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Restoration and Development of the Degraded Loess Plateau, China

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Cover caption: Front cover: Terraced fields, a typical rural landscape of the Loess Plateau. *Back cover: Left*: Apple trees, planted extensively in the Grain-for-Green Program. *Center*: Resource exploitation by small-scale oil well drilling. *Right*: A traditional method of milling cereals

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Preface

The Loess Plateau of China is known to all the world for its serious land degradation/desertification problems, which have both natural and anthropogenic aspects. This book presents state-of-the-art scientific evidence and technological innovations to restore degraded lands on the plateau. Also included are case studies of policy and project results over the past 30 years, based on the research in collaborative projects between China and Japan.

In the Loess Plateau, the Grain-for-Green Project and Western Development Action were launched by the Chinese government in the 1990s and the beginning of the twenty-first century, respectively. These influential programs emphasize ecological protection and economic development in the region. This book describes how ecological restoration and protection have contributed not only to conservation of soil and water, but also to economic development. Furthermore, we present challenges in the region resulting from such development interventions, which have not yet been fully addressed. These include soil and vegetation degradation caused by improper farming activities, excessive energy resource exploitation, economic disparity between urban and rural residents, environmental impacts of ecosystem or vegetation restoration, conflict between monoculture-based plantations and biodiversity conservation, and other factors. We still face old and new problems; however, these must be solved in the near future.

The Loess Plateau is a very rare and esteemed success story in overcoming desertification and land degradation problems, at least in some respects. This noteworthy success has been achieved by appropriate policy measures, supported by a rapidly developing Chinese economy and dissemination of effective technology based on accurate scientific understanding. Readers can learn basic theory of desertification/land degradation and practical measures to combat desertification and restore degraded lands through academic results based on previously published peer-reviewed articles. Such policies and projects were initiated in the 1990s, and their effects were observed in the first decade of the twenty-first century. Thus, now is the right time to show these amazing reports to the world.

The contents of the book are summarized as follows.

1. Case studies of success or failure in practice, based on peer-reviewed and academically verified evidence. Rare success stories of good practices in the field of combating desertification are highlighted.
2. Description not only of technical issues such as erosion control and breeding of stress-tolerant plant species, but also of socioeconomic measures (such as Grain-for-Green) taken by the Chinese government, and lending policies with support from the World Bank.
3. Presentation of comprehensive measures against desertification, such as water and wind erosion, salinization, and deforestation.

We anticipate that this book will be read by an academic audience, including professors, researchers, and students above the undergraduate level. It will be of interest to those in the academic fields of soil physics and chemistry, plant nutrition, rural development, rural engineering in agricultural sciences, social technology and civil engineering, biology, ecology, climatology, physical and human geography, development economics, international cooperation, and official development aid in economics. It will also provide useful information for engineers, government officials, NPOs, and NGOs involved in afforestation, ecological restoration, combating desertification, disaster prevention, and sustainable rural development.

This book was edited based on results from collaborative projects between China and Japan, especially from “Researches on Combating Desertification and Developmental Utilization in Inland China.” That project was funded by the Core University Program from the Japan Society for the Promotion of Science (JSPS) and the Chinese Academy of Sciences (CAS) over the 10 years from fiscal years 2001 to 2010. Thus, we express our deepest gratitude to Professor Tian Junliang and Professor Shinobu Inanaga, who initiated the project and have made tremendous contributions to the development of our collaborative activities through their strong leadership.

Since the project began, Tottori University has been adopted for the twenty-first Century Centers of Excellence (COE) Program and Global COE Program and designated a Joint Usage/Research Center by the Japan Ministry of Education, Culture, Sports, Science and Technology (MEXT). This action acknowledges the university’s development as a core foundation of studies/education in the field of dryland sciences in Japan. Further, the Institute of Soil and Water Conservation (ISWC) was adopted for a CAS Western Action program and Chinese Ministry of Science and Technology (MOST) project, establishing its stable position as a research core base in China.

We are very grateful to Dr. Nigussie Haregeweyn Ayehu, who helped and supported the editing work. We are grateful to Springer Japan and to Tottori University, who facilitated the publication of this book. The work was also supported by the Global Center of Excellence for Dryland Science, funded by MEXT.

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Part I
Nature of the Loess Plateau

Chapter 1
Location, Geology and Landforms of the Loess Plateau

Mei-Jie Yan, Qiu-Yue He, Norikazu Yamanaka, and Sheng Du

Abstract The Loess Plateau is a highland region in north-central China with average elevation about 1,200 m. It has the thickest known loess deposits in the world. Although there are several definitions in the literature for the plateau boundary and area, two definitions are the most commonly reported. The first of these defines the plateau from the standpoint of physical geography. As a large geographical unit, "Loess Plateau" is defined as the highland area with thick loess deposit, covering about 380,000 km^2. Another commonly accepted definition, is that of the "Loess Plateau region", which refers to a larger loess-distribution area with loess landscape and related environmental characteristics, covering about 640,000 km^2. Formation of the plateau began about 2.6 million years ago. Information about past global climate change has been derived from samples taken from deep layers of loess deposit. Since loess is highly subject to erosion, a unique morphology has developed in the region. Typical landforms are loess Yuan, Liang, and Mao and various valleys of different erosion magnitudes. Loess hills and gullies are very common and are symbolic landscapes of the plateau region.

Keywords Area • Coverage • Geology • Landform • Location • Loess sequence

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1.1 Location of Loess Plateau

The Loess Plateau in north-central China is a highland region with average elevation about 1,200 m above sea level. As the name loess implies, the plateau is made from soils of fine-grained, yellowish silty sediment, deposited by wind action over a long period of time. Loess soil is prone to water erosion; as a result, the upper and middle reaches of the major Yellow River (Huanghe) that flows through the region carry a significant volume of suspended yellow sediment. This suggests that the river was named after the color of sediment eroded from the plateau. Large amounts of sediment discharge in the lower reaches have resulted in substantial elevation of the riverbed, which became much higher than surrounding fields, villages and towns; flood disasters have been a serious concern along this river's lower reach for centuries.

There are several versions in the literature for the boundary and area of the Loess Plateau. Two definitions are commonly used for the plateau. One comes from the standpoint of physical geography. As one of the largest geographical units in China, the "Loess Plateau" is defined as the highland area with thick layers of loess deposits (tens to hundreds of meters high) and typical loess landforms. It is bordered by Taihangshan Mountain on the east, Wushaoling Mountain on the west, Qinling Mountain on the south, and the Great Wall on the north (e.g., Chen et al. 1988; Yang et al. 1988; Li et al. 2008). Four administrative divisions of the nation are partially covered by the plateau. These include almost all of Shanxi Province, parts of Shaanxi and Gansu Provinces, and part of Ningxia Hui Autonomous Region, covering an area of about 380,000 km^2