciglionamento* system is common in the northern part of Italy (Piedmont region and pre-Alps area), on the hilly soils developed on sandstone and conglomerate.

Fig. 9.17 Picture of a slope modelled by the *ciglionamento* system. Municipality of Montespertoli, Tuscany. *Photo* by Agnelli

The width of the fields is function of the slope: considering a fixed height of the step, higher is the slope, minor is the width of the fields. In case of mixed crops, the width increased, and a slight downstream slope is given to the fields. Generally, hydraulic control systems are absent.

9.6.15 *Terrazzamento* (Terracing)

Terraced slopes are widely distributed in the world since ancient times both for productive and aesthetic purposes (Gardner and Gerrard 2003) and represent a large portion of the world's cultivated slopes (Sandor 1998). Terrace building required a complete slope reshaping that in the past was carried out manually. Currently, some mechanization is used in favourable morphologic conditions (Veek et al. 1995), particularly where roads and slope allow accessing. Soil terraces provide a stable topographic base for crops and favour soil moisture conservation in the crop root zone, which is particularly important in coarse-textured soils and in the Mediterranean regions (Sandor et al. 1990; Ramos et al. 2007).

Terracing is commonly adopted on hills and mountains (Figs. 9.18 and 9.19), with a slope ranging from 25 to 50 %.

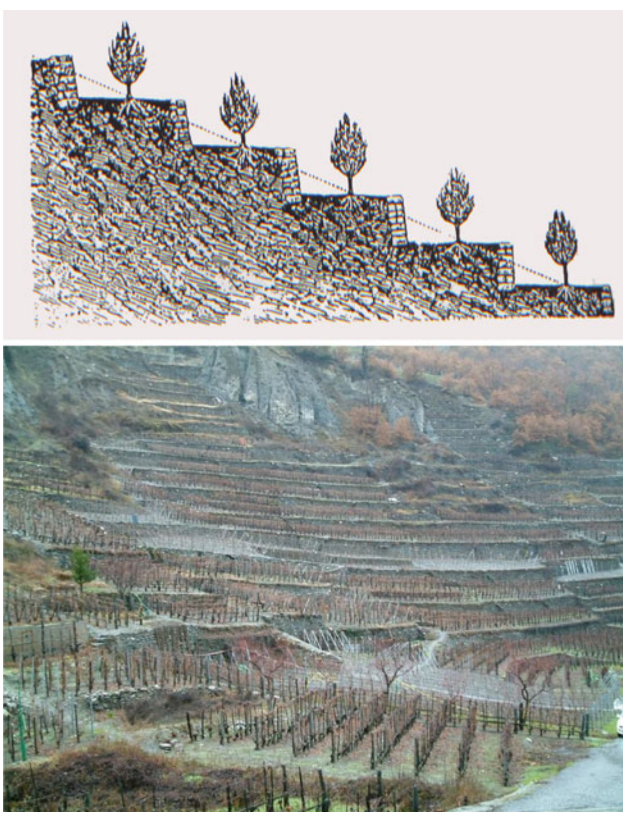


Fig. 9.18 *Up* schematic representation of the terracing system (from Caruso 1898); *down* picture of terraced vineyards in the Municipality of Morgex, Val d'Aosta. *Photo* by Cocco

Fig. 9.19 *Up* schematic representation of the *lunette* system (from Caruso 1898); *down* picture of an olive grove organized with *lunette* in the Municipality of Vaiano, Tuscany. *Photo* by Costantini

The building of terraces begins from the lower part of the slope with the digging of a 0.4–1.2 m deep trench (*piegaia*), where a wall 1.5–2.5 m high and at least 0.6 m thick is built with the lithic material obtained by the excavation of the trench or soil tillage. The space between the slope and the wall is filled by the soil material coming from the trench excavation. As for *gradonamento* and *ciglionamento*, the width of the fields is function of the slope. The fields have a downstream slope of 2–3 %, and in case of mixed cultures, a tree row is planted on the external border of the terrace. The hydraulic control system is comprised of small ditches and drains connected to main collectors that run along the maximum slope.

Terraced slopes require frequent maintenance of the wall structure (Posthumus and De Graaff 2005) and of the network of tracks and minor roads that connect the terraces. A continuous effort is required because slope instability, excessive run-off velocity, rainfall infiltration, and susceptibility of soil to erosion can threaten terrace stability, leading to soil loss and even slope failures (Yaalon and

Arnold 2000; Van Dijk and Bruijnzeel 2003, 2004; Duran Zuazo et al. 2005; Allen et al. 2006).

9.6.16 *Lunette* (Small Moons)

This is a system used in the steep and rocky slope. The *lunette* (Fig. 9.19), made by dry stone walls about 1–1.2 m high, with circular or semi-circular shape, and with a diameter of 2–3 m, is functional to retain a certain thickness of soil around a tree. This system was generally adopted for the olive trees but, in southern Italy, also for carob tree (*Ceratonia siliqua* L.).

9.6.17 *Fosse Livellari* (Level Ditches Circling the Hill)

This system represents an evolution of the traditional agricultural systems for hill and steep sloping surfaces (Fig. 9.20). In fact, around the 1950s, with the increase in the mechanization of the agronomic practices, there was an abandonment of the areas with steep slopes and of the traditional mixed cultures. Through the removal of walls and other artefacts and a reshaping of the slopes, simpler systems which allowed better viability for the machines and a more intensive exploitation of the productive surfaces have been adopted. The fields, once freed of the residue of the old systems, were subdivided along the downstream direction every 60–100 m in correspondence of changes in slope, by level ditches. The trenches were 5–10 cm deeper than the tillage depth, with an inclination of 1–2.5 % and less than 200 m long. These trenches were perpendicular to the maximum slope direction, collect both the superficial and the deep water running on the ploughing sole and were connected to natural or artificial collectors. Often, the level ditches were substituted by a track with a slight counter-slope that, other than collecting the water from the upstream slope, favours the movements of the machines. When the fields were used for vineyards or other orchards, subterranean drainage systems were installed.

Fig. 9.20 The *fosse livellari* system. From the book of Lami (1938)

9.6.18 Piani Raccordati

This system was adopted for the sandy hills of Asti province (Piedmont region) cultivated with vines and other orchards. The system derived from the *ciglionamento*, with the construction of planes that have alternatively opposite inclination (Fig. 9.21). In this way, each plane is connected with the plane above through one end and with the plane below with the other one, with the advantage of an easy circulation of the machines among the different levels of the slope.

9.7 Agronomic Drainage Systems

The agricultural systems seen above are not able to remove the excess of water from the fields if these latter are at the same or lower elevation than the discharge basins (stream, river, lake, etc.), or when natural obstacles hinder the natural flow of the water towards the collectors. In these cases, the use of the soils for agricultural purposes is not achievable, nor soil reclamation is possible on a farm scale and needs the construction of drainage systems on higher land scale, considering whole provinces or regions.

After the Netherlands, Italy is the country with the largest agricultural surface reclaimed from marshes and swamps through methods to control the level of the water either in than above the soil surface.

The objective of the agricultural drainage systems is to increase the thickness of the available soil for the crops, and this goal can be reached through two different ways: raising the level of the soil surface or lowering that of the groundwater. The systems are made to guarantee a sufficient

Fig. 9.21 Picture of the *piani raccordati* system taken in the Chianti area nearby Olena, Municipality of Barberino Val d'Elsa. *Photo* by Costantini

soil thickness free of water (*franco di bonifica*) even in the worst meteorological conditions. In Italy, the techniques used for increasing the soil thickness bringing the soil surface at higher level were *colmata* and *mazzuolatura*, while the groundwater level is usually lowered by draining pumps.

9.7.1 *Colmata* (Filling)

The aim of the *colmata* system is to raise the soil surface at a higher level than discharge collectors through the accumulation of soil material. The traditional *colmata* method consists in diverting in a delimited area the water of a river or stream that runs in the vicinity and allowing the material suspended to sediment. The surface to be reclaimed (*cassa di colmata*, filling crate), bordered by a main dyke and subdivided by secondary dikes in smaller areas (*casse* or *preselle*, crates), is flooded thanks to an artificial canals that deflect part of the water flow of the river. Once inside the *cassa,* the water flow reduces its velocity and lets the suspended material to sediment, after, through a spillway, the water is left to run away to another canal that brings the water to the river. The size of the sediments is function of the flow speed, but also of the soils that mantle the watershed.

The small crates inside the *cassa di colmata* are generally in succession, and sometimes, they are cultivated even during reclamation. Crops cultivated are those with spring-summer cycle that need high amount of water such as maize, tomato, rice, watermelon, alfalfa. The soils obtained with this system are generally fertile, thanks to their good chemical properties due to the fine and rich-in-nutrient materials deposited by the water of the river. In contrast, physical properties of the sediments are usually poor and require several mechanical works to be improved.

Notwithstanding its efficiency and low costs of achievement, nowadays, this system has been abandoned because of the long time (20–40 years) required to obtain a sufficient soil thickness free of water.

The colmata system was born in Tuscany during the Renaissance, as attested by some writings of Leonardo da Vinci and by the fact that Evangelista Torricelli, a student of Galileo Galilei, designed the *colmata* system utilized for the reclamation of the Chiana valley, close to Arezzo (Fossombroni 1835; Taddei 1957) (Fig. 9.22). Another important land reclamation accomplished by the *colmata* system was that of the Grosseto plain, central Italy (Fig. 9.23). In this case, the operations started around the beginning of 1800 (Taddei 1957) taking advantage of the Ombrone river that crosses the area to be reclaimed. It has been estimated that this river would have been able to transport about 2.4 kg of solid *per* m^3 of water and that the amount of suspended material would have allow to deposit a layer of about 10 cm per year. In contrast, the rising of the soil surface was much lower (around some mm per year) and, consequently, in the 1930s to complete the reclamation of this area, the system was implemented with 4 draining pumps with a total flow rate of 17.7 m^3 s^{-1}.

Another version of this hydraulic system is the artificial *colmata*, where the rising of the soil surface is achieved by using earthy materials of various origin or extracted from quarries, transported and deposited in the reclaimed area. The artificial *colmata* is suitable for small surfaces, but

Fig. 9.22 The canale maestro della Chiana (main canal of the Chiana valley), in Tuscany, an artificial canal that runs for 62 km from the Chiusi lake to the Arno river. The canal was part of a drainage system till 1788; then, it became the main canal of the *colmata* system used to bring sediments on the most depressed areas of the valley. *Photo* by Agnelli

Fig. 9.23 Two images of the Grosseto plain (Tuscany) initially submitted to the *colmata* system, which exploited the cloudy waters of the Ombrone river and then drained by pumps (the *white* building in the picture below is that where the pumps are located). *Photo* by Agnelli

nowadays, the distribution of any lithic or inorganic material at the soil surface requires special permissions.

9.7.2 Mazzuolatura

This system achieves the increase in the soil surface at a higher level than discharge collectors through the accumulation of soil material excavated from trenches opened each 8–10 m one from the other and parallel to the long side of the field. The soil strips among the trenches are called *mazzuoli,* and the network of trenches is responsible for the collection and removal of water. Since the large surface needed to realize soil stripes free of water, this system was not very effective in giving much soil surface: in fact, 1,000 m^3 ha^{-1} of soil were required to enhance the field surface level of about 10 cm.

This system was applied in some valley of the Emilia-Romagna, and in two Tuscan areas, that of Massaciuccoli lake (Lucca) and that of the Bientina swamps (Pisa). After the World War II, this agriculture drainage system was abandoned because of the high cost of achievement and the hindrances (numerous trenches, small fields) that prevent modern agriculture practices.

9.7.3 Drainage System (*Prosciugamento*)

This system consists basically in the removal of the excess of water through one or more effluent ducts running along the watershed lines of the basin (Fig. 9.24). During the planning of the system, it is important to consider the physico-chemical characteristics of the soils, so as to avoid problems related to their subsidence due to the compaction occurring after their reclamation. When possible, the effluent duct discharges the water in lower areas, conversely draining pumps are required. This latter option raises the costs of reclamation, even though usually the pumps work only during night when the electric power is cheaper. On the base of the energy required for the water discharging, the outflow is ranked in *high water*, that naturally are discharged in the collector basin, *medium water*, that sometimes required the help of the pumps to be discharged in the collector basin, and *low water*, that always required the hydraulic uplift.

This system has been used for the reclamation of marshy and unhealthy areas in many Italian territories in the last century (Sani 1962; Ronchi 1971; Costantinidis 1981), such as Polesine and the Piave lowland (Veneto), Ravenna, Parma and Reggio Emilia provinces (Emilia-Romagna), Agro Pontino (Latium), the Fucino plain (the bottom of an ancient lake at 650–680 m above sea level in Abruzzo) and Arborea (Sardinia). The Fucino plain, surrounded by mountains that hindered the water discharge, was reclaimed by the excavation through the rocks of a 500-m-long artificial effluent that allowed the flow of the water in the downstream valley.

9.8 Soil Management in Different Physiographic Agro-Ecosystems

Italian rural landscape can be considered as a dynamic system influenced by natural and cultural processes of different spatial and temporal scales (Bracchetti et al. 2012). During centuries, forest soils and marshes were reclaimed and rural territories modelled to improve environmental conditions and soil production. Till about 60 years ago, Italian farmers respected soils nature and equilibrium as they had low economic objectives and scarce technical instruments. The advent of the mechanization and the use of chemical fertilizers and pesticides implied a heavier soil management, which differently impacted on the

Fig. 9.24 Pictures of lands reclaimed by *prosciugamento*: **a** Agro Pontino (Latium); **b** Polesine (Adige-Po valley, Veneto); **c** Arborea plain (Sardinia)

environment. Further, the heterogeneous physiography of the country influenced differently the progress of agriculture, which was favoured in plains and hills and, obviously, limited in the mountains because of shallow soils, steep slopes and cold climate. In these latter areas, however, agriculture became a way to conserve many high-elevated mountain areas like Val d'Aosta, Valtellina, or Cinque Terre area in the Maritime Alps (Terranova 1989; Stanchi et al. 2011).

Considering the map of the soil regions of Italy (Costantini et al. 2004), the heterogeneity of the Italian soil types in terms of physical and chemical parameters, depth, facing, exposure, vegetation and organic matter content implies different land suitability and requires specific soil management for maintaining soil quality and resilience. This fact had produced different physiographic agro-ecosystems, which are here resumed into high-alpine environments, pre-alpine fringe, Po plain, Apennines environment, southern regions and great islands (Sardinia and Sicily).

9.8.1 High-Alpine Environments

In the alpine regions, soils frequently show strong limitations for climate, slope, thickness, rockiness, stoniness and acidity. Because of their high potential water erosion and landslides risk, they were classified between the 4th and the 8th class of Land Capability when they are in elevated areas, and between the 2nd and the 3rd class when they are in the valleys, which are frequently occupied by urban settlements (Costantini et al. 2004). Forest and permanent meadows, which are the dominant land covers, are today frequently abandoned and threaten by strong water erosion and landslides. The abandonment of meadows and pastures of marginal areas, as well as the removal of hedges and banks, led to loss and fragmentation of habitats with an impoverishment of the ecological communities of the cultivated environments (Giupponi et al. 2006). Critical hazards for these soils were emphasized since 1950s during the general exodus from the Alps, with consequent lack of human presidium and abandonment of soil management and conservation practices (Giupponi et al. 2006; Monteiro et al. 2011). Unsuitable soil management was in some cases disrespectful of climax conditions like in the case of pastured grasslands on Udorthents or Cryorthents (Zilioli et al. 2011) or Lithic Borofolists developed on limestone under subalpine vegetation belt (Strunk 2003). In fact, changes in the management of these fragile ecosystems (forest fires, clear-cutting and overgrazing by cattle and horses) slowly erased the organic horizons reducing their water absorption capacity and favouring the formation of gully erosion with consequent severe soil losses along the slopes (Strunk 2003).

In the Alpine region, the tree cultivation is rather widespread, especially for vine and apple trees. Recently, Monteiro et al. (2011) observed changes in soil management of the high and south-exposed slopes of Valtellina where meadows were converted to vineyards and orchards. Vineyards and many apple tree plantations are traditionally cultivated on human made-terraces, which have been more or less maintained or subjected to mass movements in function of the financial supports provided by different local administrations (Costantini et al. 2004). In the Alpine steep slopes, terraced agro-ecosystems cover considerable surfaces and represent the ancient sustainable soil management to protect mountain soils (Scaramellini and Varotto 2008). The soils of the terraced slopes are anthropogenic soils (Yaalon and Arnold 2000; Hammad et al. 2004; Posthumus and De Graaff 2005; Shi et al. 2004; Van Dijk and Bruijnzeel 2004; Sang-Arung et al. 2006; Zornoza et al. 2009) and host high-quality crops such as vines and fruit trees. Terraces are made of a human-reworked substrate where pedogenesis occurs under a strong human influence, and soils have generally a coarse texture and limited development. Terraces are subjected to progressive decay due to erosion processes and slope failures if abandoned; hence, they need maintenance because their stability is threatened by excessive run-off velocity, rainfall infiltration and the susceptibility of soil to erosion (Van Dijk and Bruijnzeel 2003, 2004; Duran Zuazo et al. 2005; Allen et al. 2006; Khanal and Watanabe 2006). Consequently, the preservation of the vertical structures, the tracks network and the drainage system is necessary. The substrate, morphology and soil characteristics show a remarkable heterogeneity, but some common points can be observed, such as the loss of fertility and soil quality when terrace management is not efficient, with a sudden enhancement of erosion and soil losses due to abandonment (Stanchi et al. 2011).

With the development of the winter sports, frequent manipulations of the alpine environment occurred. An example is the construction of new ski-runs and associated infrastructures (Caravello et al. 2006), often at elevations as low as 1000–1500 m. At this altitude, the effect of climate warming on snow conditions and the increasing demand for longer skiing season (from November to April) has caused an increase in the production of artificial snow and ski-slope preparation (Keller et al. 2004). Development of ski resorts generally induces drastic land modifications and topographic adjustments that cause the degradation of soil and vegetation (Isselin-Nondedeu et al. 2006). The consequent alteration of both ecologic and geomorphic processes caused by heavy machines has an impact on the soil properties, biomass production, composition of plant species and hydrologic system, thereby increasing the risk of land degradation by erosion, landslides and avalanches (Cavallin et al. 1996; Arnaud-Fassetta et al. 2005; Jamieson and Stethem 2002). Thus, also hydrologic changes occur and, to a large extent, they are caused by the removal of soil material that could store water. To create ski-slopes, the natural landform is often levelled, exposing unweathered parent material or deep soil horizons (Freppaz et al. 2002). The extremely scarce development of the ski-slopes soils involves an almost complete lack of structure, with subsequent problems of soil compaction and reduction in water and air permeability (Tsuyuzaki 1994).

9.8.2 Pre-Alpine Fringe

At the base of Alps, a wide hilly chain called Pre-Alps divides the high mountain from the Po plain. These alpine foothills, belonging to Friuli Venezia Giulia, Veneto, Trentino-Alto Adige and Piedmont regions, are particularly devoted to high-quality wine production. In Piedmont, where viticulture interests fine-textured soils, soils with a grass cover are protected against water erosion especially during summer season, while without grass covering erosion may assume an intense character (Corti et al. 2011a). High-quality wines are also produced in the Collio area (Friuli Venezia Giulia), where vineyards are mainly planted on terraced soils.

A particular ecosystem of this area, along the boundary between Pre-Alps and plain in Friuli Venezia Giulia is the so called *Magredi*, which in the local dialect means poor land. This habitat has particularly poor and gravely soils, which developed from fluvio-glacial sediments deposited at the end of the last glaciations (Würm). The *Magredi* habitat represents one of the last examples of a steppe landscape in Italy, and for this reason, it is actually protected (S.C.I.: Site of Community Importance). In this environment rather rainy, the well-drained soils of the *Magredi* are somewhere cultivated with vines, kiwi (*Actinidia* sp.) and asparagus (*Asparagus officinalis* L.), which give appreciated yields thanks to the mild water stress to which cultivations are submitted. Gravels and pebbles of the *Magredi* system are protected by law, and collection is restricted to citizens who may pick up only a certain amount per day.

9.8.3 Po Plain

Po plain occupies more than 44,000 of the 77,000 km^2 of Italian plain land and consists of the flat area situated along the course of the Po river and within its watershed. The Po plain is the most intensive agricultural area in Italy as it hosts 36 % of the utilized agricultural area (UAA) and 75 % of the total livestock units (ISTAT 2000). The soils of the area developed from alluvial sediments and their main characteristics depend upon the parent materials from which the deposits originated. The main distinction that should be made at this regard is between the deposits originated from the Alps (rocks of igneous or crystalline nature) and those coming from the Apennines (sedimentary rocks like marl, sandstone, limestone and shales). These features determine the presence of gravely soils in the upper plain close to the Alps (northern Po Plain), while the soils located close to the Apennines have mainly sandy and clayey textures. Loamy soils (silty-clay-loam, loam, silty-loam), with optimal condition for the agricultural exploitation and for the cultivation of a widest range of crops, spread over 45 % of the cultivated area of the Po plain.

The flat landscape is the results of many human modifications that began with the Romans, who divided this land in portions that afterwards became green ways or drainage canals (Tozzi 1972). As described by Tempesta (2010), after the advent of mechanization, the area was transformed following an intensive agricultural model and by a simplification of the landscape with residential and industrial settlements dispersed in the plain. After the innovation in mechanization, in the last decades, the European CAP induced deep alteration of the Italian landscape, particularly in this plain. Many typical lands with perennial vegetation were abandoned, and fields were enlarged to favour mechanization, while hedgerows, tree plantations, natural meadows and mulberry trees gradually disappeared from the plain.

The main crops of the Po plain are as follows (Giardini et al. 1994; ISTAT 2000):

- Forage crops (permanent meadows and alfalfa), which cover about 27 % of the UAA and are diffused especially in the plain along the borders of Alps and Apennines.
- Summer cereal cultivations (mostly maize, for both silage and grain), which amount to 25 % of the UAA and are located in the central plain of Lombardy (provinces of Milano, Como, Cremona, Bergamo, Brescia and Mantova) and in the provinces of Turin and Rovigo.
- winter cereals (wheat and barley), which cover about 20 % of the UAA and are located mainly in the plain of Alessandria and in other areas in the provinces of Pavia, Modena and Bologna.
- Industrial crops (sugar beet, tobacco, soybean and sunflower), which cover about 20 % of the UAA with higher percentages in the eastern part of the Po plain.
- Rice (9 % of the UAA), which is cultivated in very specialized areas located mainly in the north-west (provinces of Vercelli, Novara and Pavia), where soil drainage is reduced by the presence of fragipan or horizons with fragic properties within 1–2 m of depth.
- Vineyards, which cover 5 % of the UAA and are located in highly specialized areas (provinces of Asti, Alessandria, Pavia, Verona), where the cultivated surface often overpasses 50 % of the land.
- Fruit crops (apple, peer, peach and others), which cover about 3 % of the UAA and are diffused mainly in the eastern part of the area, in particular in the provinces of Ferrara and Verona.
- Vegetables (potato, tomato and others), which cover about 3 % of the UAA and are mostly located in the central area of the plain.

All the soils of the Po plain are deeply ploughed (40–50 cm of depth) and, even though in areas close to livestock farms, a certain reintroduction of organic matter is practised, the intense agricultural use has degraded the fertile soils, which now suffer of low organic matter content and nitrogen leaching. In fact, the high-productive cropping systems that characterize the plain is largely dependent on the addition of N fertilizers (Tilman et al. 2002). In some areas of the plain to mitigate the effects of diffuse agricultural pollution, farmers realized vegetated buffer strips among the fields. Buffer strips and other management practices are provided under current and future regional planning to support the development of more sustainable agriculture (Borin et al. 2010).

9.8.4 Apennines

Large changes in landscape characterized the high Apennines areas, triggered by the depopulation occurred in the last 50–60 years. The abandonment of traditional agriculture and farming, which represented a human presidium of the territory of these areas since the Renaissance, brought to the decline of crops and grasslands as woodlands expanded at the expense of the fields. This general trend was observed at large scale in rural mountain areas in Italy as well as in other European countries (Bracchetti et al. 2012). For example, in the Apuane Alps (Tuscany), the decline of the mountain population caused a great landscape mosaic transformation besides the alteration of structure, density, and the specific composition of tree vegetation (Agnoletti 2007). The elements that are most likely to disappear from the landscape of Apuane Alps are chestnut groves, meadows, pastures, pastures with trees and cultivated lands. Further, it has been found a relationship between landslides and changes in land use linked to abandonment of terraced chestnut groves due to the lack of terrace maintenance.

The hilly fringe made of plio-pleistocene pelitic (silt clay) marine sediments that mantle the Apennines chain in central and southern Italy show many sloping areas that are prone to land degradation because of their peculiar climatic, pedological and morphological characteristics. On these sediments, the most representative soils show middle-high plasticity and a high sodic nature, which makes them easily dispersible when wetted (Capolongo et al. 2008; Clarke and Rendell 2006; Moretti and Rodolfi 2000). According to Alexander (1982) and Clarke and Rendell (2006), the hill morphology, seasonal rain distribution and often unsuitable soil managements combined with these soil peculiarities, favoured the catastrophic erosion phenomena and a land degradation that brought to the formation of badlands. This probably happened mainly during the Medieval Warm Optimum (950–1250 A.D.) when a strong demographic increment induced a heavy exploitation of the hilly forests concentrated in a short time. On these soils vulnerable to erosion, this exploitation caused rapid decline of the structure and changed the soil hydrologic equilibrium, with consequent formation of badlands. In the badland environments, also transformations of the twentieth century were intense, with slopes that were levelled and remodelled with the help of dynamite before vineyards, olive tree and orchards were implanted. In the soils of these areas, after rainfall events, there is a tendency to develop a layer of reduced permeability that becomes a crust during drier period (Robinson and Phillips 2001). Crust development was inversely related to stability of soil structure, which in turns depends on organic matter content and exchangeable sodium percentage. In this context, soil management particularly influences degradation of soil structure. In fact, while under semi-natural wood-land and scrubs, soil aggregates are stable and crust did not occur, in cultivated soils, aggregates were weak and prone to raindrop energy. The decline of soil organic matter content and the consequent lost of structure in Tuscan and Calabrian fine-textured soils were attributed by Papini et al. (2011) to the long-term application of deep ploughing on steep slopes and agronomic techniques like removal of crop residues. Nowadays, there is a tendency to preserve the badland environments as natural habitats, but in case of land cultivated thanks to former levelling, suitable soil managements able to reduce erosion seem to be the constitution of pastures or grass cover of vineyards and orchards. Unfortunately, in many regions, the soils of badland environment are still used for durum wheat production, so as to further worsen soil quality and increase erosion (Fig. 9.25).

9.8.5 Southern Italy

In Mediterranean regions agriculture may play an important role both in economical and social terms (e.g. peopling of hilly marginal lands) as well as under environmental aspect such as the control of erosion phenomena (Bombino et al. 2011). However, intensive agricultural activities together with climatic, geomorphologic and land-use factors, such as high rainfall intensity, scarce vegetal coverage, low soil organic matter content, expose the fragile soils to degradation and erosion risks (Van der Knijff et al. 1999; Grimm et al. 2003). Therefore, in the agricultural lands under semi-arid conditions, soil degradation problems must be accounted for proper soil management systems with low environmental impacts, especially on soil hydrology. Following the application of the EU CAP measures, in southern Italy, soil management exerted important effects on land transformation during the last 50 years (e.g. Clarke and Rendell 2006; Piccareta et al. 2006). These actions resulted in reclamation of badlands and degraded grasslands for agriculture, principally for the cultivation of durum wheat. This farming practice and the abandonment of some of the remodelled areas increased the risk of soil erosion and desertification processes, as manifested by land degradation and diffusion of rill networks and gullies.

In southern Italy, most of the higher slopes (even in badlands) and the majority of the river catchments have soils with fine texture and are cultivated with durum wheat. In contrast, the plain along rivers and close to the sea are devoted to the production of fruit and vegetables thanks irrigation systems constructed after the 1950s (Clarke and Rendell 2006). Because of the over-exploitation of the

Fig. 9.25 Picture of a land formerly cultivated with durum wheat and now subjected to catastrophic erosion processes that are addressing it towards badlands transformation. Nearby Crotone, Calabria. *Photo* by Pier Paolo Roggero

groundwater, especially in the last 30 years in many coastal areas, soil salinization phenomena have occurred.

A considerable amount of land of southern (and central) Italy is occupied by soil developed from various types of volcanic parent materials like lavas or pyroclastites that mantle the volcanic apparata (see Chap. 2 of this book). Thick layer of volcanic ejecta can be also found on southern Apennines mountains made of calcareous rocks (Matese, Majella) as an effect of aeolian transport of pyroclastites. According to Scarciglia et al. (2008), the occurrence of soils developed on volcanic-bearing parent materials appears to have been strongly underestimated because of the distance of volcanic soils from the volcanic complexes. For example, in Calabria, there is no volcano, but soils of the western coast of the region (on Capo Vaticano–Monte Poro Promontory and on the Sila and Aspromonte massifs) show andic properties. The same is true for the Abruzzo region, whose high altitude mountains show accumulations of volcanic materials and, at sites, Andisols (Giraudi 1995; Corti et al. 2011b). Nonetheless, Andosols or soils with andic properties developed in Veneto, Tuscany, Latium, Campania, Basilicata, Calabria, Sicily and Sardinia (Adamo et al. 2003; Lorenzoni et al. 1995, Lulli et al. 1988; Scarciglia et al. 2008; Vacca et al. 2009).

These soils were frequently terraced and showed a good suitability for both agricultural and forest uses since the Roman Age, when a large part of these fertile soils were cultivated (Inoue et al. 2009). Nowadays, only in plain, most of these soils are still devoted to intensive horticulture, vineyard, and cultivation of fruits tree and flowers, while the steep slopes are occupied by woods made of Turkey oak (*Quercus cerris* L.), beech (*Fagus sylvatica* L.) an chestnut (Terribile and di Gennaro 1996; Lulli et al. 1988). A part few exceptions, the volcanic-bearing soils under the climate of central-south Italy are susceptible to heavy machine disturbance as they have low bulk density and lack of cohesion. Especially on slope, when these soils are disturbed, they may collapse and reach the liquid limit because of their thixotropic properties. Because of this, catastrophic landslides and soliflucions are common on slopes covered by Andosols or soils with andic properties (Basile et al. 2003), and this has caused disasters in the provinces of Naples, Caserta and Salerno (in the years 1910, 1949, 1954, 1971, 1972, 1973, 1974, 1986, 1993, 1997, 1998 and 1999), Messina (2007, 2009 and 2011) and in the Ischia island (1910 and 2006) (Diodato et al. 2000; Dipartimento Protezione Civile 2012). The stability of these soils requires appropriate forest planning and soil management (Terribile et al. 2000a, b), and the fact that most of the disaster dealing with these type of soils concentrated in the last decades can be taken as a clue of the abandonment of the soil management and the forest practices that favoured stability of the slopes. For example, in the Naples-Salerno provinces, all the steep sloping surfaces covered by pyroclastites originated from Vesuvius and the Flegrean volcanic complex were historically interested by a network of drainage canals and ditches that neatly conveyed the water down slope and allowed flourishing the cultivation of vegetables and fruit trees that required much water during the summer season. Moreover, even though of uncertain origin, the rearing of the Italian water buffalo (*Bubalus bubalis* L.) for the production of *mozzarella* diffused mainly in the provinces of Salerno and Caserta during the seventeenth century thanks to the abundance of water all along the plains. After the World War II, the construction of irrigation systems has induced the abandonment of canals and ditches maintenance, as well as of any other land management. The same is true for the Messina provinces, whose andic soils were terraced but, after the "economic boom" of the 1950–1960s, the terraces have been left to their fate.

9.8.6 Great Islands

9.8.6.1 Sardinia

In Sardinia, only 18 % of the soils have few ecological limitations while 28 % are shallow soils often characterized by medium and high erosion risk. The remaining 54 % of soils belongs to different classes of Land Capability depending on the parental material, landscape morphology and vegetation cover (Aru et al. 1991). The range of soil moisture regimes varies from *xeric* to *dry xeric*, locally *udic,* while temperature regimes are *thermic* and locally *mesic*. In this context, according to the main Land Capability classes for cultivated lands, the soils belong to the 2nd and 4th class, while most of the grazing and forest soils fall into the 7th and 8th class because of many limitations such as thickness, high erosion risk, slope, stoniness and rockiness, drought, acidity (Costantini et al. 2004).

Concerning the land use, as reported by the regional survey carried out within the Rural Development Plan 2007–2013, Sardinia is characterized by a high incidence of rural areas sensu OCSE (a rural commune has less than 150 inhabitants per km^2). Within the rural areas, the Campidano plain, in the south-west of Sardinia, has the highest percentage of intensive and highly specialized agriculture (mainly dairy cattle and horticulture systems) while the 81 % of the whole regional territory is occupied by marginal or less-developed rural areas. In these latter sites, the average land productivity is relatively low due to several factors such as low innovation technology, market constraints, etc. At the same time, the protected sites with high environmental value like Sites of Community Importance (SCI) and Special Protection Areas (SPA) are concentrated in these areas. The prevalent land use in Sardinia is "forests and semi-natural areas" (53 % of the regional territory) followed by "agricultural areas" (43 %) where pastures and forage systems are highly represented.

To understand the actual land uses and soil management practices and the role of different drivers on their dynamics, it is important to look at the past and at the more recent trends. Since 1950s, there was a general trend towards intensification of the land uses. D'Angelo et al. (2001) analysed the evolution of the soil uses along the period 1955–1996 and observed a marked increase in improved pastures at the expense of cork woodlands. Sheep grazing was taken over and intensified with negative consequences for cork oak regeneration (Ruiu et al. 1995). Since the 1980s, due to the EU CAP that allocated subsidies on the number of animals and on the introduction of mechanized farming, the traditional agro-pastoral landscape of Sardinia was subjected to a further marked intensification. Wide areas of *Macchia Mediterranea* were cleared to create artificial pastures through bush and stone removal, tillage and sowing of forage species (Pulina et al. 1997; Rivoira et al. 1989). Among these agricultural practices, tillage and mechanical shrub removal (which were made, in many cases, on steep slopes along the maximum gradient) were considered the main causes of land degradation. In many agro-pastoral areas of Sardinia, these have been carried out once every 3–5 years aiming to remove invasive not palatable species that re-colonized the pastures (Zucca et al. 2010). These practices resulted in losses of the shrub layer, so contributing to soil organic matter decline, soil exposure and erosion particularly on steep slopes (Vogiatzakis et al. 2008 and references therein). In an agro-pastoral area of central-eastern Sardinia (Irgoli, Nuoro province), Zucca et al. (2010) estimated a soil loss between 30 and 60 t ha^{-1} y^{-1} in pastures after 15–30 years since *Macchia Mediterranea* clearing and periodical tillage. These authors found that the early autumn rainfall events were very erosive and could have a great impact on pasture soils, deprived of the vegetation cover by grazing and, eventually, by ploughing, which was generally carried out at the end of summer. Other authors found lower soil erosion rates, with soil losses over 6 years up to 3 t ha^{-1}, but for different cropping systems (*Eucalyptus* plantations) on more gentle slope conditions (Vacca et al. 2000). In pasture areas of the same study site of the work of Zucca et al. (2010), challenged water erosion was found to be intense too (Zucca et al. 2006). This was mainly attributed to over-exploitation of the pastureland and to the creation of new pastures on unsuitable marginal land managed by periodical tillage, often carried out along the maximum slope gradient.

In more recent years, the agricultural landscape of Sardinia have been subjected to deterioration processes through abandonment of marginal land and intensification of most favourable areas. This has led to a substantial increase in areas classified as permanent pastures, although many of them are actually abandoned arable lands previously cultivated with durum wheat (Roggero et al. 2011). The increase in the permanent pastures, provided the maintenance of the same or even lower livestock numbers, seems consistent with the objective to protect soil quality from overgrazing and ploughing of steep areas. Nevertheless, as stated above, the increase in permanent pastures is also strongly associated to the abandonment of the farming activities, since farmers, who are dealing with a global agro-food crisis and with a serious crisis of the Sardinian agro-pastoral sector, are strongly oriented to reduce production costs (i.e. fuel, seeds, extra-farm feeds). It is debated whether the effect of the abandonment could be positive or negative (Mazzoleni et al. 2004). Under limiting water and nutrients conditions causing low soil fertility and vegetation production, abandonment could enhance land degradation, while under more favourable conditions abandoned land can be rapidly colonized by vegetation facilitating the accumulation of soil organic matter and, in turn, increasing the overall soil fertility. At the same time, increased plant biomass in abandoned land also could create higher risks of wildfires and, thus, the soil could return to a status more susceptible to erosion. However, research findings analysing the impact of land abandonment on soil processes are not so far available for the specific contexts of Sardinia.

Regarding the impact of intensification in the most favourable areas, some processes of soil degradation are occurring. One case is that of the anthropic salinization, which is related to the over-pumping of coastal groundwater that has caused the infiltration of sea water. The use of this low-quality water for irrigation is increasingly affecting several coastal areas like the Cedrino river delta in eastern-central Sardinia and the Muravera coastal plain in southern-eastern Sardinia (Vacca et al. 2000). The sea water intrusion was recognized as an important driver of soil salinization also in the Nurra district in the north–east of Sardinia, but other various geochemical processes due to the groundwater–rock interaction, including ion exchange with hydrothermal minerals, and clays were found to be involved (Ghiglieri et al. 2009).

9.8.6.2 Sicily

Sicily encompasses several agricultural landscapes and agro-forestry systems. As a consequence of different natural and historical settings intersecting for millennia, Sicily can be viewed as representative of the Mediterranean area as a whole. Sicily has hosted continuous and intensive agricultural activity since the Neolithic Age (Sereni 1997), leading to remarkable growth of its autochthonous species in terms of both quantity (with varieties brought from other regions as a result of historical events) and intra-specific biodiversity (through anthropic selection). Sicily's high environmental variability is particularly visible in locations where plains, hills, mountains, sea and sizeable human settlements all occur within a small area. Traditional landscapes (sensu Antrop 2005) are often encountered in such areas, showing historical identities that were largely stable until the mid-twentieth century (Antrop 2005; Bignal et al. 1995; Vos and Meekes 1999); however, in recent years, they have been subject to either agricultural intensification or abandonment (renaturalization) and degradation (e.g. urbanization). Through these processes, traditional landscapes are now shrinking and gradually disappearing (Aalen 2001; Agnoletti 2007; Green and Vos 2001).

Traditional agricultural and agro-forestry landscapes are characterized by low-intensity systems and land management activities, providing a high degree of multifunctionality (Jones-Walters 2008; Pinto-Correia and Vos 2004; Vos and Klijn 2000) in terms of production (typical products), environment (e.g. soil protection and biodiversity) and culture (distinctive landscapes).

The area of Mount Mongibello (Etna volcano), in the east coast of the island, is characterized by a mixture of different traditional land uses and covers. In general, natural and semi-natural communities (especially forests and shrublands) prevail above 1,000 m of altitude (Poli-Marchese and Patti 2000). Below 1,000 m of altitude, the flanks of the volcano are characterized by various combinations of closed agro-forestry systems (Barbera et al. 2004; Busacca 2000), which are terraced and cultivated with mixed fruit crops and other traditional crops such as pistachio, hazelnut and vine. Irrigated agricultural systems are located below 300–400 m above sea level and host citrus trees, olive tree, almond trees, pistachio and cactus pears. The coastal plain hosts intensive irrigated agricultural systems characterized by orchards and vegetable gardens that recall the *huertas*.

In south-east of Sicily, the Mazzarrone area "is a very clear example showing the effects of the land-use change in the soilscape by large scale farming over time" (Lo Papa et al. 2011). In this area, the rapid expansion of vineyards for table grape production involved deep irreversible transformation of the soils that, due to anthropic pressure, underwent a process of entisolization leading to the formation of strong anthropogenic features (Dazzi and Monteleone 2002). The soils of Mazzarrone, after a deep mixing of the original horizons occurred about 30 years ago to establish the vineyards, changed according to WRB (FAO/ISRIC/ISSS, 1998) from Calcaric Kastanozem to Aric Regosols (Dazzi and Monteleone 2007). Recently, the same soils were classified as Geomiscic Anthrosols as a consequence of the addition on their surface of transported earthy material and a deep ploughing in order to improve the quality of grape (Dazzi and Monteleone 2007).

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10 Soils in Urban Areas

Franco Ajmone Marsan and Ermanno Zanini

10.1 Introduction

Soil is a crucial compartment of the urban ecosystem and, although frequently overlooked, it contributes, directly or indirectly, to the general quality of life of the citizens (Bonaiuto et al. 2003; de Hollander and Staatsen 2003; van Kamp et al. 2003; Chiesura 2004). With respect to natural or agricultural soils, in urban areas, the soil establishes distinctive relationships in space and time with the other components of the ecosystem, viz. air, water, biota and, most of all, humans. On the one hand, as an element of the landscape, it provides esthetical and recreational functions in parks and gardens and contributes to the preservation of biodiversity; on the other hand, urban soils often undergo rapid use changes which entail mixing with other anthropogenic materials that may modify its functioning and often end up with extensive sealing (Morel et al. 2005) (Fig. 10.1).

In addition, anthropic activities, such as traffic, heating, industry and waste disposal, often result in soil pollution (Ajmone Marsan and Biasioli 2010). Therefore, most of the major threats to soil conservation listed by the European Commission (2006) are active in urban environments.

The concern for soil quality is particularly strong due to the proximity of urban soils to humans which could enhance the effects of poor soil management. In 2010, more than 50 % of humankind, that is, around 3.5 billion people, was living in urban areas (Table 10.1). In Italy, this proportion had already been reached in 1950, and by 2010, more than 41 million people out of 61 million were concentrated in urban agglomerations (United Nations 2010).

Urban soils are considered in classification systems as *anthropogenic* or *technogenic* soils (Dudal 2004), but no specific categories are provided based on their location. Rather, it is the composition which guides their characterization, so the urban qualifier does not necessarily coincide with techno- or anthropogenic and vice versa. The World Reference Base includes them in the Group of the Technosols, whose soil properties are dominated by technical human activity in the form of artefacts or geomembrane or a pavement; subgroups are defined as either Ekranic (sealed), Linic (lined), Urbic (rubbly), Spolic (industrial wastes), or Garbic (organic wastes) (Rossiter 2007). An overview of the classification systems of urban soils was provided by (Lehmann and Stahr 2007). The International Committee for Anthropogenic Soils (ICOMANTH) (Galbraith 2004) is working towards the definition of specific classes for urban soils in the USDA classification system.

Despite this taxonomic endeavour, the application to urban soils has been sporadic as very few systematic studies have been conducted if compared with the knowledge that has been accumulating about agricultural, forestry and natural soils. As a matter of fact, the usual approach to soil survey and investigation, that is, used in open, non-urban areas cannot be applied due to a number of problems that complicate the inference process which is commonly used for rural areas.

A major drawback in urban soil studies is the high spatial variability of their chemical, physical and biological properties both in the horizontal and in the vertical direction. Recent research (Madrid et al. 2006; Wei and Yang 2010) reported a very high variability in some urban soils, even in the short range, not only of the general soil-quality indicators such as pH or cation-exchange capacity but also of the pollutants. Intense anthropogenic activity in the city environment adds to the natural spatial variability thus intensifying soil heterogeneity. Excavation, redistribution and mixing of the soil matrix and addition of extraneous materials are frequent in the urban and peri-urban areas as a consequence of the intensive use of the territory and the rapid land-use changes. Soil-forming processes are deeply modified or interrupted when sealing of the surface occurs and are partially resumed when built areas are dismantled.

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Fig. 10.1 Excavation of a soil for building a parking lot exposed a sealed soil

Table 10.1 Percentage of population residing in urban areas by major area and in Italy, 1950–2050 (United Nations 2010)

	1950	1960	1970	1980	1990	2000	2010	2020	2030	2040	2050
World	28.8	33.0	36.1	38.9	42.6	46.4	50.5	54.4	59.0	63.9	68.7
More developed regions	52.6	58.8	64.7	68.3	70.8	72.7	75.2	77.9	80.9	83.7	86.2
Less developed regions	17.6	21.8	25.3	29.4	34.8	40.0	45.1	49.8	55.0	60.5	65.9
Italy	*54.1*	*59.4*	*64.3*	*66.6*	*66.7*	*67.2*	*68.4*	*70.9*	*74.6*	*78.1*	*81.2*

Soil properties are then the result of complex processes that might be very far from the natural, more predictable ones (Fig. 10.2).

Another obvious feature of the built environment is the fragmented distribution of the areas where the soil is exposed because a large proportion of the surface of an urban area is sealed by constructions or roads. These areas have very variable size and are usually non-randomly distributed. This adds a constraint to the sampling design which would then be limited to the exposed surfaces and not necessarily representative of the entire urban area. The sampling coverage can be further distorted by the limited accessibility of the areas where soils can be studied for various reasons: private property, construction areas, no-traffic areas. In conclusion, the possibility of applying geostatistical techniques for the interpretation and mapping of urban soil data (Cattle et al. 2002; Wong et al. 2006) is very limited as they very rarely

Fig. 10.2 Soil compaction under a walking path in a public park

Table 10.2 Concentration of metals and other toxic elements in the soils of Italian cities

City	Soil type/use	Number of samples	Element	Concentration (mg/kg)			Reference
				Min	Max	Mean or median	
Rome	Park		lead	37	1357	330.8	Angelone et al. (1995)
			cadmium	0.03	1.9	0.311	
Naples	Park and garden		copper			20.1	Basile et al. (1974)
			lead			67.4	
			zinc			57.2	
Turin	Urban	30	arsenic	8	21	11	Biasioli and Ajmone Marsan (2007)
			chromium	140	480	233	
			cobalt	14	190	27	
			copper	33	290	94	
			lead	42	490	124	
			mercury	0.1	4.4	0.9	
			nickel	91	350	164	
			silver	0.1	29	2.5	
			zinc	30	460	170	
			cadmium	0.2	8.1	1.3	
Turin	Various	123	chromium	65	930	172	Biasioli et al. (2007)
			copper	15	349	87	
			lead	24	905	143	
			nickel	77	790	188	
			zinc	53	553	165	
Turin	Parks, roadsides	70	chromium	67	870	191	Biasioli et.al. (2006)
			copper	34	283	90	
			lead	31	870	149	
			nickel	103	790	209	
			zinc	78	545	183	
Naples	Flower beds	207	cadmium	0.1	6.9	0.6	Cicchella et al. (2003)
			chromium	0.8	149	15	
			lead	20	2052	204	
			palladium	8	110	12.7	
			platinum	1.6	52	4.2	
			zinc	35	3211	223	
Rome	Undisturbed	111	platinum(ng/g)	7	19.4	11.2	Cinti et al. (2002)
Naples		173	chromium	1.7	73	11	Imperato et al. (2003)
			copper	6.2	286	74	
			lead	4	3420	262	
			zinc	30	2550	251	

(continued)

Table 10.2 (continued)

City	Soil type/use	Number of samples	Element	Concentration (mg/kg)			Reference
				Min	Max	Mean or median	
Turin	Urban	25	mercury	0.21	0.9	0.47	Rodrigues et al. (2006)
Palermo	Green areas	70	chromium	12	100	34	Salvagio Manta et al. (2002)
			cobalt	1.5	14.8	5.2	
			copper	10	344	63	
			lead	57	682	202	
			manganese	142	1241	519	
			mercury	0.04	6.96	0.68	
			nickel	7	38.6	17.8	
			vanadium	21	124	54	
			zinc	52	433	138	
			cadmium	0.27	1.86	0.68	
Pisa, Livorno, Carrara	Parks, playgrounds, roadside, allotments	29	lead	30	1025	122	Bretzel and Calderisi (2006)
			zinc	45	337	107	
			copper	28	305	62	
			nickel	28	112	55	
Padua	urban	30	platinum (ng/g)	0.1	5.7	0.9	Spaziani et al. (2008)
Rome		16		7.0	19.4	10.6	
Viterbo		31		4.9	20.0	9.6	
Naples		15		4.7	14.3	8.4	
Palermo		14		0.2	3.9	0.7	

possess the qualities of a regionalized variable, viz. a continuous variation in space and some structure in its variation. An urban area is therefore a place where it is most unlikely that soil data exhibit some spatial dependence, that is, *where its values at locations close together are more similar than those further apart* (Webster and Oliver 1990).

All these limitations have certainly hindered the interest in the genesis and properties of urban soils except for those aspects more strictly related with their environmental quality: pollution and the transfer of pollutants to the adjoining compartments. Heavy metals and metalloids (Table 10.2) were in particular investigated in view of the numerous source of pollution within urban agglomerations.

10.2 Studies on the Environmental Quality of Urban Soils

Early studies in the urban area of Turin (Sapetti et al. 1974) had observed high Pb contamination in the urban and peri-urban zone. In the same year, Basile et al. (1974) had reported elevated concentrations of Cu, Pb and Zn in soils surrounding industrial plants and streets of Napoli. Analogously, Zanini et al. (1993) and Bonifacio et al. (1995) had observed high levels of Pb in the soils of an urban park in the city of Torino.

A first systematic study of heavy metals in soils was carried out in the city of Palermo (Salvagio Manta et al. 2002) where 70 samples were collected from the topsoil of green areas and parks. The results indicated that Pb, Zn, Cu, Sb and Hg were good tracers of anthropic pollution, whereas Mn, Ni, Co, Cr, V and Cd were inherited from the parent material. Vehicular traffic was the main source of diffuse pollution with the contribution of point sources of contamination. For the same city, Orecchio (2010) reported that the most abundant polycyclic aromatic hydrocarbons in the soils of the botanic garden were benzo[a]pyrene, benzo[b]fluoranthene, perylene, chrysene, fluoranthene and pyrene. The sum of the concentrations of 23 compounds, ΣPAHs, ranged from 947 to 18,072 µg/kg and were 2–3 times higher than the other urban soils and about 20 times higher than that of rural sampling locations.

Imperato and co-workers (2003) investigated the concentrations and chemical forms of Cu, Cr, Pb and Zn in the surface and sub-surface soils of gardens, parks, roadside fields and industrial sites of Naples and compared their results with historical data. They found that the soils have a mainly neutral or slightly basic pH, due to the presence of carbonates and that a coarse texture prevails. Copper, Pb and Zn largely exceeded the legislative limits for contamination, and Zn, in particular, resulted to have the most liable forms. Their concentrations had greatly increased since a study carried out in 1974, with higher accumulation in soils from roadsides thus indicating the vehicular traffic as the main source of these pollutants.

In a study that investigated specifically the soils within a former steel plant in the outskirts of Napoli, Adamo et al. (2002) found that disturbance of the soil profile by the industrial activities had been prominent due to mixing with extraneous materials. The contents of Cu, Co, Cr, Pb, Zn and Ni were above the legislation threshold, and their chemical speciation indicated that Cu and Zn were present in readily available forms. These Authors also observed some translocation of metals along the profile, associated with fine particles.

These results were confirmed by a similar study in the same location (Tarzia et al. 2002) that explored the industrial site at depth down to 5 m. By using Pb isotopes, it was observed an anthropogenic pollution together with a significant natural contribution from hydrothermal solutions of volcanic origin. This would have prevented any effective remediation action.

In Caserta, a study of the soils of the municipality reports high concentrations of Cu, Pb and Zn, as in Naples, together with high Sb and Hg, in the most densely populated and industrialized zone (Vitrone 2003).

These results for the Campania region were later confirmed by an extensive geochemical investigation by Cicchella et al. (2008). They analysed approximately 2000 topsoil samples from the urban areas of Avellino, Benevento, Caserta, Napoli, Salerno for 40 elements. These Authors found a positive correlation between high values of toxic elements (Sb, Cd, Hg, Pd, Pb, Pt, Cu, Zn) and the most densely populated areas, the high traffic flows, and with industrial settlements. By the use of isotopic data, it was possible to attribute the high concentrations of Pb in soils to the high traffic flows.

Twenty-one urban soils were sampled in the city of Ancona and its surroundings (Businelli et al. 2009). All the soils were calcareous—pH ranging from 7.9 to 8.4—and with a texture ranging from clay loam to sandy loam. The cation-exchange capacity varied from 7.4 to 35.7 $cmol_{(+)}\ kg^{-1}$, and the organic carbon (OC) from 17.6 to 88.5 $g\ kg^{-1}$. The concentrations of heavy metal were compared with the limits established by the Italian Law (D. Lgs 152/2006) for public and private parks, gardens and residential areas. Copper, Cd and Cr concentrations were below the limits in all sites while Zn, Pb and Ni concentrations were found to be above the limits in 67, 29 and 5 % of the examined sites, respectively (Fig. 10.3).

Fig. 10.3 Soil excavation, transport and re-distribution is typical of an urban setting

A total of 29 samples were collected in the towns of Pisa, Livorno and Carrara in public parks, playground areas, roadsides and allotments (Bretzel and Calderisi 2006). The soil properties were very variable except for a pH which was always sub-alkaline. Among the metals analysed, lead showed the highest content and it was found in all roadside soils. Lead and zinc were correlated in all urban soils, suggesting a common origin of the two metals. The concentrations found by these authors, however, exceeded the legislative limits for contaminated soils except in few samples.

In the city of Roma a survey of platinum concentrations in urban and rural soils was conducted on the suspicion that catalytic converters of cars could have released this element in the environment and finally in the soils (Cinti et al. 2002). The Authors compared results of 2001 analyses with those obtained in 1992 and suggested that a possible increase in Pt concentration was underway. In addition, they observed a decrease in the concentration of Pb and attributed it to the phasing out of leaded gasoline.

Angelone et al. (2002) determined the concentration of Cd, Cu, Hg, Pb, Zn and Pt in the soils of the urban area of Naples. Their results indicated that Pb (mean 71, range 19–318 mg/kg), and Pt (mean 8.5, range <1–13.8 ng/g) concentrations were comparable with those found in other Italian urban soils while Zn, Cu, Cd and Hg were close to unpolluted soils. The relatively high concentration of Pb suggested that the main pollution source could be the vehicular emissions.

Similarly, Cicchella et al. (2003) analysed 195 urban and non-urban soils of the city of Naples for Pt and Pd. They found a large number of samples from the urban area with anomalous concentration of Pt (>6 μg/kg) and Pd (>17 μg/kg) and correlated those values with the major traffic flows.

More recently, Spaziani et al. (2008) reported the results of a study of platinum distribution in urban soils and dusts of five cities, from northern Padua, central (Rome and Viterbo) and southern (Naples and Palermo) Italy. They observed an enrichment in urban soils, with concentration ranges of 0.1–5.7 ng/g in Padua, 7–19.4 ng/g in Rome, 4.9–20 ng/g in Viterbo, 4.7–14.3 ng/g in Naples and 0.2–3.9 ng/g in Palermo. These results were related to vehicular traffic, because the concentrations decreased with the distance from the roads.

A comprehensive amount of data is available for the city of Turin. In 2006, Biasioli and co-workers compared soils within the city with those in the surrounding rural area. They observed that city soils had a higher pH (7.2) than the rural soils (5.6) and attributed this to the incorporation of extraneous materials such as bricks and construction debris that could increase the pH. This could also have influenced the particle size distribution as urban soils which show a coarser texture with respect to the surrounding area. The mean values of OC content are similar in urban and rural samples most probably for the low content of the latter.

While 58, 49 and 27 % of the urban soils were above the legislation limit for Pb, Zn and Cu, respectively, none of the rural samples was above the limit for these elements. Although Ni and Cr have a high natural background in the area, the difference between urban and rural shows a considerable contamination in the city soils. Ordering the samples with increasing distance from the city, an abrupt division between urban and rural soils was evident for Pb, Zn and Cu. The transport of pollutants from the city to the surrounding areas seems to be very low, as no trends with the distance were observed (Fig. 10.4).

Further investigations on Turin soils (Biasioli et al. 2007) confirmed that Pb, Zn and Cu are effective tracer of urban pollution while the association of Ni and Cr is due to the mineral composition of the substrate which is rich in serpentinitic minerals. In addition, the comparison of soil properties and metal content in the upper (0–10 cm) and lower (10–20 cm) layers clearly showed that the soil mixing and perturbation was such that no vertical trend was identified, in line with the expected high spatial variability of these soils.

The data of Turin were compared with those of Sevilla (Spain) and Ljubljana (Slovenia) and revealed that, regardless of the geographical location, climate and size of the urban areas, the *urban* factor—type and intensity of emissions and human influence on soils—is dominant in determining environmental quality of the urban soils.

Fig. 10.4 A mixture of various materials, including soil

A study on Hg concentration in the soils of the parks of five European cities (Rodrigues et al. 2006) reported a median value for Turin of 0.48 mg/kg of mercury in the topsoil but once again highlighted the high variability of concentrations both within each park and between cities. Short-range variability was found to be up to an order of magnitude over the distance of only a few 10 m.

The same variability was documented by a study on PAH contamination (Morillo et al. 2007). The soils in Turin had a concentration of PAH (ΣPAH) ranging between 148 and 3410 mg kg^{-1}, and only one sample could be considered as *non-contaminated*. The three most abundant PAHs were phenanthrene, fluoranthene and pyrene, and this, together with some molecular indices based on ratios of selected PAHs, suggested that the source of these pollutants was mainly motor vehicle exhausts.

A specific investigation on the soils of the urban parks of Turin for a broader variety of contaminants (Biasioli and Ajmone-Marsan 2007) revealed that the average contents of Co, Cr, Ni, Pb, Sn and Zn were above the legislation limits, but all thresholds were exceeded at least once for all the elements analysed except for Sb and Se. In particular, all the samples were above the limits for Sn, in 97 and 93 % of the samples for Cr and Ni, 67 and 53 % for Co and Zn, 37 % for Pb and V, 20 % for Cu, 13 % for Cd and Hg, and 3 % for As and Tl. The legislative limits were frequently exceeded also for the organic contaminants, and this was especially true for the most toxic molecule such as benzo[a]pyrene, indeno[1,2,3]pyrene, PCBs and PCDDs/DFs.

The high toxicity of the contaminants found in urban parks, where the proximity to humans is very high, enhance the concern for human health and reflects the environmental role played by soils in urban agglomerations.

10.3 Conclusions

A wide variety of properties is observed in the urban soils of Italy which make them a unique ecosystem, most often very different from the soils of the surrounding rural areas. The anthropogenic factor seems to prevail, in most cases, over the other factors of soil formation. This brings about an abnormal spatial variability of the soil characteristics and indicates pollution as the most common unifying property. Under these conditions, it appears inadequate or ineffective to use the traditional tools for the classification of soils as no useful information can be obtained. Land-use change is so rapid that a map of urban soils would become obsolete before it is ready to print.

A viable alternative is systems of numerical classification that can be organized to host other ecosystem parameters and pressure (such as population, proximity to green areas, traffic data) that actually defines the environmental quality of urban soils. Such systems (see e.g. Vrščaj et al. 2008), although they provide only point data, can be stored online and be updated in real time as new information becomes available.

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Future Soil Issues

11

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11.1 Introduction

11.1.1 Preface

We believe that addressing and selecting future soil issues for a specific country must be made by adapting soil issues to current and future country needs. We thus start this chapter by analysing both Italy's physical landscape along with the social and economic structure and its population. On this basis, we identify the most important country-specific contributions of soil science to the well-being of Italy. Rather than showing advanced techniques for applications in soil science, we start from soil issues considered important for the future needs of Italian society. Our analysis is based on the evidence that there appears to be no countrywide need for specific research issues such as soil mineralogy, soil micromorphology, soil genesis, study of humic substances, site monitoring of soil pollution, site monitoring of soil biology, geostatistics of small plots, soil biodiversity of specific sites and soil modelling calibration/validation of specific sites. We believe that all these basic issues (and many others), which are indeed important and are sometimes fundamental for soil science and for the progress of science, should be developed within the framework of society's needs. Then, soil scientists must have a very active role, as sketched in Fig. 11.1, ameliorating country potentialities and mitigating country limitations. From our perspective, this is the only future feasible for soil science within the constraints of this society.

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Then we use this approach as basis for this chapter which aims to provide a different view for overcome both present-day fragmentation in soil science research and the not enough and not adequate contribution of soil science to the well-being of society. To our view in the last decade, the large majority of soil scientists have made a rather strong effort to be efficient moving towards high-quality scientific production. In a sense, each good soil scientist spent lots of energy to manufacture his beautiful brick of good science to help in building our large house (soil science contributions useful to society). The problem relies on the evidence that often we produce our own bricks not really thinking and even knowing what house are we building. The outcome of this situation is that, most probably, a large bulk of these beautiful bricks are not necessarily useful for the house and the large resources (especially human) to produce that bricks become ineffective with the resulting frustration. This happens very often to many of us when at the same time (1) we complain about present-day society who does not understand the importance of our research and (2) we question very little whether our research is really producing a useful brick for that house.

It is then clear that this chapter does not criticized very specialized research—which obviously are a must—but aims to emphasize that even highly specialized research and its outcoming bricks must be made in accordance with the actual and future need of our house.

In order to get this result, as shown in Fig. 11.2, here we anticipate that soil science requires a novel vision, novel approaches and novel education all combining in-depth knowledge with a very good broad and basic knowledge. Figure 11.2 is shown that actual situation cannot be very productive and suffer serious limitations (in the figure less roots producing less leaves) but positive thinking are feasible and realistic if we are able to have more roots better exploring the soil knowledge.

This chapter focuses on future soil issues starting from addressing some of the basic facts and figures of Italy, including country limitations and potentialities, and

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Fig. 11.1 Diagram illustrating potential country needs and potential contribution by soil scientists (*black figure* in the cartoon) aiming to mitigate limitations and ameliorate potentialities

identifies—from the authors perspective—the most important country-specific contributions of soil science to the well-being of Italy. Between them, we included and described the followings: (1) spatial planning of the landscape (oriented to urban planning), (2) archaeology and natural heritage, (3) agriculture and forestry, (4) hydrogeological risks, (5) integrated landscape management, (6) educating soil scientists, through a novel soil literacy.

On the specific issues related to land degradations, here we must specified that in this chapter (for the sake of conciseness), we only highlight the main natural risks

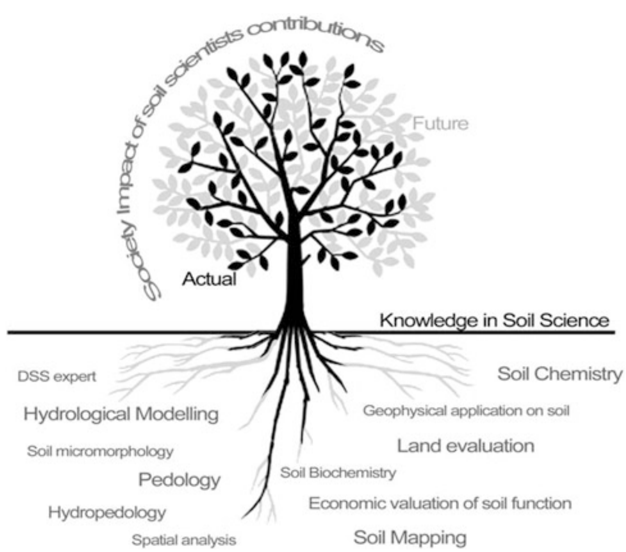

Fig. 11.2 Diagram illustrating the underlying approach of this chapter. Actual soil scientist must move towards a better contribution towards society need. In order to achieve this goals, future soil scientist need to have better exploring roots both vertically (specialized research) and horizontally (soil multidisciplinary knowledge)

specific to Italy, leaving aside other environmental issues of great global importance such as soil contamination and soil pollution, loss of biodiversity, fires, loss of soil organic carbon, etc., which are, of course, of major importance also for Italy, but they are amply covered by a wide national and international scientific literature to which we refer for further details (e.g. for Italy http://annuario.apat.it/annuarioDoc.php).

In dealing with future issues, we employ both the broad term soil science and/or the specific term pedology. In some places, both will be used interchangeably because all our work is relevant to both.

11.1.2 Italian Facts and Figures

Area: 301,338 km^2; population: 58,556,466; density: 194 inhabitants per km^2; institutional form: republic; currency: euro; language: Italian; religion: Catholic; capital: Rome. Italy is one of the six founder members of the European Community, which later became the European Union (EU). Of the 27 countries of the EU, Italy ranks seventh in land area, fourth in population and twelfth in GDP per capita. Italy has a production structure similar to that of Germany, France and the UK, with over two-thirds of GDP derived from service industries and less than 3 % of GDP from agriculture.

11.1.3 Physical Environment and Climate

The great diversity of Italy is highlighted by the presence of various landscapes, such as the Alps, the Pre-Alps, Apennines, the mountains of Sardinia, plains, coasts, glaciers, Alpine and Apennine rivers and the lakes. Italy is largely hilly and mountainous: 35.2 % of the area is occupied by mountains, 41.6 % by hills and 23.2 % by plains. In geological terms, Italy is a young country: the Alps, the Apennines and the Po Valley formed in the Tertiary and Quaternary, and the peninsula is still subject to tectonic forces, as testified by active volcanoes and earthquakes.

Compared with other countries in the world, Italy is located in an area with a good access to water. Indeed, Europe, with 13 % of the world's population, has 8 % of the global water resources; in contrast, Asia, with 60 % of the population, has 36 % of water resources, while America, with 14 % of the population and 41 % of resources, is the most favoured continent.

Italy has a mainly Mediterranean climate, with the Alps protecting the north from cold winds and the extensive coastline favouring the mitigating effect of the sea. Winters are generally mild, while summers are hot with low precipitation. There follows a summary of the main climatic zones, but further details are reported in the chapter on climate in this same book.

The climate is more continental in the Po valley and in the Alps with cold winters; summers are hot and sultry, autumn and spring rainy. Altitudinal diversity induces the formation of different climatic regions. Above 1,000 m, the Alpine area is characterized by average temperatures below 0 °C and snowfall in winter. The rainy seasons are autumn and spring. With increasing altitude, the winters are longer and colder, the summers short and cool; peaks over 3,000 m are covered by glaciers. The climate of the Padano-Veneto hill region has strong annual temperature variations and more abundant rainfall in spring than in late autumn. The climate of the Apennines is continental in inland areas and becomes temperate towards the coast. Rainfall is more abundant on the Tyrrhenian side. Climate in the Adriatic region is characterized by cold winters, with a cold wind (Bora) from Eastern Europe, and hot and sultry summers, with frequent thunderstorms. The Tyrrhenian climatic region has a Mediterranean climate with mild winters and hot summers; rainfall is moderate. The climatic regions of the south and the islands have a typical Mediterranean climate with mild winters and hot dry summers. Rainfall is scarce and concentrated in winter; the region of Puglia in the southeast is particularly subject to drought.

11.1.4 Economy

In the last 50 years, after development which profoundly changed the country's economic situation, the Italian population has become part of the 15 % of the world enjoying a high level of welfare and Italy is in the small group of countries with high income. More recently, since the beginning of 2000, the country has shown worrying signs of stagnation and loss of international competitiveness.

Economic development has led to fundamental changes in the production sectors. In 1951, Italy was essentially an agricultural country: more than 45 % of workers were engaged in agriculture. In the space of 15 years, the weight of agriculture in total employment was halved and continued to contract until the present day (4 % total employment); employment has shifted towards industry and services.

The most negative aspect of the country's growth process is the lack of modern economic development concerning the south of Italy. Over the last 50 years, southern Italy has been affected by similar structural changes to those in northern and central Italy and has grown in terms of income per capita. However, the gap with northern Italy has widened.

The economic history of recent decades (large increases in labour costs, a strong rise in oil prices, low interest rates, depreciation of the previous Italian currency, etc.) has brought Italy to a very substantial, rising and alarming public debt (1,430 billion in 2000 and 1,800 in 2010, approximately 120 % of GDP).

Other negative factors are known to strongly affect Italian economy and social life; between them, we must quote political corruption, an excessive welfarism, various wastes in using public funds. These phenomena varies from sporadic to deeply rooted in some areas of public administration, civil society and the private sector (Anti-Corruption High Commissioner 2007); in some cases, these phenomena are also linked to organized crime, particularly at local level and more concentrated especially in southern regions. A study of the High Commissioner for the prevention and combating of corruption in public administration (2006) has shown that public administration sectors most affected by these phenomena are those in which local officials take important economic decisions (e.g. construction planning, environment, health).

Overall, there is no doubt that these phenomena heavily influence the country's well-being and undermine the national economy.

Focusing on the primary sector issues and on the changes occurring in economic and social development, it can be stated that the low profitability of the Italian agricultural sector is due first to the growing dependence on external energy sources and secondly to strong international competition.

In addition, the Italian primary sector, even more in southern regions, is characterized by a strong land fragmentation and a lack of productive cooperation between farmers; all these features imply a low bargaining power (INEA 2011). This has serious consequences in the difficulties of challenging the well phenomenon of the Italian sounding, the most widespread and known counterfeiting and forgery of the *Made in Italy* food industries. In fact, international food piracy increasingly uses geographical names, logos, words, images, slogans and recipes that appeal to Italy to advertise and market products that have nothing to do with the national reality. This global consumer fraud causes enormous economic and image damages to the production and export of Italian food products (Eurispes-Coldiretti 2011).

Increasing international integration, albeit a critical element, also represents both the opportunity to expand markets and the possibility to tap productive resources, particularly human, within the international context. Indeed, the contribution made by immigrants (INEA 2009) employed in the sector is quite large (just under 6 % of total employment in agriculture). This employment is not exclusively configured as a dependent activity; indeed, immigrants are gradually becoming new farmers.

According to an analysis conducted in recent years by Coldiretti (the main Italian farmers organization), the Italian agricultural enterprises run by non-EU citizens increased by about 26 %, today accounting for just under 7,000, while the number of farms has decreased. We must also emphasize that the impact of the immigrant labour supply has also a negative effects (Fondazione 2009), namely on (1) competing (or sometime its perception) with Italians on internal labour market and (2) lack of immigrant contributions to the national finance system (ratio between public services immigrants use and their financial contribution to the state).

11.1.5 Social Structure

From Italian unification (1861) to the present day, the population has more than doubled from 26 million in 1861 to over 58 million in 2006. Today we are witnessing a process of ageing. In the 1970s, there was the most substantial and sudden decrease in the natural growth of the Italian population, which dropped from 7.3 to 1.5 per thousand in a single decade; at the same time, the birth rate underwent a real collapse (from 16.9 to 11.1 per thousand), while mortality remained stable (9.6 per thousand). Thus, Italy entered the phase of zero growth, and mortality began to exceed the birth rate (until 2001). Italy now ranks at the lowest level of the world fertility, far below the threshold that ensures generational change.

The new migration trends must be considered in this scenario. In particular, since the mid 1970s, Italy has become the destination of migratory flows mostly from the less developed areas of Africa, Asia and Latin America. This trend, common to other countries along the northern shores of the Mediterranean, has given rise to a growing presence of foreigners in Italy. The data of 2004 estimated their presence to be about 2.2 million, more than one half from outside the EU.

Demographic predictions on the Italian population (in the case of both constant and decreasing fertility) show a sharp decrease in the first decades of the twenty-first century, at the expense of ages traditionally related to the function of supporting society (adults) or required for its continuation (the young). The moderate decline of the population of working age, already begun in the 1990s, is expected to collapse after 2010. By contrast, the elderly appear to be destined to grow at a rate of one million for every 5 years. Regardless of immigration flows, the hypothetical picture of the 2041 census shows a less numerous population than currently (maybe even 10–15 million less), but mostly aged about 10 years, with a retiree every three inhabitants and three over 74 for every two young people under 15, with a death–birth ratio of five to two (assuming constant fertility).

11.1.6 Cultural and Environmental Goods

Cultural heritage represents a very important resource for the economic, cultural and social development of Italy. Archaeological, historical, artistic, environmental and landscape, archival and library assets belong to Italian cultural heritage (Article 2, DLg 2004/no. 42, Code of cultural heritage and landscape 2004). In Italy, there is about 40 % of the world's artistic heritage, more than 47 cities and sites classified by UNESCO as world heritage sites. Currently, Italy is the country with the highest number of sites included in the list of assets (www.UNESCO.org), followed by Spain (43 sites) and China (41 sites).

Among the environmental assets, Italian agricultural landscapes and protected areas must be included. Italy has a rich landscape and environmental heritage, rooted in the extreme variety of the landscape and its high-value products (oil, wine, vegetables, bread, pasta, cheese). The agricultural landscape in Italy is the result of a series of historical situations, or rather a convergence of events which formed the history of an area by shaping, adding, subtracting, building and destroying the surface (Sereni 1976).

The protected areas are also part of the environmental heritage and today in Italy represent 9.6 % of the country, an area roughly equal to that of Belgium. The 23 protected areas include national parks, which are associated with regional parks, nature reserves and marine reserves, including nearly three million hectares of sea surface.

11.1.7 Tourism

In European cultures, the wealth and diversity of cultural heritage, landscape and environment have made Italy the favourite destination of travel for centuries. We can still find historical signs of the ancient religious pilgrimage throughout the Middle Ages that crossed the country on its way to Rome. From the seventeenth century onward, Italy became a privileged tourist destination of the *Grand Tour* of the young European aristocracy.

Despite having about 40 % of the world's artistic heritage, Italy is only the fifth tourist destination in the world (2004), overtaken by France, United States and, recently, by Spain and China. In recent years, the tourist flow has stood at around 38 million arrivals (77 million in France, 53 in Spain, 46 in the US, 42 in China), while it is growing in other countries, where forward-thinking policies of tourism development have been implemented.

In Italy, there is a growing interest on the holiday farms which is a successful business solution for its ability to utilize both farm resources and the landscape resource around the farm. Over the past 10 years, the number of holiday farms in Italy has almost doubled. This has been very important because it fuel the engine of food tourism that is an increasingly important component of the *Made in Italy* tourism.

The expected trend is a further growth of holiday farm tourism activities and its outcoming income as a source of supplementary economic resource. It is also expected that this tourism activity may become a tool for a different, more profitable, orientation of agricultural production for farms (MiPAF 2010).

Generally, the regions most visited by foreign tourists (2003) are Veneto (more than 6.8 million arrivals per year), Tuscany (4.8 million), Lazio (4.7 million) and Trentino Alto Adige (3.8 million). The added value of tourism as a percentage of national GDP is 5.4 % (which is higher than that of agriculture), but if the total weight of the tourism sector is considered, the percentage rises to 12 % of GDP.

11.1.8 The Italy of Natural Risks

Italy is very much affected by natural hazards affecting the social and economic life of the country. As said, this section highlights only the main natural risks specific to Italy (leaving aside other environmental issues of great global importance).

11.1.8.1 Seismic Risk

Most of Italy is affected by earthquakes: the corrugation resulting from the pressure of the African against the Eurasian plate. These movements create a slow progressive accumulation of stresses in the earth's crust, which can episodically trigger earthquakes of great intensity. The active faults along the peninsula are numerous. The areas of high seismic risk, where earthquakes have often caused many casualties and extensive damage, are in the regions of Friuli, Campania, Basilicata, Calabria and Sicily. Suffice it to mention the earthquakes of Messina in 1908 (about 90,000 deaths), Avezzano in 1915 (approximately 32,610 victims), Belice Valley in 1968 (231 victims, a 1,000 people injured, 50,000 homeless), Friuli in 1976 (965 dead, over 2,000 injured, 90,000 homeless), the Irpinia area in 1980 (2,914 victims, more than 50,000 injured, 150,000 homeless).

11.1.8.2 Volcanic Risk

The movements of African and Eurasian plates are also the main cause of Italian volcanic phenomena. Breaking along large cracks, the lithosphere allows magma to rise, giving rise to eruptions. The most active Italian volcanoes are Etna, the Aeolian Arc, Vesuvius and the Phlegraean Fields. Up to 200,000 years ago, there were also active volcanoes in Tuscany (Monte Amiata). Vesuvius is undoubtedly the most hazardous volcano if it should recover full activity, given the densely populated towns (almost one million inhabitants) concentrated on its lower slopes. Etna is the largest active volcano in Europe, with a perimeter of more than 200 km and a total area of about 1,600 km^2.

11.1.8.3 Hydrogeological Risk

One-sixth of Italy is exposed to a high degree of hydrogeological instability. There are about 14,000 areas at risk of landslides, located mostly on the Eastern Apennine ridge and in the Alps. The Basilicata region, with an average of 27 landslide areas per 100 km^2, is the most uneven region of Italy, followed by Molise (12), Emilia-Romagna (11) and Calabria (9). The national average is five landslides per 100 km^2.

Since 1950, there have been nearly 300 serious floods in Italy, causing over 1,000 deaths, 300,000 homeless and millions of euros in damage. Campania, Veneto, Emilia-Romagna, Liguria and Piemonte are the most seriously affected regions.

Another risk factor is both the density and poor management of dams. In Italy, there are approximately 8,350 dams, collecting 13 billion cubic metres of water, only 800 of which are now monitored. It has been estimated that one-third of the largest dams is located in seismic areas and that in Italy, there are at least 1,000 small hazardous dams. Accidents, defects in design and operation have resulted in disasters such as that in the Vajont Pass in Belluno (1963, 1,910 deaths) and the Val di Stava, in Trentino (1985, 266 victims).

11.1.8.4 Climate Risk

In Italy, arid areas are present especially in the south and the islands, where groundwater resources are scarcer and rainfall less frequent (especially in summer, when water demand is greater). This situation is aggravated by the substantial wastage in the distribution of drinking water: it is estimated that 30 % of drinking water is lost before it reaches the consumer. A higher percentage is lost in the case of irrigation water from aqueducts. Water management is very fragmented and sometimes inefficient. The water emergency is made even more severe by progressive groundwater pollution.

11.1.9 Contribution of Soil Science to Italy's Main Potential and Limitations

11.1.9.1 Overview

The relevant framework underlying the potential contributions of soil science to the country's needs with an emphasis on enhancing Italy's potential while mitigating its limitations is reported in Table 11.1 and sketched in Fig. 11.1.

Table 11.1 Main potential and limitations of Italy with respect to soil science contribution

Main potential of Italy	Derived information	Relevant framework enabling soil science contributions	Examples of soil science contributions given in this chapter
Political, economic and social stability	Great potential for long-term agricultural and environmental policy	The compliance system of the new common agricultural policy (e.g. fishler reform)	Empower the environmental role of soil management (agriculture and forestry section)
Wealth of cultural and environmental heritage and great diversity of physical landscape	Great potential for a wide variety of primary products	Legislation on quality product labelling (DOC, DOCG) and its relationship with the landscape and sustainable management	Viticulture zoning; oliviculture zoning (agriculture and forestry section)
	Cultural and environmental tourism (artistic, archaeological and environmental)	Sustainable use of landscape	Soil science to better preserve and manage archaeological sites and natural heritage (in archaeology and natural heritage section)
	Opportunities for tourism in the agricultural landscape: cultural and gastronomic	Educational, tourist and landscape conservation	
		Identification, conservation and protection of pedosites of special interest (protected areas)	
Food quality and "made in Italy"	High potential for producing and marketing high quality food; fraud issues *re* food origin	Legislation on "made in Italy" food products and fraud	Traceability with respect to the origin of food (in agriculture and forestry section)
Main limitations of Italy	Derived information	Relevant framework enabling soil science contributions	Examples of soil science contributions given in this chapter
Public debt	Few resources for research and large cultural investment	Development of sustainable approaches and methods for optimized management of agricultural and forest systems	Integrated landscape management (integrated landscape management section)
Land fragmentation	Difficulty in the production management of the landscape	Optimization of soil-based production processes	Soil-based DSS, precision agriculture (in agriculture and forestry and integrated landscape management sections)
Decrease in active population in rural areas	Limited qualified human resources in agricultural and forestry management	Technical assistance to companies	
	Immigrants as new farmers		
	Ageing of farmers		
Dependence by external energy sources	Production at high costs	Optimization of production processes	
Rural fragmentation by urban soil sealing	Difficult in agriculture and environmentally based landscape management	Development of soil-based approaches to assist better landscape management	Land and soil fragmentation maps (in landscape management section)
Natural risks: high frequency of landslide and floods	High environmental and social costs	Better to assist risk management and risk zoning	Insert hydropedological parameters in the modelling of landslide and floods risks

It is important to emphasize that here we do not aim to provide neither an exhaustive nor detailed analysis of country potential and limitations but just a framework of the key issues relevant for soil science.

For instance political corruption, excessive welfarism and various wastes in using public funds are important issues in Italy determining many negative consequences; nevertheless we did not consider that soil science could play a role (or is specifically affected) on these issues, and then they were not inserted in the table.

On the basis of country potential and constraints (as described above) in this chapter, we provide a series of tables addressing the analysis of new (and sometimes old but still relevant) needs concerning different key issues (e.g. archaeology, spatial urban planning, agriculture, hydrogeological risks, etc.) where contributions by soil scientists can produce major improvements.

We identified the following potential: (1) the political, economic and social stability which enable to undertake long-term agricultural and environmental policy, (2) the wealth of cultural and environmental heritage (the so-called *Bel Paese*) and the great diversity of the physical landscape enabling both tourism and wide variety of primary productions, (3) high potential in producing high quality "made in Italy" food.

On the other side, we identified limitations based on both socio-economical issues and natural risks issues. Between them we identified the followings: (1) the high public debt which strongly inhibited large national investments on research but it may create an opportunity for the need of a sustainable and optimized development and also for degrowth policies; (2) land fragmentation (also by urban sealing) which induce a difficulty in agriculture management; (3) decrease in active population in rural areas determining a limited qualified human resource for landscape management; (4) dependence by external energy sources negatively affecting the cost of production; (5) the high frequency of landslides and floods determining high environmental and social costs.

Our analysis demonstrates that future soil science and pedology can and must relate to subject areas which are traditionally far removed, such as archaeology, integrated landscape management (including city planning), decision support systems (DSS), traceability with respect to the origin of food.

The research perspectives taken into account are all in some way connected to the fundamental aspects of Italy's cultural, social and economic development. Where possible, using the methods and techniques mentioned, we endeavour to provide short-term answers (whose importance is given in the last section of this chapter) and/or to look at costs (and sustainability).

11.1.10 New Tools in Soil Science for New Challenges

Today soil science can largely benefit from the use of newly available technical tools which have indeed increased the potential contribution of soil science to society. For the sake of readability of this chapter (avoiding redundant cross readings) in this section, we list and briefly describe some of these tools to which we shall refer in the following sections. This chapter does not aim to describe these tools in detail but to highlight those tools that enable the pedo-environments to be studied from a quantitative and functional point of view, and hence with a strong potential for our society-oriented applications. They include:

1. Simulation models (mathematical model of a system or process that includes key inputs which affect it and the corresponding outputs that are affected by it): from the most simple and static (empirical), as the framework for land evaluation proposed by FAO (1976, 2007), to the more complex and dynamic (physically based), allowing qualitative and quantitative predictions on the behaviour of soil–water-climate scenarios in different agro-environments (Rossiter 2003);
2. Digital elevation models (DEM): they are digital models of the territory, which constitute a vital source of information for regional studies, both on large and small scales. The DEM provides direct information on the landscape morphology (e.g. elevation, aspect, etc.) and may be used for specific analyses to obtain direct or derived data (e.g. concave and convex slopes, etc.). Thanks to high-precision technologies and detailed data acquisition (i.e. LIDAR detection), DEMs are being increasingly used in agriculture and soil science for in-depth studies (i.e. precision farming, viticultural zoning, etc.);
3. Techniques for the spatial analysis of georeferenced data: there are several constantly evolving techniques, allowing properties to be estimated in locations without measurements being made. They range from classical statistical techniques such as environmental correlation, to geostatistics and artificial neural networks (McBratney et al. 1991, 2000; Gessler et al. 1995; Goovaerts 1999; Zhu 2000). Methods to spatialize point data often require continuous auxiliary information to be used as environmental covariates. This is derived from DEM processing (Odeh et al. 1994), from signals acquired by satellite sensors (Odeh and McBratney 2000) or proximal sensors;
4. Low-cost estimation data techniques: simulation models require environmental input data (climate and land) to operate. Examples of input data are soil physical and chemical properties such as texture, density, *N* content

and hydraulic properties (retention and hydraulic conductivity functions), and climatic data such as rainfall and daily temperatures, cultivation parameters (for models that simulate crop growth) as the leaf area index, K_c (crop coefficient), development stage (DVS), etc. Collection and measurement of environmental data, both in terms of input data for models and information for area characterization, represent a very expensive phase in regional studies. For this reason, in recent years, soil scientists have taken great interest in data estimation techniques. Among these, the pedofunctions (Van Alphen et al. 2001; Sonneveld et al. 2003) to estimate hydraulic parameters are the most widely used in hydropedology;

5. Geographical information systems (GIS): shaped and georeferenced continuous information layers, whether the result of direct measurements or estimates, are stored and managed in a GIS environment. GIS allow us to (a) visualize data spatialized in the form of area thematic maps (layers), (b) cross maps between them, (c) combine them and derive additional information. Then GIS systems are essential for applied soil science studies;
6. Remote sensing: in soil science, simple aerial photographs from space have provided an important tool for detecting visible boundaries of soil types. More recently, remote sensing has been able to provide very important additional physical data such as spectral signatures. Generally, large-scale surveys require airborne methods and small- to medium-scale surveys depend on the use of satellite data. Spatial dynamic processes like erosion and soil moisture variation require image acquisition using multitemporal techniques;
7. Proximal sensing: this involves the use of non-destructive optical, geophysical, electrochemical, mathematical and statistical methods. In soil science, proximal soil sensing (PSS) has become a multidisciplinary area of study that aims to develop field-based techniques for collecting information on the soil from close by, or within, the soil. Among these techniques, those geophysical are very commonly used. These are based on the measurement of properties such as soil electrical conductivity by electromagnetic induction (EMI) (Earl et al. 2003). The most common geophysical techniques are as follows: (1) magnetic survey, very commonly used in archaeology, in which variations or anomalies are detected by measuring the magnetic susceptibility of the subsoil; (2) ground penetrating radar (GPR) analysis and (3) automatic resistivity profiler (ARP) techniques, which allow continuous, high-resolution maps of soil electrical conductivity to be produced, correlated to soil water content or indirectly to properties such as texture, density and soil solution pH.

11.2 Emerging Soil Issues

11.2.1 Spatial Planning of the Landscape

11.2.1.1 The Italian Scenario

The term "spatial planning" refers to a tool used by governments and public administrations to steer the distribution of population and its activities in a geographical area. The first definition adopted by the public sector in Europe comes from the European Regional Spatial Planning Charter (Torremolinos Charter), adopted by the European Conference of Ministers responsible for Regional Planning:

> Regional/spatial planning gives geographical expression to the economic, social, cultural and ecological policies of society. It is at the same time a scientific discipline, an administrative technique and a policy developed as an interdisciplinary and comprehensive approach directed towards a balanced regional development and the physical organisation of space according to an overall strategy (Council of Europe 1984).

Spatial planning is typically applied on local, regional, national and international levels and includes regional planning, urban planning, land use planning and environmental planning. It is also part of a broader framework of development policies that, since 1999, with the approval of the "European Spatial Development Perspective" (European Commission—ESDP 1999), have begun to promote new strategies aiming to integrate economic, social, cultural and environmental components for area development. Among the general principles underlying the objectives and policies set out by the ESDP, designed to ensure sustainable and balanced development, respecting the specific characteristics of an area, we find:

- balanced and polycentric urban development, new urban–rural links;
- enhancement and proper management of natural and cultural heritage.

It is clear that these principles and objectives are interrelated, especially when referring to soil resources. In this context, the most recent guidelines for protection, management and development of landscapes (European Landscape Convention 2000) and the environment (Environmental Regulations 2006) show that, to improve the protection, recovery, rehabilitation and enhancement of an area, it is necessary to base planning decisions on both environmental components and the assessment of their interrelations. Particular importance must be placed in the relationship of the physical/biotic environment and the historical/cultural aesthetic environment. This approach lends particular importance to soil, which represents one of the "natural structuring factors" of the land and the environment, the principal "place of the interrelationships and trade" between the environmental components and, finally,

Table 11.2 New (and old) country needs and potential contribution by soil scientists with respect to spatial planning

Emerging soil issues	Needs		Response to needs: potential contribution by soil science		
	New (and old) needs	Reason for this need	Aim of the contribution	Potential tools to be employed	Relevant selected bibliography
Spatial planning of landscapes Sect. 11.2.1	Integrate existing regional/provincial/municipal planning tools (PTR, PPR, PTCP, PUC) with soil information concerning its potential and its threats	• Ameliorate landscape conservation and management	Include soil information to: • Assess land degradation	• Development of new methods of spatial analysis	Lehmann et al. (2008), Lehmann and Stahr (2010)
		• Improve urban policies in relation to impacts on the environment	• Assess the fragmentation of rural areas and their soils	• Development of methods of economic evaluation of soil functions	Vrscaj et al. 2008
			• Evaluate soil sealing dynamics	• Implementation of new ideas for implementing soil information in case studies	
	Introduce new planning and management tools: • Soil Protection Plans	As a resource, soil is as important as water and should be granted a similar importance in planning tools	Provide soil knowledge supports ready for use by land planners		
	• Soil Management Plans				
	• Soil-based decision support systems				

the link between environmental factors and human activities (European Parliament 2001—Directive 2001/42/EC).

Despite these general guidelines, including legislation, in the real life of land use planning, assessment and evaluation of the "soil", as an environmental component, is often very generic or even absent. Moreover, while for other environmental factors—such as water—mapping and measures to protect the resource are required for specific sector plans (e.g. Water Protection Plans), this does not occur with regard to soil. This situation is clearly due to the absence of an approved "Framework Directive for Soil Protection", which is still in its proposal stage (COM 2006 232) and remains under consideration by Member States without any guarantee of its approval. Indeed, the situation about water is very different: under Community and national law regulations are already in force, and it is widely considered in terms of resource to be protected (European Parliament 2000; Italian Legislative Decree 11/05/1999 n. 152) and of flood risk (European Parliament 2007—Directive 2007/60/EC; Italian Legislative Decree 23/02/2010 n. 49).

The cognitive activity to create a soil map of Italy proceeds through studies coordinated at national and inter-regional level (e.g. MiPAF 1999—National Soil Map Project) see Chaps. 2 and 4, and is supported by projects related to specific issues (Italian Ministry for the Environment, Land and Sea 2007). In the absence of a binding regulatory framework, the use of soil information in spatial planning is left to the sensitivity of the planners themselves. Examples of soil studies geared to land planning are reported below.

The 2006 Landscape Plan of Sardinia (Regione Sardegna 2006) includes the Soil Heritage category in the technical standards for the implementation of the plan "sites whose landscaping value is recognized for their pedological features". With respect to these, specific value and peculiarities attributes are recognized in relation to scientific aspects such as palaeo-environmental evidence, rarity and representativeness in the environment of Sardinia. These sites are then placed in the more general "areas of further natural interest", whose detailed mapping is left to sectoral and local planning instruments.

In the proposed Territorial Coordination Plan of the Province (PTCP) of Naples (Provincia di Napoli 2007), soil is recognized as a "constitutive element of the province" and, as such, its structuring factor. Following this criteria, in this plan, the soil information is not really focused on the "pedological singularity" but rather on using soil as a component of a broader scenario of interaction between human activities and natural processes. For the sake of this view, the following soil themes were employed: (1) map of potential soil fertility, (2) map of soil degradation risk, (3) map of the rural and open land fragmentation.

At the municipal level, there are also some examples of action to address specific issues related to soil use. In order to limit soil sealing, for example, the town of Bolzano has included, in the Municipal Building regulations, the Building Impact Reduction (RIE) index: this index is applied to all processing operations of the municipal building and town planning, so as to certify the quality of the works in terms of soil permeability and public greenery (Bolzano—Municipal Council Resolution 11/2004).

However, the functionality of urban soils is often neglected in land use planning despite the fact that biomass production, flood prevention and ground water recharge are essential contributions of natural and anthropogenic urban soils for the livelihood of cities. Even less recognized but important are contributions of urban soils for sequestration of dust and carbon as well as their contribution to providing a comfortable urban climate by cooling and humidifying. Therefore, the poor recognition of ecological functions of natural and anthropogenic urban soils by decision makers and spatial planners is clearly contradictory to their significance for environmental quality and hazard protection in cities (Lehmann 2010).

These and other examples show that the pedological approach in land planning does not set out to ensure the scientific correctness of soil property definition and soil classification. In reality, it aims to make pedological data "readable" and "available" to planning experts.

11.2.1.2 New Needs and Potential Contribution from Soil Scientists

Table 11.2 lists the main "needs" (relevant to soil science) of spatial planners and potential "responses" from soil scientists. We focused on the following needs:

Integrate existing Regional/Provincial/Municipal planning tools (PTR, PPR, PTCP, PUC) with soil information concerning its potential and its threats.

It is well known that soil performs several functions (ecological, biological, productive, landscape/culture, nature), with qualities differing in importance depending on the roles of the uses and planning requirements, thus making it difficult to carry out exhaustive assessments.

According to some authors (Vrscaj et al. 2008), the main questions which must be answered regarding the quality assessment of a particular soil are as follows: (1) what function is performing the soil? (2) what functions could it perform? (3) are these the functions that we want it to perform? (4) is this the best use of the soil?

Answering these questions requires both further knowledge of the relationship between soil properties and their functions, and the development of advanced methods for the evaluation of soils used for different purposes in landscape planning. Several attempts, also in the recent past, have been made to introduce the subject of soil and evaluate soil functionality in urban planning (Vrscaj et al. 2008; TUSEC-IP 2006; Lehmann et al. 2008; Lehmann and Stahr 2010), although the effects of such works are still scantily known poor in land use planning. In addition to standard urban policy issues such as those referring to the new urban settings, soil science can also contribute to steer policy and actions to protect and manage soils and to specific interventions to reduce the risk of land degradation.

Introducing new tools for planning and management

Up till now in Italy, there have been few examples of soil information used by planners in their planning activity: most such examples refer to the spatial knowledge of soil productivity potential. The required information is thus limited only to primary productivity and is certainly inadequate to address many other environmental challenges required by spatial planning. However, it should be emphasized that at present, there are few tools which have been adequately tested and are ready to use by spatial planners, which make it possible to implement other soil ecosystem functions in landscape planning. In this context

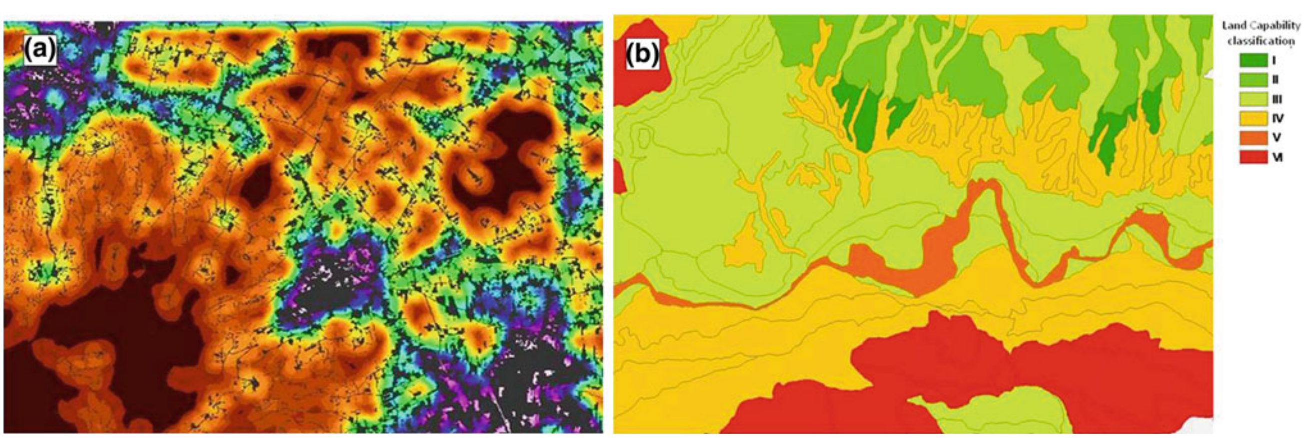

Fig. 11.3 Examples of soil-related maps relevant to spatial planning: **a** land fragmentation, **b** land capability

and in line with typical Italian area planning documentation, we believe that pedologists and soil scientists should produce at least two new key documents: soil protection plans and soil management plans.

The plans for soil protection should highlight the need to protect the soil as an important natural resource, both in terms of productive potential and with respect to all other ecosystem functions. Moreover, these plans should also contribute to define the areas with the highest rural integrity (low urban fragmentation—brown colour in Fig. 11.3a). Indeed, the land management plans should define “iso-areas” with similar management problems (example land capability classes in Fig. 11.3b); these areas are where specific legislation could be applied by setting specific constraints (e.g. soil mapping units with hydromorphic features cannot be used for specific activities).

In all cases, the absolute need of major research work (still to be set up) to evaluate, quantify and manage the different functions of soils is absolutely clear.

11.2.2 Archaeology and Natural Heritage

11.2.2.1 The Italian Scenario for Archaeology

For centuries, our archaeological heritage has played a fundamental role in the representation of our country, starting with Rome and the classical antiquities. The archaeological heritage in Italy is very substantial: it is characterized by cultural variety and a dense network of sites throughout the country, often sited in landscape contexts of high quality and value. There are about 5,668 bounded archaeological real estate, in addition to museums, archaeological sites, about 317 underwater archaeological sites.

Pedology can make a contribution to the knowledge, management, protection and dissemination of such a rich heritage.

First of all, *soil should be considered cultural heritage*. In the soil, there are the roots of human existence, in the soil many aspects of rural life occur and urban cultures develop. The soil is a cultural box. It contains archaeological remains, artefacts and ecofacts, whose properties and state of preservation depend on the soil. The soil is evidence of past events (it comes from a complex interaction of physical, chemical and biological processes acting over time on the rock and sediment).

Further, the central concept of modern archaeology consists of human–environment interactions. Of primary importance are the geographical and physical conditions surrounding the archaeological site for the choice of subsistence strategies, economic organization and community life in general, of which the archaeological site is one example. On the other hand, environmental factors have played a key role in processes of site formation both during human presence and after abandonment, when the sites were subject to erosion, sediment and pedogenesis.

11.2.2.2 The Italian Natural Heritage Scenario

Our country has an important and unique natural heritage. According to a recent survey of the Ministry for the Environment, Land and Sea (October 2011—www.miniambiente.it) more than 15 million hectares of land in Italy are classified as protected areas, sites of Community importance or within the network of Natura 2000. In particular (October 2011—www.miniambiente.it), there are 601 special protection areas (4,379,683 ha; 14.5 % in all), 2,287 sites of Community importance (4,770,850 ha; 15.8 %) and 2,564 Natura 2000 sites (6,316,664 ha; 21 %).

About half of the land area in Italy is, therefore, considered to be part of our natural heritage that includes parks and natural reserves, national or regional. Natural heritage nationwide has a huge environmental and social value. This is testified by the criteria used for classification of natural areas, parks and reserves that are defined by an Italian law dating back to 1991 (Law 324/91). These criteria are based on concepts such as areas of natural interest, the presence of integral ecosystems or geological, geomorphological or biological formations of national interest, the presence of important species of flora and fauna, the presence of recreational or educational features, etc.

Under conditions of particular ecosystem vulnerability, natural areas or parks are classified as “protected”. In this issue, we believe that soil science can contribute to protection, sound management and social awareness of this essential asset. Soil is indeed an integral part of terrestrial natural ecosystems and it affects their delicate energy balance. Knowing about soils (characteristics, potentials and limits) present in natural areas and reserves can be very important in applying the most suitable strategies for the sustainable management of such areas.

11.2.2.3 New Needs and the Potential Contribution of Soil Scientists

Table 11.3 lists the “demands” from archaeology and natural heritage stakeholders and potential “responses” to such demands by soil scientists. These contributions are framed to improve analysis, conservation, reporting and displays of archaeological sites. We chose the following to focus on:

Prospecting and shallow diagnostics: *Geophysical applications and Digital Terrain Models*

The term *archaeological recognition* (or *prospecting*) includes a range of techniques and applications required to identify archaeological evidence that has left more or less substantial traces on the ground. The prospecting techniques are aimed at the identification, mapping (spatial distribution), knowledge and protection of the archaeological heritage. As an element of archaeological reconnaissance, soil

Table 11.3 New (and old) country needs and potential contribution by soil scientists with respect to archaeology and natural heritage

Emerging soil issues	Needs		Response to needs: potential contribution of soil science		
	New (and old) needs	Reason for this need	Aim of the contribution	Potential tools to be employed	Relevant selected bibliography
Archaeology and natural heritage Sect. 11.2.2	Improve *prospecting methods* and shallow diagnostics	Identify artefacts and archaeological sites and their spatial distribution	Provide: • Rapid responses	• Geophysical application on soils (magnetic, GPR, ARP)	
			• Spatial distribution by means of high quality maps	• Digital elevation models	
			• Instruments and approaches applicable to broad spatial scales (tens of hectares)		
			• Use of non-invasive instruments		
			• 3D visualization for DEM tool diffusion		
	Create suitable instruments for the protection and management of archaeological heritage	Many areas of archaeological interest and high potential of archaeological risk in Italy	• Provide data and information to draw up maps of potential or archaeological risk	• Soil maps	
			• Plan and optimize archaeological operations according to soil features	• Land evaluation	
			• Contribute to the environmental analysis and interpretation of the archaeological site		
	Identify indicators of human presence and activities (during excavation)	• Optimize excavation operations • Define the functional spaces inside the archaeological site	Provide fast and easy-to-use field techniques for site search, activity areas and their spatial distribution;	P soil analysis (*with portable field techniques*)	
	Archaeological data interpretation, human and natural units and microunits	Correct interpretation of archaeological data and site reconstruction	Provide methods of analysis for undisturbed microcosms (inclusions, fragments, microstructures, etc.)	Soil micromorphology (thin sections)	Courty et al. (1989) Macphail et al. 1997 etc.
	Contribution to natural heritage conservation and management	Better natural resource use and conservation	• Strengthen the use and management of natural resources by using soil information.	• Aid in planning natural paths and conservation management	
			• Soil monolith exhibition at natural heritage sites	• Soil monoliths	

geophysical prospecting (Campana et al. 2009) allows the presence of underground structures to be identified rapidly and over large areas. The acquisition and processing of high-resolution data can be used to draw maps of the spatial distribution of finds and archaeological structures. Excellent results are achieved in the field of prospecting with integrated approaches between geophysical and remote sensing applications, both non-invasive and destructive (Gallo et al. 2009; Ciminale et al. 2009). Among the most widely used are as follows: (1) magnetic prospecting, (2) surveys with GPR (Piro et al. 2003, 2007; Gaffney et al. 2004; Goodman et al. 2004; Goodman and Piro 2009), (3) the ARP method—*Automatic Resistivity Profiler* (Campana et al. 2009).

The use of DEM is a relatively new method of archaeological applications among the shallow diagnostics. DEM, particularly if high-resolution DEMs (derived from remotely sensed LiDAR data), have provided archaeologists with the opportunity to study the area at a scale not previously possible (tens of hectares) and with great precision by identifying even the smallest irregularity in elevations, often a symptom of structures or human intervention (buried structures, sets of agricultural terraces in the past), (McCoy et al. 2011; Salzotti and Valenti 2003).

Creating suitable instruments for protecting and managing archaeological heritage

The numerous areas of archaeological interest in Italy are often situated on productive soils and thus are still attractive areas for cultivation and on highly urbanized land or that suitable for building. The high risk to archaeological heritage in Italy poses the problem of protecting and managing such heritage through appropriate approaches. Mapping tools such as the *Map of Archaeological Potential* or *Map of Archaeological Risk* meet the need to provide information on archaeological potential or areas at risk, allowing us to hypothesize the presence of archaeological sites even where no excavations have yet been made and to plan the necessary interventions properly and in advance. Such maps are tools that the planner should take into account in drawing up urban plans. Soil maps can make a major contribution both in the design phase of archaeological prospecting and in the analysis and interpretation of archaeological sites (Cremaschi and Rodolfi 1991).

In the reconnaissance planning phase, pedological characteristics can provide information about the primary or secondary position of the finds and their state of preservation.

The properties of the soil in which finds may lie can determine the conditions for stability, erosion or accumulation of past and present and thus allow us to predict the likelihood that it still contains relics of a specific time period. In summary, soil maps allow us to "read" the landscape and its diachronic features, identifying the age of ancient surfaces, existing or extinct geomorphological and pedological processes and to highlight certain landscape traits determined by humans (drainage, ducts, etc.). Such soil map characteristics are equally useful in the analysis and interpretation of the archaeological site as they can integrate the archaeological site in the environment that surrounds it.

Soil maps can be used successfully to apply *Land Evaluation* techniques in archaeological studies. While considering the limitations concerning the application of land evaluation approaches in a past context, evaluation of soil suitability can provide explanations about specific settlement strategies of the past and therefore provide guidance in the archaeological prospecting process (Cremaschi 1990). Land evaluation techniques have been successfully used to evaluate the productivity of certain crops in specific areas of ancient civilizations and historical periods (Louwagie et al. 2006).

Identify indicators of human presence and activities

Archaeological research has always been interested in the identification of indicators of human activities in several ancient communities. Definition of these indicators allows targeted excavation and supports and validates otherwise weak interpretations. Phosphorus is the only persistent element to be a sensitive indicator of human presence. The addition of phosphorus in the soil comes from human and animal waste, from the presence of burials or cattle and soil fertilization by organic compounds, etc. Thanks to these characteristics analysis of phosphorus in the soil has long been a subject of interest in archaeological research.

In this section, we examine the techniques of field determination of phosphorus. Interest in these approaches lies in the potential ability to use phosphorus levels in the soil for field research of archaeological sites and to map areas of activities (Holliday and Gartner 2007). An important step towards this goal was the development of the spot test or ring test (or "Gundlach method"—Gundlach 1961) for a quick evaluation of phosphorus levels at archaeological sites.

The effectiveness of the method lies in its simplicity and usefulness as a field survey (Bjelajac et al. 1996; Lippi 1988).

Archaeological data interpretation, human and natural features and microfeatures

In performing modern stratigraphic excavation, archaeology is called upon to interpret the complex issues raised by the study of the excavation data, anthropogenic and natural units (and micro units) at the same time. Unlike the approaches mentioned so far, the use of soil micromorphology in archaeology is neither rapid nor easy to apply, especially over large areas.

Soil micromorphology is shown in the present context for the unique contribution that it is able to provide for archaeological research. The experience shared by many experts in this field indicates that soil micromorphology is the most suitable technique to solve the complex problems posed by the study of anthropogenic and natural units (Courty et al. 1989). To date, micromorphological surveying of archaeological soils has produced excellent results in the identification of inclusions and finds, microfabrics, structures and pores typical of human presence and of specific human activities from the past. Plant and animal residues (bones, phytoliths, coprolites), coal fragments, building materials and artefacts (bricks, pottery, flints, metals), not visible to the naked eye, found in anthropogenic deposits are connected with human waste and activities on occupied lands (Courty et al. 1989; Macphail et al. 1997).

Contribution to natural heritage conservation and management

Italian natural heritage occupies about 50 % of the country and should be preserved because it is an invaluable source of biological diversity (*species and habitats*) as well as of historical and architectural diversity. In this context, soil science could certainly contribute to better conservation and management of natural areas and support the knowledge–education issue. This is because soil science is one of the main components of landscape ecology (Towers et al. 2002): as soils act as integrators of other environmental variables, soil knowledge and management inevitably affect the conservation of natural resources. It is known that soils and natural flora are intrinsically intertwined and often rare plant species are dependent on very specific soil chemical and hydrological properties. For instance, Elam Caitlin et al. (2009) showed that the occurrences of two rare plant species, a species-rich flora, ten natural plant community types and an assemblage of wet and dry soils were objective factors justifying the recognition of a significant Natural Area in North Carolina.

We believe that soil science can provide a major contribution to managing protected natural areas and parks. This must include sustainable landscape management for maintaining the delicate balance of these ecosystems, identification of the best natural footpaths (also useful to wildlife), linkage between soils and the local flora and fauna to enhance the awareness of the population concerning the value of the land where they live, and soil monolith exhibitions to enable people to have a "touch" and a closer look at the soils that they are walking over.

11.2.3 Agriculture and Forestry

11.2.3.1 The Italian Scenario for Agriculture

Soil is a resource of key importance for primary productivity and plays a key role in the biochemical and physical processes of most environmental ecosystems (biodegradation, water balance, solute fate, biodiversity). Hence, its proper management represents the only way ahead for agriculture to combine and reach environmental sustainability and economic competitiveness. These two objectives have by now become an integral part of the Common Agricultural Policy COM 2006/231 EU Soil Thematic Strategy, especially since the multifunctional character of agriculture has been recognized.

According to a survey of the National Institute of Agricultural Economics of Italy (2011) on Agriculture, Environment and Society, the Italian agricultural sector is characterized by very diversified situations caused by the changes in land use in recent decades (reduction in utilized agricultural area, decrease in grazing land, increase in afforestation) and by the pressure from urbanization (especially in lowland areas). Moreover, despite important changes in agricultural practices, which has in fact led a reduction in the use of external inputs (fertilizer and pesticides), an increase in production intensity has been observed.

A great interest has also been observed in alternative agricultural approaches (organic farming, integrated farming, conservation farming and precision farming), which use the new knowledge and technological innovation to reduce the misuse of natural resources and external inputs. In this context, it may be noted that the number of multifunctional farms has increased in recent years. The success of these farms is due to the combination of the traditional role of agricultural farms with new sources of income like production of renewable energy, agro-kindergartens and aquaculture. According to the sixth general census of agriculture realized in 2011 by the Italian National Statistics Institute (ISTAT), an increase was noted in farms participation in local initiatives (e.g. proper water management, protection of communication networks), as well as those initiatives involving the public sector. These increments regard both horizontal and vertical relations between businesses, which involve subjects upstream and downstream of the manufacturer (ISTAT). In addition, the agricultural sector is subjected to adaptations due to climate change which require a rethinking of production models. Agriculture is performing its environmental duties, helping to reduce the emission of greenhouse gases through the improvement of the use efficiency of agricultural resources (reduction in fertilizer and improving of schedules, better water resource use, better crop management) and a change in land use from agriculture to forestry.

> As regards farm structures, Italian agriculture shows a strong family-based character: direct family-owned farms are in a clear majority. At present there are about 1,600,000 farms in Italy with a utilised agricultural area (UAA) of altogether 12.7 million hectares and employment amounting to 1.3 million labour units (INEA, Italian agriculture 2008). Compared with the previous surveys (2000), there has been a reduction of about 32 % in farm numbers, which has been more pronounced in the north.

According to preliminary data from the sixth general census of agriculture (ISTAT 2011), farms with less than one hectare of UAA decreased by 50.6 % in the last decade. *At the same time, it is estimated that there has been a slight increase in average farm size, rising* from 5.5 to 7.9 ha of UAA (+44.4 %). *There are, therefore, some signs of dynamism, indicating a gradual, though slow, process of strengthening of farm structures.* Moreover, Sardinia shows the highest average farm size (19.2 ha of UAA per farm), exceeding Lombardy (18.4 ha); the lowest values are recorded in Liguria (2.1 ha), Campania and Calabria (4 ha) and Puglia region (4.7 ha). All regions in southern Italy are of below average size compared with the national average, with the exception of Basilicata (9.9 ha of UAA per farm). In Italy, 54.5 % of farms are located in just five of the twenty administrative regions (Puglia, with the highest number of farms; Sicilia; Calabria; Campania and Veneto).

Parallel to the changes that have affected land use and production dynamics, the recent census records further interesting changes. Compared to the past, the land structure is more flexible, with an increase in land ownership forms (more land rented). At the same time, the average age of farm managers has fallen (there has been an increase in farm managers below 30 years of age), and the average education level has risen, as has the use of technology (increasing numbers of farms have a personal computer, a website, and use the Net to communicate with public administration).

Along with the short description of the agriculture scenario for Italy, here we must report the importance of Italian food industry (also named agro-industry) which refer to industrial activity dealing with the supply, processing and distribution of farm products (or processed farm products).

An estimate by the Italian Institute for Services on Agricultural and Food Market (ISMEA) highlights a food industry turnover of about 110 billion (USA unit) euros with a growing trend (ISMEA 2007).

In the period 1995–2006, the advantage gained by the food industry with respect to the total Italian industry is evident. In this period, the growth rate of the food industry is about +21.7 % against +5.9 % of the total Italian industry. The underlying trends in the market demand for food products are strongly affected by the growing demands from emerging countries. Future scenario must evaluate the increasing economic impact of the evolution in energy prices (oil and electric energy).

11.2.3.2 The Italian Forestry Scenario

Italian forests have been subject to intense exploitation for many centuries. In the recent past, they were an important source of income and employment for the rural and mountain communities, being a fundamental component for socio-economic development. In the last two decades, there was a 7.2 % growth in forest area, a process that has seen from 1920 to today the total area of Italian forests almost triple at the expense of agricultural and pasture areas (INEA, Italian agriculture 2008). According to the recent update of the National Inventory of Forests and carbon sinks (INFC—Global Forest Resources Assessment, FAO 2010), in Italy, the total forest area is estimated to be 11 million hectares (36.2 % of the country): over 50 % is concentrated in the northern regions, 59 % in the mountains, 36 % in the hills and 5 % in the plain for.

> Turning to the state of health of forests in Italy, recent studies have shown that the degree of defoliation between 2006 and 2007 deteriorated. The percentage of dead trees, or with moderate to severe defoliation, increased from 31 % in 2006 to 36 % in 2007. Such deterioration is due to climatic trends during the year in question, which was particularly hot with maximum temperatures frequently above average (INEA, Italian agriculture 2008).

Whether Italy's geographical, geomorphological, pedological and climatic features result in the broad specific diversity of forest formations, the current forest landscape was produced by profound man-made changes for crops, grazing and/or settlements over the centuries. Since the 1950s, the forests have gradually assumed a smaller role in the national economy as a result of the gradual abandonment of rural and montane areas, with the consequent decrease in forestry and sheep-farming businesses (INEA, Report on the status of agriculture 2011). Forest products have represented on average in the last 20 years just over 1 % of total production in the primary sector, remaining one of the lowest in the EU. Although 81 % of the national forest area is available to timber harvest, the difficult conditions of topography, the location in disadvantaged areas (mountainous and hilly areas), fragmentation of land ownership, inadequate road communications and the high cost of skilled labour have increasingly inhibited forest uses.

The functions attributed to woodland by society have thus gradually changed. Today, increasing attention to environmental protection both at social and political levels has led to the attribution of new functions and significance for forestry which is often difficult to quantify in economic terms. In addition to the historical function of woodland for the production of renewable raw and environmentally friendly materials, there is also a demand for the following: the production of clean energy, climate change mitigation, protection of biodiversity, promotion of cultural activities, recreational and educational activities, water purification and flood control, limitation of soil erosion and desertification, natural disaster prevention and protection of the landscape as the country's historical and cultural heritage. Thus, now more than ever before, the woods may be the driving force for economic, social and environmental development of marginal areas (rural and mountainous areas of Italy) as well as to achieve the objectives signed by Italy in the matter of ecosystem protection.

11.2.3.3 New Needs and Potential Contribution by Soil Scientists

Even though the agriculture and forestry in Italy are in a constant phase of growth and evolution in terms of technical management, production capacity, and product quality and characteristics, the challenges they will face in the coming years will be increasingly tough. The world population continues to grow, as does food demand, with the latter expected to increase by 70–100 % within the next 50 years (Pretty et al. 2010). Italy also has to play its role in meeting this challenge.

Table 11.4 New (and old) country needs and potential contribution by soil scientists with respect to agriculture and forestry

Emerging soil issues	Needs		Response to needs: potential contribution by soil science		
	New (and old) needs	Reason for this need	Aim of the contribution	Potential tools to be employed	Relevant selected bibliography
a					
Agriculture and forestry Sect. 11.2.3	Useful soil map	Better assistance in land management	Ameliorate soil map performance	Digital soil assessment	
	Support in improving sustainable production (quantity)	• Increase in global demand for food	• Define best plant, soil and water management practices in accordance with landscape potential	• Landscape Hydropedological characterization	
		• Decrease in employees in agriculture and forestry and consequent decrease in land management expertise	• Identify the most productive and fertile soils	• Use of SPA modelling to simulate agriculture and forestry scenarios	Pretty et al. (2010)
					Spiertz (2010)
	Increase C-stock in agro-ecosystems	Reduced levels of carbon sequestration due to agriculture intensification and loss of forest lands	Create and/or protect long-term carbon sinks	Use of modelling to simulate C sequestration in new agro-forestry scenarios	(UNEP 2011)
	Protect groundwater	• High chemical inputs in agro-ecosystems	Identify vulnerable ecosystems	• Modelling soil water and pollutant fluxes	Parris (2011)
		• High costs associated with the removal of pollutants (e.g. drinking water)		• Functional approaches to land classification	Basile and Terribile (2008)
	Use of marginal lands for biomass production	Need for sustainable bioenergy production	Classifying marginal lands	• Use of ecosystem quality indicators	Gayathri et al. (2011)
				• Functional approaches to land classification	Bhardwa et al. (2011) Odeh et al. (2011)
b					
Agriculture and forestry Sect. 11.2.3	Support to quality-based production	Most social attention to the quality of products	• Contribute to defining management strategies	• Landscape and environmental suitability classification	Bonfante et al. 2011; Bouma et al. 2008; Costantini et al. 2008, 2009
			• Landscape zoning	• Digital soil mapping	
				• Functional soil characterization	
	Food quality and traceability	• Safeguard food against fraud	• Define chemical links between soil and food	New analytical approaches to identify and map natural fingerprints	Horn et al. (1993), Swoboda et al. (2008), Zampella et al. (2011), Di Paola-Naranjo et al. (2011)
		• Strong interest of society: management of marketing, brand and emergency	• Identify soil origin markers		
		• Better response to product recalls			
		• Better management of supply chains			
	Cope with the future climate change	• Required increase agricultural production efficiency	• Improve water resource management	• Use of agro-hydrological models to simulate the effect of a future climatic scenario on agriculture and forestry ecosystems	Schumacher et al. (2004)
		• Reduce CO_2 emissions The future impacts of mean temperature increase and rainfall decreases	• Promote development of cropping systems and technologies that deliver highly productive systems for combined food, feed and bioenergy production	• Use of simulation models and GIS for regional optimization of land use	Tubiello et al. (2000)
				• Use of simulation models to find mitigation and adaptation measures for food, feed and bioenergy	
		• Increase in marginal areas (i.e. soil salinization, desertification)	• Reduction in crop inputs (water and fertilizer)		Mearns et al. (1999)
					Takáč and Šiška (2009)
					Lenz-Wiedemann et al. (2010)
					Olsen et al. (2000)
					Liu et al. (2011)
					Ludwig et al. (2009)
					Luo et al. (2009)

In order to cope with future food demand, the experts expect optimization and not maximization of crop production. The future increase in food demand must be satisfied without significant increase in consumer prices, taking into account future climate change which will impose inevitable adjustments on crop management. Adaptations will also cover policy and decision-making spheres (national and international policies) that will support more sustainable and efficient use of land resources and agro-forestry.

In this context, in October 2011, the commission presented a set of legal proposals designed to make the CAP a more effective policy for a more competitive and sustainable agriculture in the Europe 2020 strategy (http://ec.europa.eu/agriculture/cap-post-2013/index_en.htm). The document states

> Despite the progress that has been made in integrating environmental concerns into the CAP and in introducing environmental legislation at farm level, water quality and quantity, soil quality and land availability are still areas of major concern, together with the question of how to protect, maintain and further enhance farmland habitats and biodiversity and to enhance the role of agriculture in preserving ecologically valuable landscape.

The document identifies three broad policy objectives for the future CAP:

- Contributing to a viable, market-oriented production of safe and secure food throughout the EU, promoting sustainable consumption and enhancing the competitiveness of agricultural holdings.
- Ensuring the sustainable management of natural resources, such as water and soil, and the provision of environmental public goods such as preservation of the countryside and biodiversity.
- Contributing to the balanced territorial development throughout the EU by responding to the structural diversity in farming systems.

This is the scenario that will characterize the future of the agriculture over the next decade on European scale. It is then self-evident that it will increasingly require the input of scientific research in the field of soil science.

Another important aspect concerns scarcity and the occasional lack of communication between the world of scientific research, policy makers and professionals, which inevitably exacerbates the difficulties in development. In the near future, a major challenge will be to improve the synergy between the actors involved in developing agriculture and forestry. Table 11.4a and b report the new (and old) needs of agriculture and forestry and the contribution that soil science may make to respond to such needs.

Useful soil mapping

Soil formation is conceptually accounted for by the five-factor of Jenny equation or “clorpt equation” (Jenny 1941), which is a mechanistic soil description without any explicit spatial refinement. The set of digital soil mapping (DSM) procedures has now been well established. It represents a quantitative alternative to traditional soil mapping. DSM deals with the soil state definition in both the attribute and the spatial domains, where soil is solved in the realm of SCORPAN-like models (McBratney et al. 2003), that is $S = f(s,c,o,r,p,a,n)$.

Today the interest in DSM applications is rapidly growing but still far from a large implementation scale. There are many developments in the private sector and mainly in high-income crops where for instance new georeferenced combine equipment opened interesting opportunities.

Some DSM applications also exist at the administrative level as policy and/or decision-making devices in Italy such as the followings: (1) soil C reservoir at regional scale for the whole Emilia-Romagna (Ungaro et al. 2010), (2) soil C at national scale (Fantappiè et al. 2011), (3) effect of land use changes on SOC variations during the last 3 decades at national scale in Italy (Fantappiè et al. 2010).

No administrative undertakings are required to apply DSM procedures such as a systematic land resource catalogue of Italy nor can highly specific private undertakings solve DSM at the regional/national scale, due to the clearly stark divergence of both scale and concern (profit vs. welfare). Only the continental scale is nowadays systematically addressed. Examples of effort are (1) the institution of the DSM working group of the European Soil Bureau Network (Dobos et al. 2006), and (2) the GlobalSoilMap.net project. The latter is a well known and established global consortium that has been formed to make a new digital soil map of the world using state-of-the-art technologies for soil mapping and predicting soil properties at fine resolution.

Among DSM procedures, precision agriculture (PA) in cropping systems is without any doubt one of the major applications in the Italian scenario. It has quickly grown in recent years due to the demand made by mostly advanced cropping systems manufacturing high quality Italian brands (e.g. wine, olive oil, cheese, etc.) which are highly prized on domestic but largely on foreign markets.

Towards digital soil assessment

DSM cannot be seen as an end itself, but as a framework providing support to evaluate soil functions and threats to soils. This calls for an expanded DSM procedural framework which is called digital soil assessment (DSA-Carrè et al. 2007). The European Commission has published the thematic strategy for soil protection (TSSP) which consists of a Communication [COM (2006) 231], a Directive [COM (2006) 232] and Impact Assessment [SEC (2006) 1165 and SEC (2006) 620]. The TSSP points to the important role soil plays on earth and to a series of degradation processes it undergoes, such as organic matter decline, sealing, landslides and decline in biodiversity. The scientific literature contains many works addressing DSM procedures worldwide, as emphasized in the cogent surveys by McBratney et al. (2003) and Grunwald (2009). We believe that major efforts should be spent to fulfil the attribute space inference—by means of empirical (e.g. PTF) or mechanistic (e.g. SWAT) modelling—of soil attributes in order to make viable the routine, easy handling of end products (digital maps) which depict soil functions, soil threats or soil processes. This is a milestone in raising awareness about soils. Furthermore, DSA outputs in combination with other social, economic, political and/or environmental parameters will aid decision making through scenario testing and digital soil risk assessment (DSRA). These findings mean that future developments should bridge the gap between soil profile observations and DSA/DSRA maps. The key requirement to do this work is concerned with the building of cognitive (lack of multidisciplinary know-how) and technical (hardware and software solutions) infrastructures. Examples of this trend, albeit in its infancy, are spatial decision support systems (S-DSS) mostly developed on specific topics: the SuSAP web (http://susapnetwork.iambientale.it/SusapNetworkII/Default.aspx) was developed in Lombardy for the sustainable use of agrochemical; AQUATER (http://aquater.entecra.it/) was developed in the south of Italy for the parsimonious use of water in agriculture; and desertification indicator system for Mediterranean Europe (DIS4ME—http://www.unibas.it/desertnet/dis4me/index.htm) was developed to give desertification indicators.

Support in improving sustainable production (*quantity*)

The expected increase in demand for food, fibre and biofuel will be satisfied only if the available land and water resources, at global scale, are used and managed as efficiently as possible. According to some authors (Pretty et al. 2010), the future increase in food and feed demand will require a significant increase in production of food and biomass, as well as acceleration of the rate of technological innovation in agro-forestry. This scenario at the global scale needs a response at national and local scale, and in this sense, we wish to treat this topic in this chapter because we think that Italy should also play its part in the issue of food security. A national necessity, related to "support in improving production", is certainly attributable to the evidence that in future, the number of people employed in the agricultural sector will continue to decrease and the interest of new immigrants towards this sector will presumably be strengthened. This scenario (see the first section in this chapter) means that soil system research will have to provide very efficient tools to support crop production. In this context, efficient use of agricultural resources is only possible with knowledge of the land, understood as the whole soil–plant-atmosphere (SPA) system. Thus, soil science can contribute (1) to establishing rules for proper management of soil and water, (2) to the identifying and characterizing potentially more productive and efficient soils at regional scale.

Today, the soil experts are familiar with the various approaches and have tools to study pedosystems quantitatively and functionally. Defining standards for the proper management of soil passes through the study of the dynamics in the interactions between water, soil and nutrients.

The use of physically based mathematical models allows such interactions to be simulated. Prospective studies can then be made to answer questions like "what happens if?". Today we are moving towards the application of multi-models that consider not only environmental aspects but also socio-economic aspects to study sustainable systems for crop production; spatially explicit land-use and water use patterns with global coverage are computed by combining socio-economic information on population, income, food demand and production costs with spatially explicit environmental data on potential crop yields and water availability for irrigation. This can allow, at the same time with the use of less complex approaches (e.g. FAO Framework for Land Evaluation), potentially more productive pedosystems to be predicted, in different environmental conditions (e.g. climate change).

In the work of, an example of a model to simulate crop yields across a landscape is used to translate assumed spatial patterns of soil and management conditions into spatial patterns of yields. The derived relationship then allows one to infer from observed yield patterns the true proportion of yield variability explained by soil and management. In Boegh et al. (2004), the relationship between the soil water balance and vegetation growth is represented by coupling a hydrological model and a vegetation model which simulates the interactions between soil, vegetation and atmosphere including the seasonal variation in plant structure and function.

Increase the C-stock in agro-ecosystems

According to a survey carried out by the Agency for Environmental Protection and Technical Services (APAT) in 2002 through the application of the carbon sequestration evaluation model (CSEM), the carbon stock of natural ecosystem formations in Italy in the year 2000 is estimated approximately equal to 1,150 Mt C, of which 355 Mt C is in tree biomass and 795 Mt C in the soil.

Agricultural and forestry systems are, therefore, a natural carbon sink, but also a source of emissions that affect climate change (INEA 2011—Agriculture, Environment and Society). The productivity of the agricultural sector is subject to great pressure because while on the one hand, there is a need to use soil as a carbon sink, there is also a need to cope with the increase in food demand due to the world's growing population. In this context, soil science will be able to contribute to studying, at national scale, those agro-ecosystems seen as long-term carbon sinks. Functional analysis of such systems (input–output relationship) can be done through the use of modelling that simulates C sequestration in agro-forestry systems. The consequences of long-term C accumulation in soils can only be assessed through modelling.

In the literature, there are numerous works in this regard: in Liu et al. (2011), the carbon change was simulated over a period of 50 years under the effects of simulated land use change, natural disturbance and climate change. Nieto et al. (2010) simulated the dynamics of carbon in the soil under different land uses and soil management systems in a Mediterranean olive grove; the authors found interesting relationships between fine soil fractions and organic carbon sequestration and also simulated the effects of soil erosion on carbon dynamics. Lugato and Berti (2008) projected model simulations from 2008 to 2080, hypothesizing different reliable SOC sequestration practices to be compared with the usual scenario. They used climate data from four global climate models. The results indicated that management practice could affect the C balance in agro-ecosystems more strongly than climate change.

Protect groundwater

Water quality in terrestrial ecosystems is strongly influenced by agricultural practices. This topic has been identified as being extremely important within OECD countries.

Parris (2011) emphasizes that the agricultural sector is the main factor responsible for several environmental hazards related to water: nitrates, phosphorus, pesticides, salinity, microbial water pollution (from farming operations and breeding). Despite this evidence, it is also clear that the agricultural sector can play the opposite role (under proper business management) to improve water quality, for example, using the filtering function of the soil.

Water pollution caused by agriculture has highly associated costs, generally related to the removal of pollutants from drinking water, to ecosystem damage and fish sales, to recreation, to cultural values associated with the quality of rivers, lakes, groundwater and seawater. Specifically in Italy, groundwater constitutes about 85 % of the resources for human consumption, and the protection of these strategic reserves to prevent their degradation in terms of quantity and quality is a priority in European and Italian policy. This priority is reflected in the work developed in the regulatory field, from the DPR (Presidential Decree) 236/88 of 1988 until the most recent DL 152/99.

In particular, this innovative regulation aimed at groundwater protection taking into account loads of soil fertilizer, nutrients and pesticides and requires plans for monitoring and control measures on the state of the aquifers; all such documents have to be incorporated into regional basin plans. Among these studies, a major issue is mapping landscape vulnerability. In this respect, the Agency of Environmental Protection of the Ministry of Environment (APAT) has the task to support activities for identifying vulnerable areas. These are ecosystems with low level of water table protection and/or subjected to severe anthropogenic pollution (e.g. external inputs such as nitrates from intensive agriculture). In this context, the methods used for these vulnerability studies by APAT refer to the Sintacs method (Civita and De Maio 1998). This involves the use of only two data to parameterize the protective component of soil: the organic matter content (SO) and the clay and silt content (AL). It is not surprising that this oversimplification, when subjected to verification with measured data, shows important limitations (Basile et al. 1999).

Soil science can—and should—make a major contribution to this issue. It should address both identification, the functional study and management support of vulnerable ecosystems.

The ability of an ecosystem to protect groundwater from pollution depends mainly on its soils. Soil systems thus have to be characterized from a functional point of view in order to define an accurate degree of vulnerability. This approach relies on point-based measurements or on the estimation of hydraulic and physico–chemical properties of soils and the subsequent dynamic analysis of "behaviour" in different ecosystems through the use of simulation models of the water and solute movements in soils. The use of spatial interpolation techniques of point-based data also allows us to obtain thematic maps of this information at different scales. Integration of thematic maps with information on the dynamic properties of soil systems enables landscape classification to both identify and manage vulnerable ecosystems.

Examples of such applications are numerous in the literature. For example in Basile and Terribile (2008), the nitrate pollution problem and the definition of vulnerable ecosystems at the regional scale are addressed by modelling applications in some of the pedosystems in Campania. In the work of Flipo et al. (2007), geostatistics and physically based models were used to better understand the fate of nitrate in an aquifer. Almasri and Kaluarachchi (2007) implemented a framework for modelling the impact of land use practices and protection alternatives on nitrate pollution of groundwater in agricultural watersheds. In McLay et al. (2001), a leaching risk assessment model was used in a region of intensive agriculture to assess the risk of nitrates leaching to the groundwater. In Pang et al. (2000), a physically based model was used to simulate water movement and solute transport (picloram, atrazine and simazine) in soil and groundwater in a domain with a depth of 10 m.

Use of marginal lands for biomass production

With the rise in fossil fuel prices, the uncertain future concerning energy supply and the growing threat of global warming, sustainable bioenergy has become an important goal for many countries. The use of marginal lands to produce energy crops is becoming an important strategy for achieving this goal in many countries including Italy (e.g. APAT 2007a, b), but implementation is still at a very early stage. Definition of the term *marginal lands* is rather broad because many factors or causes can make land marginal. Generally, it indicates arid and inhospitable land that has little or no potential for profit and often has poor soil or other undesirable characteristics (i.e. degraded or saline soils). These lands are often located at the edge of desolate areas. Delimitation of marginal lands is then influenced by both the area of these limiting environmental factors and the potential use of land. It could be based on precipitation as in the case in which the most limiting factor for dryland agricultural intensification is low water availability caused by low rainfall.

We believe that on this topic, soil scientists must lend their support in identifying and classifying marginal lands aiming to cultivate energy crops. Typically the approach to this type of study since the 1970s has entailed the use of land evaluation methods developed by the FAO, based on matching tables of land characteristics and land use requirements. In recent years, these static methods (termed *static* because they are empirical and qualitative methods) are being (partially) replaced by dynamic approaches (mechanistic and quantitative methods) based on the use of mathematical simulation models which simulate the behaviour of the soil systems (soil–water-climate) in different agro-environmental scenarios. Through the application of simulation models, it is possible to estimate the crop response in marginal lands and then classify, quantitatively, the areas more or less potentially suitable to biomass production. Studies on the topic involving the use of classical and modern approaches are numerous; Gayathri et al. (2011) tested a framework that incorporates multiple criteria including profitability of current land use, soil health indicators (erosion, flooding, drainage or high slopes) and environmental degradation resulting from contamination, for classifying marginal land in the state of Nebraska and estimated the potential for using marginal land to produce biofuel crops. Bhardwa et al. (2011) defined both an empirical land marginality index (LMI) based on land capability classes, slope, soil erodibility, soil hydraulic conductivity and a soil quality index (SQI) based on 12 soil physical and chemical properties in order to classify the land according to the relation between the aboveground net primary productivity, the land management approaches used and the indexes defined. Odeh et al. (2011) explored the potential environmental suitability and economic viability of growing two biodiesel crops in marginal regions of Australia. They used a global circulation model to simulate a climate change projection to determine the shift in potential areas for the investigated crops. In a study presented by the Asia–Pacific Economic Cooperation (APEC 2009), the Energy Working Group examined the marginal lands in APEC economies and evaluated their biomass productivity potential for biofuels. They first classified marginal lands by using a FAO approach and then estimated the biomass productivity by using a mechanistic crop production model that consider various inputs (i.e. soil properties, weather data) to simulate plant development.

Support to quality-based production and "Made in Italy"

Today in the world and particularly in Europe, consumers tend to prefer tasty healthy food, with a high nutritious content obtained from sustainable, environmentally friendly production techniques, placing particular attention upon quality in general. In the global concept of food quality, the modern consumer combines concepts such as hygiene and food safety which are objective, demonstrable, measurable and reassuring. In recent years, however, this concept of quality is integrated with a new form of quality connected to the history of places and production methods which recall traditions and respect for the environment and animals. This form of quality adds value to products through so-called quality labels but requires that soil and land scientists play their part, providing their expertise to study the link between territory, quality and specific properties of the products obtained by specific pedoclimates.

Indeed, soil scientists have tools to define, in collaboration with producers, the best land management strategies up to the farm scale, particularly as regards the relationship between product and the SPA system (Bouma et al. 2008; Costantini et al. 2008, 2009). At the same time, they may characterize broad soil systems of production in terms of physical, chemical and functional properties, as reported for the Valle Telesina in Campania (Bonfante et al. 2011).

Classical approaches involve the use of more or less complex tools applied in studies of landscape and environmental suitability classification that aim to classify the landscape with respect to its crop suitability attitude or more specifically with respect to different varieties or cultivars. The complexity of the approaches is related to the quality and quantity of environmental data required or also the use of more or less complex tools for measuring and monitoring environmental data. In this field, viticultural and oliviculture zoning can play a crucial role. In general terms, this consists in the characterization of pedosystem production in terms of dynamic interactions between soil, topography and climate (through functional characterization of pedosystems and simulation modelling). Although land zoning for vine and olive has been known since decades (Renouil and De Traversay 1962), in recent years, it has exploited data analysis techniques and modern tools, such as dynamic simulation models, geophysical techniques and DSM through which production pedosystems can be characterized in greater detail and applicability can be determined. In the work of Van Leeuwen et al. (2009), the key role was shown of water deficits in producing quality grapes for red wine. The study demonstrated the applicability of water balance modelling in defining the effects of regional water deficit on grape growth at field scale. According to van Egmond et al. (2009), the combination of geophysical methods and DSM techniques can provide a rapid cost-effective approach to creating high-resolution digital soil property maps for large areas. These methods can be used for precision farming and will improve the production of crops at desirable quality and safety levels. Connor (2005) stated that the cultivation of olive orchards in low-rainfall climates could be improved in terms of productivity and oil quality by the application of crop water balance models to help define the optimum canopy size.

"Made in Italy" is an expression which seeks to differentiate and value the quality of products made in Italy compared to those produced abroad. One of the sectors where "made in Italy" is most important is certainly food (pizza, pasta, olive oil, wine, tomatoes, etc.). For Italian companies that invest in product quality, recognition of their efforts to ensure the consumer taste, reliability and authenticity is extremely important. The reputation of Italian products abroad is a commercial advantage, and hence, there is a great problem with counterfeiting, especially in the present-day globalized world where Italian-type products are created in other countries which misappropriate the made in Italy brand (e.g. Parmesan cheese). In this context, the issue of traceability is of great importance.

Food quality and traceability

The traceability of a product allows you to trace and follow the path of food or substance intended or expected to become part of a food, through all stages of production, processing and distribution. The importance of food traceability can be defined to both the "security" and to the "quality" of food.

Security: the possibility to identify the origin of food is crucial for the protection of consumers and to avoid negative impact on the market. The Community legislature has in fact developed a general system of traceability of products covering the whole chain, from primary production to marketing, in order to conduct targeted and accurate withdrawals or provide information to consumers in case of danger for food safety, thus avoiding unnecessary or wider disruption.

Quality: the Italian food industry is characterized by many local peculiarities and by the presence of several excellent products (e.g. wine, olive oil, cheese, etc.) which, to compete in the global market, need to be differentiated and collocated geographically, besides to protecting from imitation and fraud. Also in this case, the traceability of food acquires a fundamental importance. In this context, it is understood as the possibility of tracing the geographical origin of a food, and thus the area of territory in which it was produced, conferring an added value to the product, as it will be possible to claim the specific characteristics, result also of the territorial context of production.

With reference to the quality and traceability of the geographical origin of food products (Oddone et al. 2009), soil science can and must play an important role. In fact, many of the molecular, genetic and metabolic (metabolomic) markers typically used as indicators of product traceability are not very useful to determine the geographical origin of a product because (1) the production and processing techniques can vary greatly chemical signals, (2) the identification of genotypes cannot be correlated to a specific environmental context. In this scenario, assume great importance the isotopic ratios of heavy elements such as $^{87}Sr/^{86}Sr$, Pb, (Horn et al. 1993; Swoboda et al. 2008; Zampella et al. 2011) along with some trace elements and rare earths (Di Paola-Naranjo et al. 2011), which may allow to identify a stable geochemical signature in a certain geographical landscape. In fact, these geochemical parameters are sufficiently stable in the production processes (pruning, fertilizing, climate) and during the food transformation (e.g. Winemaking). In this context, the future soil issue will certainly focused on set up of these techniques for several products which take into account of the spatial variability of the parameters in question.

Cope the future climate change

It is known that at global scale, the mean temperature observed is increased over last decades (0.13 °C/decade; IPCC 2007) and the CO_2 emission observed lie above most IPCC SRES scenarios, even the most extreme A1F1 scenario (Manning et al. 2010). The increase in mean temperature influences the metabolism (photosynthesis and respiration) and rate development of crops. These trends occur also in Italy where for instance in the South, it is observed increase of both net radiation and temperatures coupled with a decreasing in precipitations represent the bases for the drought risk. Thus, the agriculture area will have to cope with increasing water demand for irrigation, with additional restrictions in southern Italy due to the increases in crop-related nitrate leaching.

At global scale and also in Italy, the challenge within agriculture and forestry ecosystems is threefold: to increase production, to reduce emissions and to adapt to a changing and more variable climate (Olesen 2011) but at same time taking into account, the EU Directives and Regulation and the economical sustainability of farmer system. Moreover, the expected increase in world population coupled with future climate change will require an adapting of agricultural systems aimed at improving the agricultural production efficiency considering the needs of (1) CO_2 emission reduction, (2) the future impacts of mean temperature increasing and rainfall decreasing (changing in timing of sowing and harvesting; risk of crop failure; increase in marginal areas subjected to soil salinization and desertification processes).

In order to cope the future food and feed requests, considering the role of agriculture in the climate change (CO_2 emission; crop production for bioenergy; water use) and to improve the agriculture production efficiency, we need to (1) improve the water resource management; (2) promote the development of cropping systems and technologies that deliver highly productive systems for combined food, feed and bioenergy production; (3) reduce the crop energy inputs (fertilizer and water). To achieve these results an urgent and substantial increase in the focus of research, innovation, extension and education at all levels across all sectors related to agriculture and forestry is needed (Olesen 2011). On these issues, soil science can make important contribution studying the integrated SPA system. An example is the use of hydrological modelling coupled with GIS and spatial techniques of inference, in order to simulate dynamic (i.e. time-varying) behaviour of the SPA throughout the landscape (i.e. variable in space) and when subjected to different agro-environmental scenarios (e.g. rise in average temperatures, increasing water deficit, etc.).

Many studies have been conducted on the effects of changing climatic variables (CO_2 and temperature increase; rainfall decreases) on crop response (Pearch and Bjorkman 1983; Morrison 1987, 1989; Cure and Acock 1987; Brouwer 1988; Mitchell et al. 1995; Nonhebel 1996; Weigel et al. 2006; Kersebaum et al. 2009a, b; Manderscheid and Weigel 2007). These approaches do not integrate the whole SPA system but they analysed mostly a part of the system (plant-atmosphere) and the results on crop adaptation were not entirely realistic and applicable at field or territorial scales.

In order to consider completely the behaviour of SPA system in the evaluation of climate change impacts on agricultural production, we need to use the physically based simulation models of SPA system (SWAP, van Dam et al. 1997; CropSyst, Stöckle et al. 2003; APSIM, Keating et al. 2003; STICS, Brisson et al. 2003)

They can be applied for study both impacts and adaptation of cropping systems to climate change, helping us to find the best water resource management in according with high production levels and low fertilizer applied in compliance with EU Directives and Regulation. These models can work at different scales (punctual, local, regional) giving at local and regional, the possibility to optimize the crop spatial distribution reducing or improving the use efficiency of water and reducing the leaching of pollutions. The use of physically based simulation models represents dynamic and integrated study of the ecosystem where the soil behaviour is robustly described.

In Italy, the project AGROSCENARI (MIPAAF, D.M. 8608/7303/2008) studies the response of typical Italian production systems to future climate change in order to identify the crop varieties more compatible to future scenario. One approach applied in this project, in two regions of southern Italy, is based on the investigation of thermal and water regimes, which integrate the standard approach based on climatic factors that directly influences the crop growth and its DVSs (the shifting of sowing and harvest time; the reaching of thermal sum for specific crop; vernalization) with a physically based approach which use the simulation models in order to describe the future soil water regimes. This latter is compared with the yield response functions to assess the adaptability of varieties to the expected climate and their foreseen spatial distribution.

The availability of data with the necessary geographical detail, like soil hydrological information, is currently the major limitation rather than computational capability or basic understanding of crop responses to climate change.

11.2.4 Hydrogeological Risk: Landslides and Floods

The seriousness of landslides and floods in Italy has often been stated. These very natural risks, rather frequent in Italy, often involve, or evolve over, soils (Iamarino et al. 2009). Hence, knowledge of soils can play a very important role in helping identify areas susceptible to these risks but also in setting up suitable early warning strategies.

11.2.4.1 The Italian Landslide Scenario

In evaluating and managing hydrogeological risk, the study of catastrophic events with high intensity and magnitude is of particular importance in Italy. The types of landslides mainly responsible for these events in Italy are known to be both mud-flows and debris-flows (APAT 2007a, b). The latter represent approximately 15 % of the total number of landslides inventoried in Italy (see Fig. 11.4) and have been responsible for well-known catastrophic events in recent years, such as at Sarno in 1998 and Messina in 2009.

The factors that make the surface "debris flow" particularly dangerous are (1) the high speed of initiation and propagation, (2) the possibility of a simultaneous start of several detachments within the same basin (see Fig. 11.5), (3) the close interaction with hydraulic transport processes, such as the sudden increase in solid load of rivers (landslides associated with flash floods—Fig. 11.5).

In Italy, in the last century, the most catastrophic events involved the soil cover of mountain areas (Iamarino et al. 2009). In some areas close to active or ancient volcanic

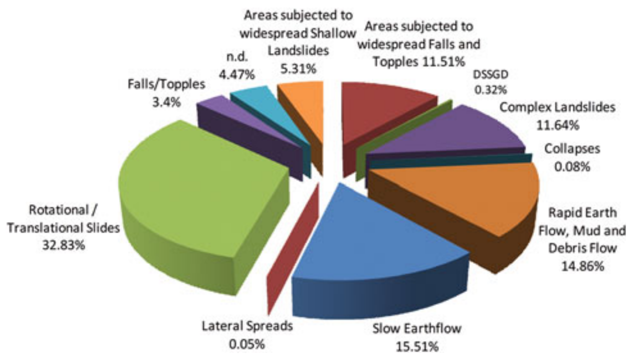

Fig. 11.4 Distribution of types of landslides. *Source* ISPRA–IFFI project, report on landslides in Italy 2007

districts, soils formed on pyroclastic materials (ash, pumice, lapilli and scoria) and in some cases developed andic properties. These properties, due to the presence of short-range order materials, in particular conditions, may facilitate (Basile et al. 2003) the initiation of landslides in these surface soils characterized by (1) low bulk density, (2) high water retention, porosity and permeability and (3) thixotropic properties. Recent studies showed a wide distribution of andic properties in soils of Italian mountains even in non-volcanic ecosystems (Iamarino and Terribile 2008). In addition, it has been shown that the silty particle size distribution of many of these soils might induce a particular sensitivity to land degration processes. This is not new: for instance, most soils from debris flow areas in Thailand are silty and of low plasticity (Apiniti and Hansa 2008). Past research (e.g. Burland and Ridley 1996) suggests that these types of materials are likely to exhibit brittle undrained behaviour during shearing and could be susceptible to static liquefaction. Wang and Sassa (2003) also showed that sand with fine-particle (loess) contents tend to have greater mobility and high pore water pressure induced during landslides. The materials found in the debris flow areas of Thailand appeared to be in this category.

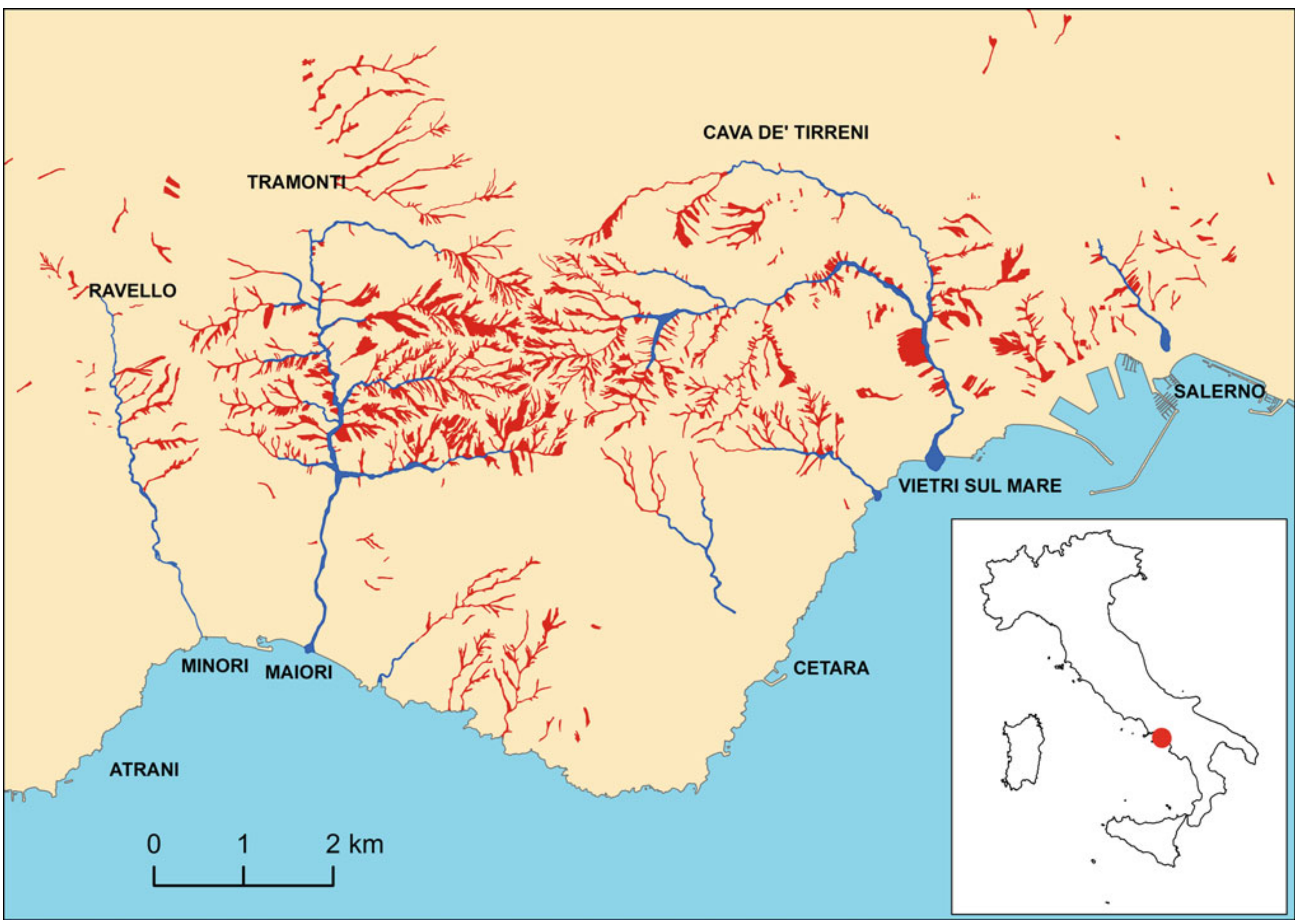

Fig. 11.5 Map of the debris flow and flash flood of the Salerno flood in 1954. The 472 landslides recorded * and flash flood which occurred on the night between 25 and 26 October on the Amalfi Coast and Salerno caused 205 deaths and 92 missing. * *Source* Regional basin authority "Destra Sele" (2011)—river basin plan; section geology—studies, surveys and processing: Geores, A. Carbone & A. Gallo Associated

11.2.4.2 The Italian Flood Scenario

Floods are known to cause great economic damage worldwide; annual statistics over the past 30 years show that they annually affect on average about 80 million people (Dutta et al. 2006) and that their number is rapidly increasing around the world in comparison with all other environmental disasters (CRED 2003; Dutta and Herath 2004). Among such events, flash floods, caused by heavy or excessive rainfall over a short period of time, are the most dangerous, which is distinguished from a regular fluvial flood by a timescale of less than 6 h (NWS 2009). Flash floods are usually characterized by raging torrents after heavy rainfall flows over river beds, through urban streets, or mountain valleys, and almost sweeps through everything. They can occur within minutes, or a few hours, after excessive rainfall. Due to their rapid occurrence, flash floods usually result in a very limited opportunity for warnings to be prepared and issued, and therefore they are extremely dangerous events, often leading to catastrophic consequences and particularly in the form of loss of human life and property (Collier 2007).

Floods, together with wind-related storms, are considered the major natural hazard also in the EU in terms of risk to people and assets (European Environment Agency 2010). Between 2000 and 2009, Europe has witnessed some of the largest flooding events in its history. Recent major flooding events include the 2007 floods in the United Kingdom, the Elbe and Danube River floods during the summer of 2002 and the Piemonte floods in October 2000. Over the last 10 years, floods in Europe have killed more than 1,000 people and affected over 3.4 million others (Guha-Sapir et al. 2010; EM-DAT 2010). Currently, more than US$ (or USD) 40 billion per year is spent on flood mitigation and recovery (incl. compensation of flood damage) in the EU. More than 75 % of the damage caused by floods occurs in urban areas (Ashley et al. 2007). About US$3 billion per year is spent on large-scale flood defence structures alone. Population increase and increases in asset values in flood-prone areas may contribute to this scenario (European Environment Agency 2010).

Looking more closely at the national scenario in Italy, landslides and floods are responsible for extensive damage to both human activities and the population (see Figs. 11.6, 11.7). According to the latest available official data, 29,517 km^2 of Italy's land area has been classified as "hydro-geologically highly critical", 17,254 km^2 for landslides and 12,263 for floods, corresponding to 9.8 % of the whole country, with peaks close to 20 % in regions such as Campania and Emilia-Romagna. There are 6,633 municipalities involved, representing 81.9 % of Italian municipalities (see Table 11.5).

Looking at future trends, flood risk seems to be very much worsening.

The ongoing urbanization worldwide, as reflected by the growth in the number of megacities, also in deltaic areas, will thus require even more action in relation to this hazard. By 2050, 70 % of the population will live in urban areas (United Nations Population Division 2008) and the

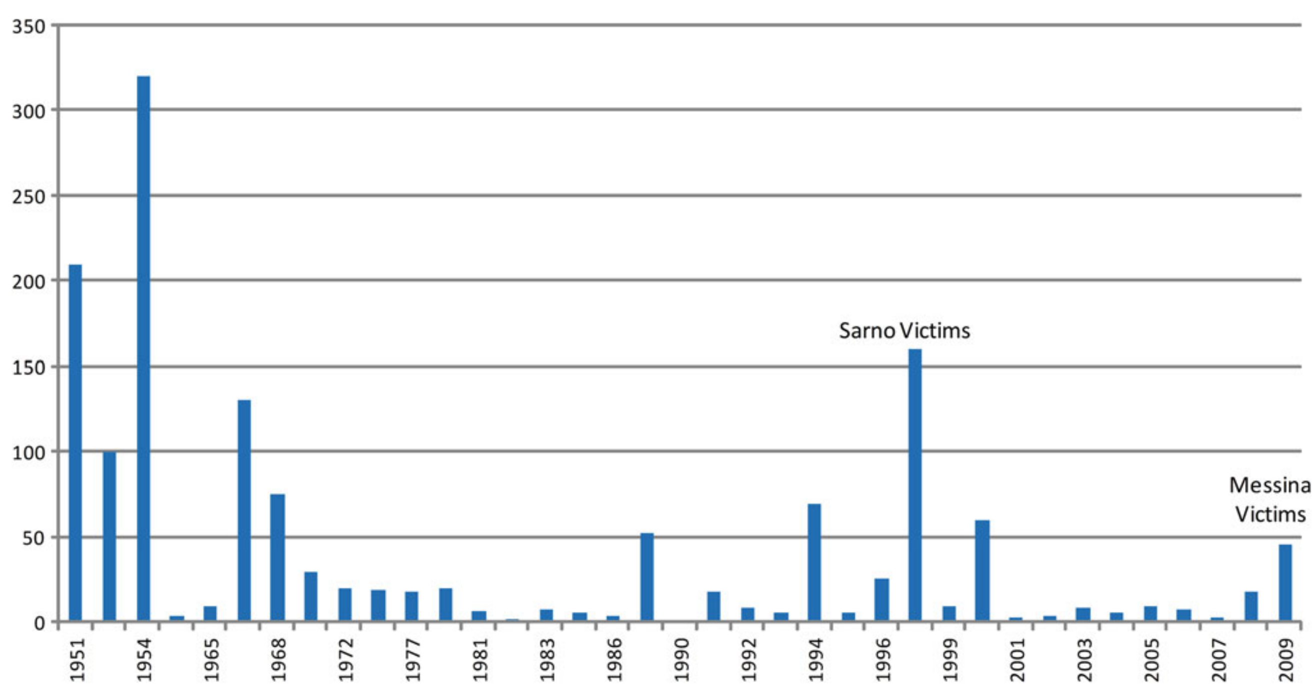

Fig. 11.6 Victims of major floods in Italy (after ISPRA 2010)

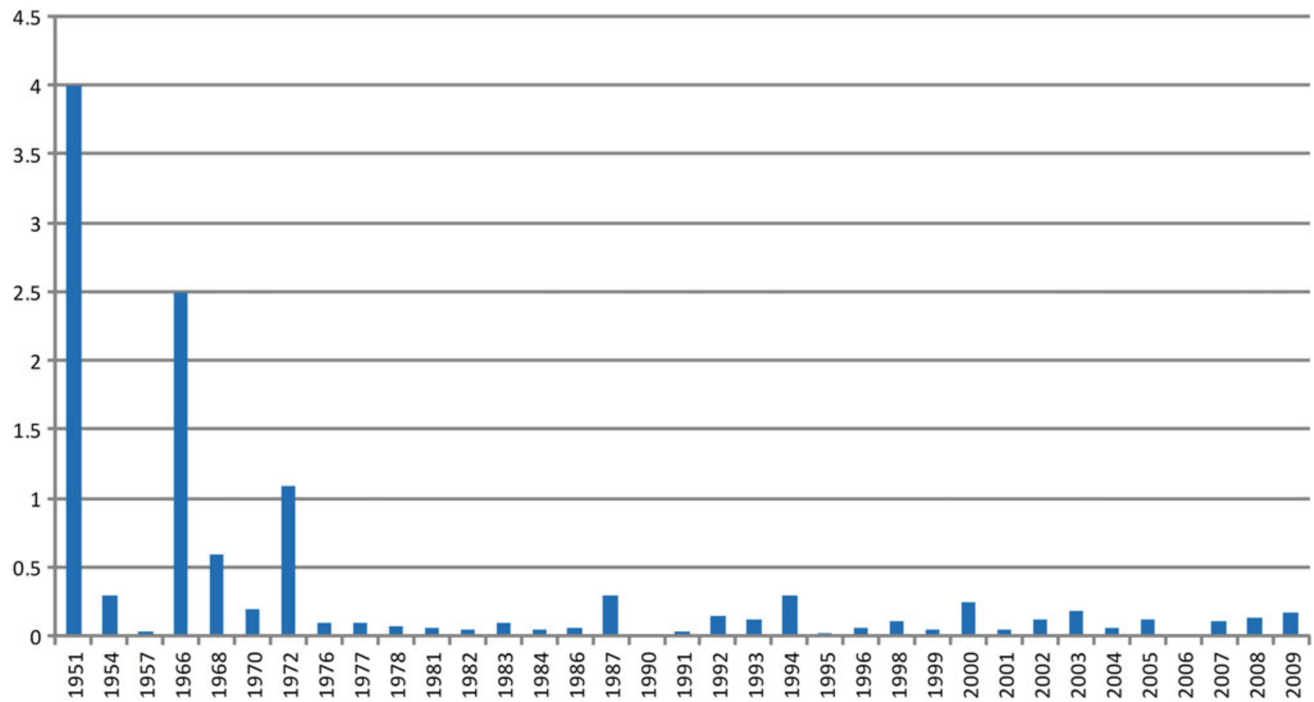

Fig. 11.7 Estimated total loss in GDP (ISPRA 2010)

economic values in these areas are constantly growing, which means that flood risk in urban areas will increase disproportionately: flood damage in Europe could rise to US$100 billion per year by the end of the century (European Environment Agency 2008).

Moreover, for many authors, flood risks increase as a result of potential changing climate worldwide (Frei et al. 2000; Milly et al. 2002; Kundzewicz et al. 2005). Warmer temperatures can hold more water vapour in the atmosphere and thus are likely to intensify the global water cycle, and hence increase flood risk (Hall et al. 2003; Ikeda et al. 2005; Huntington 2006; Kerr 2006). Frei et al. (2000) showed growing evidence of a moistening of the atmosphere cause by global warming. Similarly, Kundzewicz et al. (2005) projected increasing occurrence of flood hazards in Central Europe using climate models under a warming climate scenario. However, it is unclear whether or not the increasing flood damage is a consequence of changing climate or human activities such as intensive land use along and on floodplains (Pielke and Downton 2000; Changnon et al. 2001).

Flood risk can also accelerate as a result of rapid urbanization (Teng et al. 2006; Nirupama and Simonovic 2007). In a study of European river floods, Mitchell (2003) argued that increased flood damage is attributed to both the migration of population and capital into floodplains and human modifications of hydrological systems. Traditionally, flood management practices have focused on defensive practices. In the past 2 decades, due to the realization that risk could and should be actively managed, a shift has been observed from predominantly defensive actions to the wider focus of proactive management of risk (better land use planning, space in urban areas to accommodate increased overland flows, river and coastal defences, flood-proofing of buildings) (Evans et al. 2004, 2008).

11.2.4.3 New Needs and the Potential Contribution of Soil Scientists

Table 11.6 gives the relevant needs for hydrogeological risks and potential responses to these needs by soil scientists. Among them, we focused on the following:

Improving techniques for identifying landslide areas

Recognition of landslides which have occurred in a given area is essential because (1) it allows areas of landslide risk to be identified, (2) it may enable the output of landslide triggering and propagation models to be validated, (3) it helps to understand landslide phenomena. Therefore, it is very important to obtain a precise delimitation of past landslide events especially using pedo-geomorphological knowledge.

Shallow landslides are hard to detect after a few years from their formation; in fact, often the sliding soils are very fertile and enable a rapid plant colonization. It is, therefore, necessary to resort to all possible signs of past landslides. New approaches for identifying landslide areas are based on the evidence that landslides have effects on some soil

Table 11.5 Distribution of areas with high levels of hydrogeological hazard in Italy (self-governing regions and provinces)

	Areas of high hydrogeological hazard		Municipalities involved		Critical areas near the municipalities involved		
Regions	Km^2	%	number	%	Susceptible to floods (%)	Susceptible to landslides (%)	Total floods and landslides (%)
Abruzzo	899.1	8.3	294	96.4	1.0	7.5	8.5
Basilicata	539.9	5.4	131	100.0	2.4	3.0	5.4
Calabria	1,157.2	7.6	409	100.0	3.3	4.3	7.6
Campania	2,597.8	19.0	504	91.5	4.5	15.0	19.5
Emilia-romagna	4,315.6	19.5	307	90.0	9.0	12.3	21.3
Friuli V.G.	1,212.1	15.4	201	91.8	10.3	5.9	16.2
Lazio	1,309.1	7.6	372	98.4	2.7	5.1	7.7
Liguria	470.4	8.7	232	98.7	2.5	6.2	8.7
Lombardia	2,113.9	8.9	929	60.1	7.0	5.0	12.1
Marche	955.0	9.8	245	99.6	0.9	9.0	9.8
Molise	836.3	18.7	136	100.0	3.1	15.6	18.7
Piemonte	3,096.7	12.2	1.049	87.0	6.7	6.5	13.3
Puglia	1,370.8	7.0	200	77.5	5.2	2.7	7.9
Sardegna	613.6	2.5	306	81.2	0.8	2.1	2.9
Sicilia (*)	830,.0	3.2	277	71.0	2.9	1.5	4.4
Toscana	2,542.2	11.1	280	97.6	5.9	5.6	11.5
Umbria	898.7	10.6	92	100.0	2.3	8.3	10.6
Valle D'aosta	556.5	17.1	74	100.0	0.9	16.2	17.1
Veneto	1,549.6	8.4	327	56.3	11.8	0.8	12.6
P.A. Bolzano (*)	47.7	0.6	46	39.7	0.0	1.5	1.5
P.A. Trento	1,605.6	25.9	222	99.6	0.7	25.2	25.9
Italy	**29,517.7**	**9.8**	**6.633**	**81.9**	**4.6**	**6.4**	**11.0**

Source Ministry of the Environment, Land and Sea, Directorate General for Soil Protection, Il Rischio Idrogeologico in Italia, 2008
(*) partial data

properties. A common feature is that the landslide area is structured into mass depletion and accumulation zones that may differ in soil fertility (Walker et al. 1996). For acid and nutrient-poor soils in south Ecuador, Schrumpf et al. (2001) postulated that landslides improve soil fertility because they bring deeper, less weathered and therefore nutrient-richer material to the surface. For instance, they reported the occurrence of less weathered phyllosilicates, increased pH, and the presence of more exchangeable nutrients in soils on large landslides, radiocarbon dated as 600–700 years old (Schrumpf and Guggenberger, personal communication).

Differences in soil fertility may lead to differences in vegetation cover, for whose identification remotely sensed vegetation indices can lend a great contribution. Of the various vegetation parameters, the NDVI is one of the most common and easy to obtain, it is representative of plant assimilation conditions and of its photosynthetic apparatus capacity and biomass concentration (Groten 1993; Loveland et al. 1991). Hence, it is time-varying according to changes in meteorological and environmental parameters. Valdez et al. 2010 developed a method to identify landslide areas, after Hurricane Mitch[1] in 1998, using images differencing approach between pairs of landsat NDVI images of the same area collected at different times (pre- and post-event).

A better understanding of landslides through soil analysis

A high percentage of catastrophic landslides in Italy (mud- and debris-flows) involve soil cover (Iamarino et al. 2009). However, the public authorities responsible for defining and delimiting the landslide risk areas do not yet use soil information for understanding landslide occurrence. The initiation of "rapid flow" landslides depends on both the breakage mechanisms of soils and the water movement

[1] Hurricane Mitch struck Central America in 1998 and it will be remembered as the most deadly hurricane to strike the Western Hemisphere in the last two centuries. It produced enormous amounts of rainfall that resulted in devastating flooding and landslides (more than 500,000) with more than 9,000 fatalities and three million people displaced.

Table 11.6 New (and old) country needs and potential contribution from soil scientists on hydrogeological risk

Emerging soil issues	Needs		Response to needs: potential contribution of soil science		
	New (and old) needs	Reason for this need	Aim of the contribution	Potential tools to be employed	Relevant selected bibliography
Hydrogeological risk: landslides and floods Sect. 11.2.4	Improve techniques for identifying landslide areas.	It allows areas of landslide risk to be identified, the output of landslides triggering and propagation models to be validated, to better understand landslides phenomena	Analysis of soil and biomass perturbation in forest ecosystems can help landslides identification	Use of vegetation indices from satellite images and quantitative geomorphometry	Walker et al. (1996), Schrumpf et al. (2001), Groten (1993), Loveland et al. (1991), Valdez et al. (2010)
	Better understanding of landslides using soil analysis.	In Italy many catastrophic events involve soil cover, and then soil information can provide much help in hazard mitigation.	Production of suitable soil maps (including geotechnical and hydrological measurements) to be used in models of landslide initiation and propagation.	• Hydropedological survey on landforms with in situ measurements of hydrological behaviour (soil texture, organic matter, thickness)	Montgomery and Dietrich 1994
					Bertoldi and Rigon (2004), Simoni et al. (2007), Van Alphen et al. (2001), Sonneveld et al. (2003), , Anderson and Sitar (1995), Iverson (2000), Toll et al. (2009)
				• Use of pedo-transfer functions and geomorphological criteria to estimate soil properties	
				• Use of appropriate geotechnical measurements (e.g. soil rheometer) for determining useful (e.g. soil visco-plastic) parameters	
	Improve procedures for identification of areas susceptible to slide (landslide hazard maps)	Current hazard maps neglect soil properties.	Analysis of soil and biomass perturbation in forest ecosystems to identify soil properties (e.g. thickness)	Use of vegetation indices from satellite images combined with morphological features influencing soil properties	McKean et al. (1991) Iamarino and Terribile (2008)
	Amelioration of landslide warning systems				Johnson and Sitar (1990)
	Ameliorate flood forecast and alert	Current systems perform poorly	Ameliorate soil component in modelling flood forecasts	• Hydropedological survey of representative landforms with in situ hydrological measurements	
				• Use of pedo-geomorphological criteria to estimate parameters for hydrological modelling	

inside them. Geotechnical and hydrological study of these mechanisms has made significant strides in recent years, developing several increasingly complex interpretive and predictive mathematical models, for example, going from models based on stationary and uniform hydraulic conditions (e.g. SHALSTAB, Montgomery and Dietrich 1994) to models able to evaluate the transient behaviour of the infiltration–filtration process in soils (e.g. TRIGRS, Baum et al. 2002; GEOtop-SF, Bertoldi and Rigon 2004 and Simoni et al. 2007). These models, however, to be effective need (1) more detailed data about the soil characteristics of the area; (2) careful evaluation of the most important soil parameters and (3) good representation of the soil spatial variability (distributed parameter models).

For soil characterization, the major input parameters used in the forecasting models are as follows: soil horizons stratigraphy, bulk density, internal friction angle, cohesion (due also to the root system in the first metres of soil), porosity, hydraulic conductivity and the volumetric water content (on saturation and residual). Recently, there has also been an attempt to implement models using the number and thickness of horizons and taking into account the vertical and horizontal variability of soils in terms of thickness and characteristics (Simoni et al. 2007). The collection and measurement of spatial data are highly expensive. However, in recent years, soil science has viewed new data estimation techniques with great interest. Of these, the use of pedotransfer functions (PTF) (Van Alphen et al. 2001; Sonneveld et al. 2003) for the estimation of hydraulic parameters is one of the most widely applied in hydropedology (see Manna et al. 2009).

Numerous natural factors, earthquakes, concentrated rainfall events, as well as anthropogenic factors, including deforestation, contribute to slope failures by decreasing shear strength or increasing shear stress of the soil mass. Most of the slope failures coincide with intense rainfall (Anderson and Sitar 1995; Iverson 2000), but landslides are frequently a combined effect of intense rainfall and previous wet soil moisture conditions. Rainfall is the most frequent triggering factor for landslides, but the amount of rainfall can only be a crude indicator of failure: the relationships between infiltration, water content change and pore water pressure change are highly complex, nonlinear and hysteretic (the term *hysteretic* here means that different values of pore water pressure might correspond to the same water content depending on whether the soil is following a drying or wetting path).

Soil moisture surrogates have been used extensively in slope stability analyses. Montgomery and Dietrich (1994), Van Westen and Trelirn (1996), de Vleeschauwer and De Smedt (2002) and Acharya et al. (2006) analysed slope stability using *wetness indices* calculated by the TOPOG model (O'Loughlin 1986). Rosso et al. (2006) presented a modified model in order to consider soil moisture in the upper soil layer, since Montgomery and Dietrich's (1994) model neglects the presence of soil moisture in the upper soil layer above the water table. The studies of Anderson and Sitar (1995), Iverson (2000), D'Odorico and Fagherazzi (2003) and Collins and Znidarcic (2004) focus on saturation level soil moisture contents as they relate to landslides. However, these studies have indirectly estimated the soil moisture or pore water pressure based on rainfall and do not directly account for the highly variable soil moisture prior to and during rainfall events. Antecedent soil moisture conditions can be obtained by in situ measurements; direct measurement of pore water pressure gives the most reliable prediction of failure of a slope and should be used in warning systems. Because pore water pressures in slopes are frequently negative (suctions), devices are needed that are capable of measuring negative pressures. Conventional tensiometers and piezometers are limited to -100 kPa. However, high-capacity tensiometers developed within the EU-funded MUSE Research Training Network are now available that are capable of direct measurement of pore water pressure down to -2 MPa, and they are also able to record positive pore water pressures (Toll et al. 2009). However, such measurements are time consuming and require complex data collection efforts even for local scales. As a result, there are very few in situ observing systems to measure pore water pressure at regional or continental scales (Gao et al. 2006).

An alternative approach is to obtain surface soil moisture from satellite remote sensing at national and global scales. Surface soil moisture can be observed (measured) using microwave remote sensing (Jackson 1982, 2002; Teng et al. 1993; Schmugge and Jackson 1994; Kerr et al. 2001; Moran et al. 2004; Loew et al. 2006). Typically, remote sensing instruments can only provide the soil moisture information from the surface soil depth down to 1–5 cm. Numerous studies (e.g. Njoku et al. 2003; Walker et al. 2004; Lacava et al. 2005; Njoku and Chan 2006; Gao et al. 2006) point out that microwave remote sensing measurements are affected by surface roughness, topographic features, dense vegetation and soil texture. This indicates that soil moisture data may have limited value on steep topography (Njoku et al. 2000). However, no validation experiments have been conducted on such terrain. As landslides mainly occur on steep slopes, a preliminary challenge is to determine whether satellites can provide a signal in landslide prone areas. Ray and Jacobs (2007) show that there is a strong relationship between landslide events, daily variations of remotely sensed soil moisture from the advanced microwave scanning radiometer (AMSR-E) on the earth observing system (EOS) and rainfall from the tropical rainfall measuring mission (TRMM).

Improving procedures for identification of areas susceptible to landslide triggering

Determination of the soil thickness on steep slopes is a very important stage in drawing up landslide hazard maps, allowing assessment of the volume of material mobilized. In this issue, great help once again may be obtained from remote sensing. Spectral vegetation indices map and spatial patterns of grass senescence are found to be correlated with soil thickness variations on hillslopes; grassland senescence is delayed over deeper, wetter soils that are probable debris flow source areas (McKean et al. 1991). The map of spatial distribution of soil thickness can contribute to giving a global view of potential landslide hazards and obtaining reliable landslide hazard maps. This issue is very important, and it is often neglected in many hazard maps inducing major approximation and even large mistakes in the outcoming results.

Amelioration of landslide warning systems

Risk zoning and the adoption of standards aimed at defining guidelines and land use constraints are an indispensable tool for the management of hydrogeological risks. However, the aim of reducing casualties and damage caused by landslides and floods requires civil protection measures based on increasingly advanced methods and tools for monitoring and early warning (early warning system) for flash floods and landslide disasters.

A very important contribution from soil science can be produced by knowing soil–water characteristic curve combined with soil moisture conditions as well as field tensiometric real-time measurement can be used to estimate the amount of rainfall needed to saturate the slope (Johnson and Sitar 1990) and provide early warning in combination with rainfall measurement.

In Sect. 11.2, we discussed the need for research on how to obtain data about the state of soil moisture, avoiding complex data collection efforts for in situ water content measurements. By combining the information from *landslide hazard maps* with real-time rainfall measuring systems and daily variations in remotely sensed soil moisture (e.g. AMSR-E), it is possible to understand when susceptible areas with significant landslide potential receive heavy rainfall and/or present high soil moisture content which might trigger landslides. Nevertheless, potential landslide locations are very hard to delineate due to the strong influence of local controls (soil thickness, root strength, localized seepage forces and bedding or fractures) and their threshold dependency, while the hydrologic processes that lead to landsliding are local, and the time scales of response to storm rainfall variations may be just minutes.

For the purpose of civil protection, the method for monitoring and alert based on both rainfall monitoring (Guzzetti and Tonelli 2004) and the definition of rainfall thresholds can be effectively integrated by determining alert thresholds of soil water content above which there are local increases in the possibility of landslides and flash floods. Real-time monitoring of such physical parameters can help implement effective “dynamic zoning”.

Improving flood forecast and alert

In the present day, and even more in the near future when the effect of climate change on floods will be increasingly severe, flood predictions are essential in risk planning and management. Such predictions can be a rather difficult task especially in ungauged basins where no hydrological measurements or data are available. As such ungauged basins are of course the vast majority of both global and Italian watersheds, making predictions over ungauged watersheds are a real must for flood predictions; especially in such basins, soil information can play a crucial role. Indeed, many flood evaluation/prediction models are based on infiltration/run-off processes in which the soil plays a crucial role, partitioning the precipitation into run-off infiltration and run-off. Specifically, the *Hortonian* or *unsaturated overland flow* concept of run-off production (Horton 1940) applies in arid and semiarid regions when rainfall intensity exceeds soil surface infiltration capacity, *saturated overland flow* applies in quasi-saturated zone (e.g. riparian zone, soils with little or no water storage capacity, etc.), and finally *subsurface return flow* applies when water infiltrates the soil of an upslope, flows laterally and ex-filtrates closer to the stream channel. Therefore, whatever approach is applied, because different soils have different water storage capacity and different hydraulic conductivity, it is mandatory to have information on the main soil features and their spatial distribution.

Although the crucial role of soil in determining run-off/infiltration processes, peak flow and intensity of flooding is well recognized by both the scientific and technical communities, its implementation in predictive modelling is unconvincing: we move from distributed strongly deterministic models (e.g. Rigon et al. 2006; IHDM, Beven 1989) based on complex physical theory and requiring large amounts of (soil)data and computational time, to statistical empirical black-box models (e.g. CN method, USDA 1986), establishing a statistical correspondence between input (precipitation) and output (run-off) in which the soil information is very simple. Of these two, conceptual models, formulated by a number of conceptual elements each of which is a simplified representation of the one process element of the system being modelled, serve as a trade-off between the deterministic approach and black-box approach.

What is evident from the literature overview is the decoupling between the recognized key role of soil in determining flood events and its implementation in provisional modelling. Specifically, the contribution of the pedologist in ameliorating flood predictions is in its infancy, being still weak from both the hydrologist and pedologist communities the awareness of the great potential of their interaction. Convincing examples of hydropedology, an emerging discipline that mutually benefits hydrology and pedology, have been presented in literature but a systematic analysis of what field pedology has to offer hydrology appears to be lacking especially where/when little information is available (Terribile et al. 2011).

In this contribution, we escape the role of expert on soil hydraulic properties for direct assessment of the soil water balance on a 3D scale. This, strongly deterministic but cumbersome approach, needs the knowledge of the constitutive relationships of water retention and hydraulic conductivity (1) for each soil horizon and (2) their horizontal spatial variability. Moreover, we did not spend so much time in fully established benefit of applying pedology in hydrology (i.e. application of PTF). We focus indeed more on the still hidden contribution of pedology in ameliorating soil component in modelling flood prediction. This choice indeed fits a new vision in watershed hydrology, as stated by : "We need to make models more realistic and useful but we must also figure out a way to embed heterogeneity or the consequence of the heterogeneity into models in a manner that does not require enormous amounts of generally unavailable data. We argue that rather than asking *what*…we must begin to ask questions of *why*".

Hydrologists could (should) translate in equations and incorporate in their numerical models much pedological information embedded in soil survey reports, soil maps and associated databases. The central point is how such potential can actually be transferred into hydrological modelling. In Table 11.7, we report that some soil features can be fruitfully employed in hydrological models without making specific hydrological tests (e.g. infiltration, test with tracers). For example, some features can be directly employed in hydrological modelling (i.e. horizon depth, carbon content, etc.) but more promising and unexplored is the implementation in hydrological modelling of many soil features which have a great but indirect hydrological meaning (i.e. abrupt outline of Fe concretions coming from alternating wet and dry condition; diffuse presence in the soil profile of coatings of manganese appearing in soils with generally high soil moisture; biological activity observed in the field and occurrence of slickensides can produce macroporosity and therefore potentially induce preferential flow paths, etc.).

11.3 Integrated Landscape Management

The previous sections covered various emerging soil issues considering the potential contribution of soil science in key themes such as agriculture, forestry, hydrogeological risk, polluted sites risks, urban planning and archaeology. It is rather evident that soil science along with agriculture, forestry and most productive activities in the landscape must provide multiple answers to the multiple functions of soils/landscapes (see section on agriculture and forestry) to a range of multiple users. Although much of the scientific literature emphasizes these multiple functions/answers, very little is actually available to understand the road map to achieve such huge expectations. Indeed, providing answers to complex issues can be a very difficult task if not impossible (when using not appropriate approaches). Moreover, existing rules and regulations may act as a brake on new developments as does a conservative, risk-averse attitude of a wide variety of stakeholders and policymakers. The different opinions and interests of all these participants, expressed in complex sustainable development debates, may easily lead to paralysis (Bouma 2010). In this complex scenario, here we provide our idea concerning the way ahead for the contribution of soil science to integrated landscape management.

Here, we refer to landscape management as an approach to planning and assessing land uses and human activities across whole landscapes. Its purpose is the long-term maintenance of landscapes to ensure the economic, social and environmental sustainability of the respective ecosystems and resources. The approach is based on an integrated management system, including various stakeholders and interest groups. It is applied on appropriate spatial scales for the necessary time periods in order to achieve multiple management objectives (Wildlife Canada 2006). The aims of landscape management are complex and multifaceted (Hochtl et al. 2007), including the sustainable supply of foods and raw materials from agriculture and forestry, recreational spaces, and the conservation of abiotic, biotic, spatio-temporal and cultural resources. Integrated environmental management is a relatively recent concept. It is the result of awareness by local operators and policy makers who have identified the need to work together to create a network of knowledge and skills in dealing with such complex issues such as land management.

11.3.1 New Needs and the Potential Contribution by Soil Scientists

In this book, several chapters have been shown that the Italian landscape has been modified strongly by land use (e.g. terracing) and much of Italy exhibits a clear human imprint. It has also be emphasized that characteristics and qualities of soils are severely affected, also because of processes of land degradation (chapter on soil threats) and then mitigation of soil threats is a priority. To this perspective, we propose here that integrated landscape management must be a key future soil issue.

Table 11.7 Soil features commonly occurring in databases and exploitable in hydrological modelling (Terribile et al. 2011)

Soil features directly usable as input in hydrological models	Indirectly usable soil features (i.e. to condition hydrological models)		
	Soil features	Simplified hydrological meaning of soil features	Examples of modelling conditioning (1D, 2D, 3D)
Horizon depth	*Mottles*	Alternating wet and dry condition with a strongly wet period	Bottom boundary condition: setting high fluctuating water table depth
Granulometry	*Fe–Mn concretions (abrupt outline)*	Alternating wet and dry condition with a strongly dry period	Bottom boundary condition: setting free drainage (hydraulic head gradient = −1)
Organic carbon	*Fe–Mn concretions (diffuse outline)*	Alternating wet and dry condition with a strongly wet period	Bottom boundary condition: setting fluctuating water table depth
Coarse fragments	*Greyish colour of the soil matrix (not lithochromic)*	Strongly redox condition induced by water stagnation	Bottom boundary condition: setting low water table depth
Cracks	*Clay coatings*	Abundant water fluxes enable to be moved in macropores	Use of preferential flow approaches (e.g. double permeability, composite porosity, etc.). Occurrence of strong 2D/3D flow field (not slope-induced)
Electrical conductivity	*Fe coatings*	Strongly redox condition induced by water stagnation	Bottom boundary condition: setting low water table depth
	Mn coatings	High moisture in soils	Simplified flow field during wet season (e.g. gravitational flow)
	$CaCO_3$ coatings	Alternating wet and dry condition with a strongly dry period. Stabilization of soil pores	Bottom boundary condition: setting free drainage (hydraulic head gradient = −1)
	Gypsum coatings	Very dry soil environment	Bottom boundary condition: setting free drainage (hydraulic head gradient = −1)
	High biological activity; high frequency of macropores and living roots	Presence of macropores and potential occurrence of preferential flow paths	Use of preferential flow approaches (e.g. double permeability, composite porosity, etc.). Occurrence of strong 2D/3D flow field (not slope-induced)
	Slickensides	Strongly alternating wet and dry condition inducing preferential flow paths	Use of preferential flow model (e.g. double permeability approach, composite porosity approach, etc.). Occurrence of strong 2D/3D flow field (not slope-induced)
	High CEC	Filtering ability towards xenobiotics (especially if cationic)	Setting of parameters for solute transport (e.g. retardation factor > 1 in convective–dispersive equation)
	High andic properties	Filtering ability towards xenobiotics. High water retention and hydraulic conductivity	Setting of parameters for solute transport (e.g. retardation factor > 1 in convective–dispersive equation) Non-applicability of standard PTF

Below we substantiate, the relevant "needs" for integrated landscape management and potential "answers" to these needs by soil scientists. Among other things, landscape complexity, rules and regulations and the coexistence of different local interests suggest the development of new models for interdisciplinary collaboration and the translation of scientific research into easy-to-use information for stakeholders, policy makers and end users.

In addition, Bouma (2010) describes transdisciplinarity as an indispensable approach in soil science. He emphasizes the need to establish teams of scientists, policy makers and stakeholders as *communities of practice* (CoPs), but also teams of soil scientists (combating current atomization of subdisciplines) as *communities of scientific practice* (CoSPs) with special attention to quality control, education and basic research, which is vital for the future of the soil science profession. Yet, the crucial question concerning how these CoPs and CoSPs could usefully interact to solve landscape multifunctional issues still remains largely unsolved. We believe that the way ahead in this respect must be sought in integrated approaches combining physical, chemical, biological and space–time techniques. These approaches mean the use of various types of knowledge, including stakeholder expertise and knowledge derived from scientific measurements and model simulations.

The systems must account for both simple, rapid and cheap procedures but also for complex, cumbersome and expensive data-intensive procedures, according to the types of study and the spatial and temporal scale at which solution is sought. These systems are generally defined as DSS. Numerous studies have documented the need and benefits of integrated DSS for various environmental landscape applications (Miller et al. 2007; Santhi et al. 2005; Koormann et al. 2005; De and Bezuglov 2006). They have evolved and developed with the ever demanding necessity to analyse a large number of options for decision makers. Thanks to the enormous strides made in information systems and web technologies in the last decade, these systems have rapidly spread in the field of environmental sciences.

DSSs are computer-based information systems that support organizational decision-making activities specially for specific situations, where there is an increasing level of uncertainty about the problem at hand and where there is a high impact relative to the correct decisions to be made. DSSs serve the management, operations and planning levels and help to make decisions which may not be easily specified in advance. A properly designed DSS is an interactive software-based system intended to help decision makers to compile useful information from a combination of raw data, documents and personal knowledge to identify and solve problems.

It is important to point out that the present-day increased emphasis on sustainable development places an extremely great responsibility on local authorities to take a longer-term view of the likely impacts of decisions involving landscape and the environment. To support such decisions, a DSS tool can profitably link the relevant science with the practical requirements of implementing planning policy, making available to non-specialists, models, information and understanding covering a wide range of relevant scientific disciplines.

DSSs have evolved into model-driven DSSs, a category or type of DSS that emphasizes access to and manipulation of a simulation model made accessible to a non-technical specialist such as a manager through an easy-to-use interface (Power 2008). DSS specifically designed to deal with spatial problems are called S-DSS. S-DSS provide an integrated set of flexible capabilities: the implementation of such a system can be achieved using a set of linked software modules. The objective of S-DSS is to provide a framework for integrating analytical modelling capabilities, database management systems, graphical display capabilities, tabular reporting capabilities and the decision makers' expert knowledge. In the context of landscape management planning in particular, land use planning requires explicit spatial visualizations of the result of the DSS output (i.e. thematic maps). Hence, the integration of a GIS and environmental simulation modelling within an S-DSS provides a simple framework to understand, for example, the spatial variability of different soil and water quality variables within the context of the landscape. Thus, various management scenarios can be studied and evaluated by altering model input parameter values, thereby functioning as a planning tool. In addition to hydrology-based models, other models such as ecological (i.e. habitat suitability) could be integrated into the S-DSS (Bryan 2003).

Easily accessible systems (web-based), easy to use by non-computer-experts started to appear only recently and show very high potential. These tools can now be conceived because developments in Internet technologies make it indeed possible for geographically dispersed groups to access and process spatial information that is distributed across the Internet on different platforms. Decision makers can then have real-time (or near real-time) access to critical, accurate, complete and up to date spatial data held in multiple data stores that may not be usually managed or maintained by them (Miller et al. 2002; Tan 2002; Prato 2003).

Moreover, Web-based S-DSS could be available to individuals, interest groups and public bodies, allowing classical top–down decisions to be integrated with bottom–up contributions to landscape planning and managing. Despite the crucial importance of having these Web-based systems, in the world, there are only rare prototypes that have been designed to address very specific issues (e.g. Miller et al. 2007; De and Bezuglov 2006; Rao et al. 2007), and there is very limited experience of the combination of S-DSS on a web-based GIS (Rao et al. 2007).

Nevertheless, it is indeed possible to observe large changes in this research area. For instance, there are experiences where, despite the lack of observed data at field scales, decision makers and planners have effectively used S-DSS by simulating the relative environmental/economic benefits of landscape policy under a variety of scenarios. UK experience (Culshaw et al. 2006) shows that such system can help land use planning, aiming to secure the most efficient and effective use of land in the public interest enabling both sustainable development and growth, which includes not damaging the environment for future generations.

In Germany, an eco-hydrological and morphological DSS developed for use at both ministerial and regional levels is used in North Rhine Westphalia (NRW) to help comply with the EU Water Framework Directive. The developed system generates different scenarios for morphological restoration measures, assesses their impacts and proposes a programme of morphological measures and preliminary cost estimation for all relevant watercourses in NRW (Sewilan and Nacken 2010).

Also in Germany, a Web-DSS has been developed to monitor and predict the hydrodynamic and water quality in Lake Constance in the Bodensee region (www.bodenseeonline.de). The system delivers to the stakeholders online or real-time information about the up to date status of the lake. Three-dimensional numerical models calculate the interpretation of the lake status. These models must include all relevant processes affecting lake hydrodynamics and major ecological components. The models calculate the transport of substances and simulate the nutrient cycle (Lang et al. 2010).

The University of Purdue (Indiana) has developed a watershed management web-based S-DSS (https://engineering.purdue.edu/~lthia/). The system uses web-GIS for watershed delineation, map interfaces and data preparation routines, a hydrologic model for hydrologic/water quality impact analysis and web communication programs for Internet-based system operation.

In Italy, there are few examples of web-based, model-driven S-DSS applications. In the Po Valley, a web-based interactive DSS has been developed to manage the growing of high-quality durum wheat crops for a less intensive and more sustainable method of farming (www.horta-srl.com). The users of this system are single farms, cooperatives of farms or single crop managers. The users directly interact with the DSS, inputting their specific crop and management data and viewing the DSS output. They can also interact with the provider for help in interpreting the DSS output.

Possibly, the first example of web-based S-DSS enabling the multiple functions of soils and landscape to be handled was developed in the framework of the SOILCONSWEB project (www.landconsultingweb.eu) involving scientist from universities (Università di Napoli Federico II), research institutes (CNR ISAFOM), the Administrative region of Campania (SeSIRCA) and a private company (ARIESPACE). The project in a test area in southern Italy aims to develop a model-driven, web-based S-DSS able to support decisions on landscape issues, to ensure both the best soil conservation and land management and easy landscape implementation of some important environmental EU Directives and Regulations (and national action plans). The system is designed around a central concept of soil and its multifunctionality. It is based on the application of GIS tools coupled with dynamic modelling (i.e. soil hydrological and crop growth modelling) and the acquisition in real

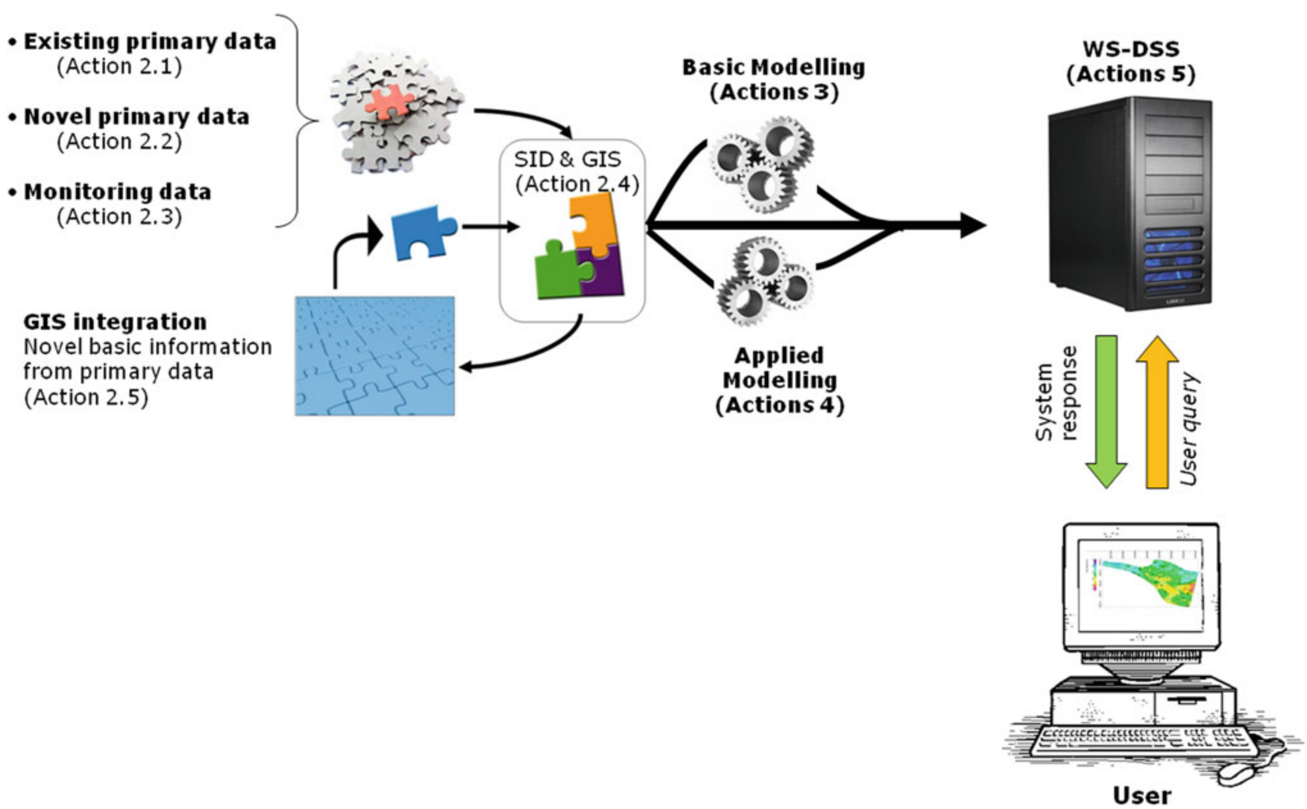

Fig. 11.8 Flow diagram illustrating an example of spatial decision supporting systems (*S-DSS*). In general terms, upon user request through Internet, the system (1) collects basic data (e.g. primary data), (2) performs a series of modelling on a remote server and finally (3) provides the answer to the user

time or near real time of environmental data (i.e. climate data). The users (farmers, local authorities, policymakers, agronomists, soil or environmental experts, etc.) interacting via the Internet can select an area of interest and query the S-DSS to get useful, updated information to make decisions about land management and soil conservation. In Fig. 11.8, a conceptual scheme is given of the system functionality upon the user's request. In general terms, upon user request through Internet, the system (1) collects basic data from either/both static (e.g. map of a specific soil feature) and dynamic (e.g. climate data of the actual year) databases, (2) on a remote server performs a series of modelling relevant for the user requests and finally (3) provide the answer (report, map, etc.). At present, modern tools and technologies enable the multiple functions of landscape management to be addressed. This can be done through a strongly soil-focused approach using both chemical, physical and biological soil features but also most importantly many soil system functions.

In this regard, soil science can indeed play a primary role, but modern soil experts are required to have a comprehensive view of the system taken as a whole (SPA). To achieve this goal, soil scientists are required to work side by side with other experts such as soil hydrologists and modelling experts. This is the case for instance when addressing issues such as the dynamic behaviour of soils, both in terms of water balance and response to crop growth. Soil experts are thus required to have extensive knowledge, culture and the necessary tools to collaborate on land management studies, including the development and implementation of model-driven and spatially based DSS.

11.3.2 The Future Soil Scientist as a Knowledge Broker

Future soil scientist must have not only an integrated and comprehensive view, but also an improved interaction between the soil science and policy makers and stakeholders. In this regard, Bouma (2010) identifies four key points to help the move in this direction: (1) creating awareness for the policy cycle as a basis for research planning; (2) providing a range of "options to choose from" when dealing with certain sustainability problems rather than offering straightforward "solutions"; (3) following the "knowledge chain" when mobilizing knowledge; and (4) improving communication.

The core issue is then to find the right way to render comprehensible communications between the world of decision making and that of scientific research and the civil society, using tools and methods based on rigorous scientific approaches. Studies of landscapes and land use are good examples to show how these interactions are actually needed. Participants in land use studies operate on a wide variety of scales. Farmers deal with issues at the field or farm scale; policy makers instead also have to consider the potential problems at the landscape or regional and national scale and beyond. In these scenarios, one of the main problems that can occur is that the European Directives issued on a national scale could be "translated" to the farm and field scale without considering in detail the specific issues at this scale.

The four key points are thus justified in these concerns. The multiscaling process (upscaling and downscaling) requires a great deal of communication by the experts involved: the so-called knowledge chains need to be created that allow not only multiscale spatial problems to be dealt with, taking into account the effects that changes of scale can have on a phenomenon studied, but also improvement in communicating basic research results to the stakeholders.

In these contexts, modern soil experts can play the role of "knowledge brokers": interacting with stakeholders, they can suggest a research path to address an issue at different spatial scales and at the same time can serve as a liaison between the world of research, policy-making and society.

11.4 The Key Future Soil Issue: Educating Soil Scientists, Through a Novel Soil Literacy, to Solve Emerging Problems

Many issues formerly pointed out in this chapter require that soil scientists and inter alia pedologists should acquire novel skills. It is common sense now that the future of soil science research lies in the ability of scientists to address many different challenges related to environment, agriculture and forestry. These themes draw attention to the dynamic and multifunctional role of soil. The complexity of these challenges requires advanced technical tools such as geographical space inference by means of DSM, attributing space inference through PTF and/or mechanistic models, handling most state-of-the-art probe sensing technologies. Moreover, the development of remote (web-based) or desktop S-DSS has shown to be a concluding device to enhance visualization and decision making at the landscape scale. In this connection, it is necessary to emphasize that the sole use of traditional tools has little future and could probably be even counterproductive to tackle many emerging and often dynamic landscape issues. Therefore, we believe that practical and exhaustive tools should be made available to give concrete responses to the many and diverse demands of society as a whole and of local communities. This obliges soil science researchers to pursue a new soil literacy simply because these basic requirements by local communities are only rarely addressed.

This is even more important given the need to answer today's knowledge paradox (Bouma 2010): in short, there is evidence that soil science "research results that could potentially provide a major contribution to innovation and sustainable development are often not accepted by or implemented in society". We believe that this problem poses a very serious question about the future and even existence of soil science and its contribution to society's needs.

A better insight into this serious problem may be attempted by recalling the classic work of Gibbons et al. (1994) in which he distinguished traditional monodisciplinary mode-1 science versus transdisciplinary mode-2 science in which scientists of different disciplines work together with various stakeholders and policy makers. Mode-1 occurs in an academic context, while mode-2 rarely occurs in academics but operates in a context of application and is thus more problem oriented. Mode-1 is characterized by autonomy, based on the independence of science and (in our view) the vast majority of research published in international soil science journals. Differently and more importantly, mode-2 is subject to social accountability.

Thus, considering this framework and country needs it is not surprising that funding agencies are strongly and continuously shifting towards mode-2 approach. Possibly, the vast majority of published research being of the mode-1 type, this may have played an important role in establishing the knowledge paradox in soils as described above. Thus, it is hardly surprising that our vision of future issues in soil science has been strongly focused on mode-2 research.

However, the mode-2 approach requires that we do not lose sight of objectivity in the approach to different problems; it is essential that scientific rigour is never lost even in a multidisciplinary and applicative vision of research. We thus believe that the mode-2 approach requires extensive high-quality research (as does the mode 1 type) and academics must provide their scientific contribution also for mode-2 research.

Here, we emphasize that environmental studies—that arise as multidisciplinary, multi-spatial and multitemporal studies—require that soil science experts play a key role as intermediaries between the aims of research and the demands of society.

This section in this chapter starts from basics which are indeed some of the major problems of pedology and soil science. It first describes the current state of the soil science discipline in Italy and around the world, then addresses the difficulties of the educational system and finally emphasizes promising prospects for the future.

The background of this outline is that novel approaches are needed in multidisciplinary framework to address societal environmental problems associated with soil (e.g. Hartemink et al. 2008) and our graduates need these skills but many universities have lost capacity in this soil science discipline but eventually there is much room for improvements.

Past and present-day problems in soil science and pedology

Pedology and soil science are known to have experienced a long period of crisis worldwide (Ibanez and Boixadera 2000), a phenomenon which has been well documented since 1970 (Dudal 1987; Nachtergaele 1990; Jacob and Nordt 1991; Hudson 1992; Miller 1992, 1993; Sposito and Reginato 1992; Warkentin 1992; Gardner 1991, 1993; Notohadiprawiro 1993; Greenwood 1993; Hillel 1993; Ibáñez 1998; Ibáñez et al. 1993, 1997, 1998; Bouma 1994; Bullock 1994; Bridge and Catizzone 1996; Yaalon 1995, 1996a, b, 1997a; Basher 1997). There is a broad consensus on the fall in credibility of soil science. The causes of this worrying decline in soil science have been attributed to various factors inside and outside the discipline. According to Hartemink et al. (2008), they are split into internal or structural factors and external factors, that is factors related to the economic situation.

Among the internal factors, (1) the traditional strong tie of soil science to agriculture and (2) the trend of educational programs to emphasize the agronomic aspect of soil science should certainly be considered. These tendencies often contradict both the interest of students in environmental issues and the general lack interest of people from developed countries in agriculture. At international level, the strong relationship of soil science to agriculture has often been blamed for the isolation of soil science from other environmental disciplines (Baveye and Jacobson 2008; Ibanez and Boixadera 2000).

In Italy, such strong relationship between soil science and pedology with agriculture has been and it is still mainly institutional since (1) the vast majority of academic soil-related disciplines are taught in agriculture faculties, (2) at local, regional administrative level, the vast majority of soil offices are present in agricultural departments. Despite these tight relationships, as shown in Chap. 1, pedology had its own rather autonomous development being partly involved also in geology and other environmental fields.

Then in the Italian case, we must add to the causes of soil science difficulties in fulfilling its potential also internal factors including the difficulties in a closer interaction with other scientific domains, the narrow view on what is pedology and what is not pedology, the strong attachment to standard soil mapping and soil classification or also standard soil chemistry forgetting soil behaviour in the field, the difficulties in useful interactions between Italian soil scientists, the difficulties in catching present-day opportunities and challenges.

Looking at a general scenario, some authors also emphasize the "inability (of teachers) to excite" factor, which is in conjunction with and derives from the inability of teachers to find their job still exciting (Baveye et al. 2006).

Among the external factors, there is the evidence that students are attracted by the chance of getting a well-paid position in society after taking a bachelor's degree. In a famous article, Engell and Dangerfield (1998), referring to the current period as the "Age of Money", argued that the road to the success of academic disciplines depends on how they meet at least one of these three criteria:

- Promising an above-average return throughout life,
- Studying money themselves (e.g. tax, financial or economic fields),
- Receiving a significant amount of money from external contracts, fellowships and financial support from private companies.

It is relatively clear that soil science, like many environmental disciplines, has great difficulty thriving in the present era under pressure from such criteria. Training in soil science does not ensure large quantities of money (such as medicine, veterinary medicine, biomedical engineering, genetics and nanotechnology), nor does it directly study money (such as economics, or finance), and finally it competes unfavourably with fields such as civil engineering and biotechnology which receive more substantial amounts of money.

Other external factors concern political change. Environmental sciences usually produce usable outputs only in high-profile, long-term policies. For example, pedology has often dealt with the rise in quantity and quality of production, and more recently also with environmental protection, two long-term policy targets. Many political analysts agree that politicians in democratic systems now focus on short-term targets, because their primary objectives are polls. Short-term political vision dominates all our institutions, which is why the sciences that contribute to long-term policies may have a hard time. This political vision is obviously questionable and is certainly inadequate from both the cultural and scientific viewpoint, inasmuch as environmental issues themselves require long-term planning.

Despite the obvious criticism, pedology should reckon with the institutional steady state of short-term political planning if the goals are its survival as discipline and its contribution to improvement in well-being.

To appreciate the importance of a short-term vision, it may be useful to underline its significant physiological basis. McClure et al. (2004) showed that human beings actually evaluate immediate rewards using a different area of the brain than they use in evaluating long-term rewards. Experiments with MRI scanning indicate that longer-term rewards are evaluated with a part of the brain more associated with rational calculation, while shorter-term rewards are evaluated with a part of the brain that is more associated with emotions. It is also clear that mass media and the actual functioning of our society bring out the emotional part and the short-term rewards of our mind.

We all would agree that good scientific work cannot be adapted/governed by this "short term reward" and also that many of soil science results deal with long-term issue (e.g. good agriculture planning), but we also believe that not taking in any account this scientific evidence concerning the importance of "short term rewards" may push soil science into a corner. Here, we like to recall that (along with much other work) also on the base of McClure et al. (2004), the new discipline of neuroeconomy has been created and that may be soil science require something similar such as a neuropedology research field.

Yet, despite all the above (often negative) evaluations, demand for soil information has increased in quality and quantity everywhere in the world and very much so in Italy. In addition, the number of scientific articles published each year on soil has continued to rise exponentially (Baveye et al. 2006; Baveye and Jacobson 2008), despite the drop in student enrolment into soil science departments. This indicates, among other things, that considerable soil research has migrated into departments of physics, chemistry, ecology and environmental engineering. Here, no doubt, some people do a great job, but the general trend is to study soil within the relatively narrow boundaries of each discipline.

Therefore, the problem may not lie in a depressed "demand for pedology". Perhaps demand has changed and we did not realize this, and perhaps we have forgotten our stakeholders. Their demand has certainly changed not only in issues to be addressed (i.e. more environmental and less farming), but also in the required approach which must often be dynamic and capable of providing a rapid response (short-term rewards) and eventually in the way these issues must be communicated. In this perspective, we believe that it is important to rethink about soil science and pedology, to identify new paradigms and prepare tools for facing modern challenges.

Soil science and pedology in the education system

It is well known that the crisis in soil science has influenced university education. The decrease in the number of students is a common topic of discussion in the international soil science community. Surveys conducted in 1992 and 2004 showed that soil science training is experiencing a significant decline in United States and Canada (Baveye et al. 2006) with a drop of about 40 % in MSc and PhD enrolments in US and Canadian universities in 2004 compared with 1992. Similar trends are also recorded in other countries, such as the UK where most soil science teaching has disappeared over the past two decades (Baveye and Jacobson 2008).

A survey conducted by Hartemink et al. (2008)—based on a questionnaire sent to 43 colleagues from universities in Europe, North America, South America, Africa and Oceania, and on long-term data about the number of students between 1980 and 2005—showed that the general trend is that of a worldwide decrease in soil science student numbers. Given that, the total number of students has not decreased, the decrease in soil science students is even more striking. Students seem to prefer other degree programmes such as economics, law and medicine, which are deemed to ensure easier and higher money earnings.

By deeply analysing the phenomenon, it can be easily discovered that the trend does not pertain to only soil science, but also to geology, geography, forestry, chemistry (Baveye et al. 2006), and to various other disciplines such as physics. It is not just the number of students in soil science, but also the number of university staff, the various research centres and soil science societies.

The numbers of university staff are almost everywhere in decline. For example, in the US alone, at Cornell University, numbers of researchers and teachers decreased from 23 to 10 from 1990 to 2008, while at the University of Illinois, researchers and teachers decreased from 17 to 7 in the same period. Staff ageing is indeed evident in many soil science departments and research centres (Boshoven and Hartemink 2003; Hartemink et al. 2008).

In Italy, soil science seems to be holding its ground in universities both within soil chemistry (agro-chemistry) and pedology (Zanini 2011). Analysis of the training programmes in 2011 shows that soil is taught in 26 Italian universities in 75 courses of studies.

Looking more closely to the occurrence of pedology in different Italian Universities, Zanini (2011) summarized the following scenario:

- Agricultural Faculties (total for Italy: 24): 17 faculties where pedology is taught;
- Natural and Biological Sciences (total for Italy: 45): 6 faculties where pedology is taught;
- Engineering (total for Italy: 56): 1 faculty where pedology is taught;
- Landscape Planning (total for Italy: 1): 1 faculty where pedology is taught;
- Pharmacy (total for Italy: 29): 1 faculty where pedology is taught;
- Often soil is not a fundamental course but is considered as "ancillary" in student curricula.
- In the country, there is also 1 master course and 9 PhD programs where pedology is taught.
- However, it should be pointed out that the scientific discipline of pedology (AGR/14) is always at risk because of the small number of lecturers.

11.4.1 Rethinking Soil Science and Pedology to Meet Present-Day Challenges

Some researchers (e.g. Ibanez and Boixadera 2000) have indicated the need to identify new paradigms from which to promote soil science and pedology in the future, among which:

1. the need to transform a highly applied discipline into a more basic one within earth sciences;
2. better linking of applicative research with environmental issues and less to agronomic issues;
3. among agronomic issues, a greater focus on state-of-the-art techniques such as precision farming.

We believe that it is not necessary to choose between these paradigms and that all are quite feasible; rather it is mandatory to adopt a new approach to soil study and research. Such an approach requires critical work on the following topics:

4. enlarging and enhancing the (vertical and horizontal) spatial and functional dimension of soils: from pedon to regolith and landform and from point/farm implementation to a landscape functioning;
5. rooting soil in the social and economic dimension: from top–down decision towards bottom–up contributions.

Advocates of paradigm (1) propose to solve the soil science decline placing greater care in and more intimate understanding of the complex processes occurring in soils (e.g. Sposito and Reginato 1992; Gardner 1991; Yaalon 1996a, b). Basic research provides a constant reservoir of knowledge that will be used in applied research to address agricultural, environmental and urban problems at regional and global scales. Underlying this position, there is the uniqueness of the soil body and of the processes that govern its development; the essential role that soil plays in water, chemical elements; cycles of organisms; the integrated and multidisciplinary nature of soil science. The challenge will be to adapt laboratory studies and modelling simulations to a natural three-dimensional body (Sposito and Reginato 1992).

Advocates of paradigm (2) agree to give less attention to agricultural issues and greater emphasis to issues related to sustainable agriculture or to critical environmental issues at a global scale such as erosion, desertification and climate change (e.g. Hillel 1987; White 1993; Bouma 1994; Bullock 1994; Singer and Warkentin 1994; Bridge and Catizzone 1996). The traditional relationship of pedology with agriculture would, therefore, have led to isolation of soil science and pedology from other disciplines. The idea is not to deny the past or abandon agricultural applications, but certainly broaden research horizons. Public opinion in modern industrialized countries is much more interested in environmental problems (erosion, contamination, etc.) than to the increase in crop yields in their countries. There food production is already very abundant due to the high crop yields per unit area.

Paradigm (3), focusing on new agricultural techniques such as precision farming (e.g. Cambardella and Karlen 1999; Van Alphen and Stoorvogel 2000) emphasizes the need to optimize crop management and yield by solving soil spatial variability through the use of new technologies such as proximal and remote sensing, information technology, and geospatial tools.

The topic presented in (4) recalls two main aspects: the enlargement of both the vertical and horizontal dimension of soil. It is necessary to study the soil as a component of a more general three-dimensional system which starts from the pedon to get to *Earth Critical Zone* (NRC 2001) including the "whole soil-regolith" (Hubbert et al. 2001; Schoeneberger 2005; Lorz et al. 2010). Although the topic is not new in literature, the regolith is still generally considered by soil scientists as the layer made of rock and minerals which underlies the solum (the only subject of interest). Therefore, the regolith is largely ignored, although it is of fundamental importance to understand the interactions between soil management and for instance, groundwater contamination or vulnerability to erosion. The horizontal dimension of soils should also be widened: from "farm and forest landscapes" towards "whole land surface" including not only agricultural and forest areas, but also wetlands, coasts and urban lands. The management of these lands has now become one of the major environmental issues in developed countries.

The topic in (5) aims to investigate soils in terms of both functional and spatial units (Lin 2010). The goal then is to fulfil the DSM part (spatial units) but above all to focus on the space inference part (functional units) of the digital soil (risk) assessment framework (Carrè et al. 2007), with which to steer a sort of digital functional hydropedology based on spatially continuous mechanistic SPA modelling. It uses pedological inputs in the form of digital maps and allows simulation, for example, of the water balance, the fate of pollutants, and organic carbon decline not at a few discrete geographical locations but in a continuous spatial context. This approach is well suited to the need to assess soil functions and threats formalized by the EU Soil Thematic Strategy (CEC 2006), in order to contribute to some important social issues including energy provision, food security, climate change, water protection, environmental protection and biodiversity. Finally, the topic (6) aims to emphasize the need to integrate classical top–down approaches with bottom–up contributions. In this respect, Bouma (2010) emphasizes the importance of stakeholders (CoP).

All the presented paradigms express fundamental concepts and should certainly be considered as integrated with each other. For example, the need for agricultural practices and sustainable land management obviously requires a synergistic effort of soil scientists in both basic and applied research.

Clearly, the complexity of reality leads to a growing demand for holistic approaches (Anon 1992). In order to contribute to sustainable land development, it is certainly useful to emphasize the importance for soil scientists to cooperate more closely with professionals from other disciplines and also to consider legal, economic and social aspects (Bridge and Catizzone 1996). Only this kind of approach would facilitate to find new solutions to new problems, to find new application domains and to legitimize the discipline and its practitioners.

11.4.2 We Need a New Generation of Soil Scientists Capable of Facing Emerging Problems

Future trends in soil science and pedology require that soil professionals diversify their expertise while maintaining a "core" (e.g. ability to describe and analyse soils in the field, understanding soil landscapes, deep understanding of soil chemistry, soil physics and soil biology) to be able to tackle new paradigms, new needs, new technologies, and new mathematical and conceptual tools. However, it is clear that not all future demands made upon soil science that range from DSM to SPA modelling or to soil chemical modelling can be addressed by pedologists alone. It is also misguided to consider building such expertise in single soil scientists, especially as working groups dealing with emerging problems in soil science are now a widely used option.

A realistic solution seems to be training up new "T"-shaped researchers following Bouma's (2010) suggestion. Here in Fig. 11.9, we adapt this idea to our focus in which broad basic soil science training and knowledge (horizontal roots moving through different soil-related disciplines) must coexists with in-depth specialization (vertical roots). Any single soil scientist or pedologist should enhance his/her horizontal roots acquiring a better knowledge of soil science fundamentals and obviously most importantly maths and statistics as many soil scientists "apply quite elementary statistical techniques out of context and without understanding" (Webster 2001). At the same time, single soil scientists or pedologists should enhance their vertical roots acquiring specialization on a specific topic, preferably of great importance in the general framework of emerging problems.

This enhancement of both verticals and especially horizontal roots between different soil scientists communities should create a large synergy as depicted by interconnecting roots (Fig. 11.9) enabling future much higher production in

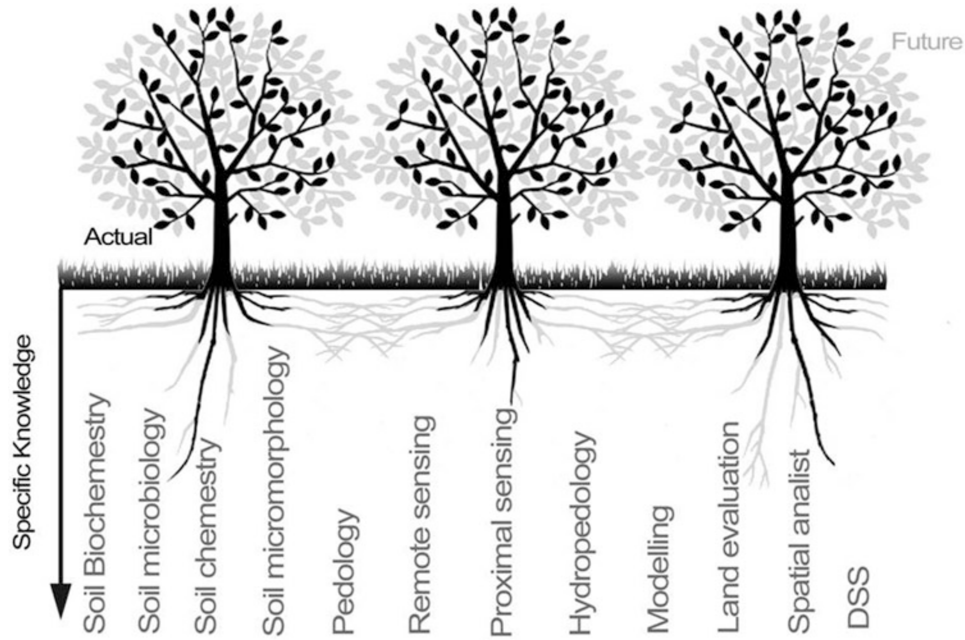

Fig. 11.9 Schematic view illustrating the need for a novel approach to soil education. Multidisciplinary basic soil science knowledge (*horizontal roots* moving through different disciplines) must coexists with in-depth specialization (*vertical roots*). *Black root/leaves* refer to actual scenario; *grey roots/leaves* refer to the required future scenario

soil knowledge relevant to society needs (grey leaves in Fig. 11.9) and then empowering soil science in society.

Among these new soil scientists and pedologists, we believe that (along with other highly specialized figures) the following professional figures should be included: DSM experts, specialized in deriving auxiliary and continuous environmental information for better spatialized soil data; scaling experts involved in downscaling and upscaling different measurements having different measurement supports, Geostatisticians involved in spatial inferences studies and studies to investigate physical data across spatial scale; experts in modelling, essential for study and model environmental and very complex dynamic processes (i.e. soil water and pollutants balances); hydropedologists experts in interpreting hydrological data for studies on soil functional properties and characteristics; experts in S-DSS for developing spatial tools useful in supporting decision on land management from field to coarser scale; soil-based landscape planners, specialized on soil functions and potentialities in the context of land use and sustainable management; experts in transferring soil information across disciplines and experts in policy interaction (see Knowledge brokers, see Sect. 11.3.2).

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Short Curricula in Alphabetical Order

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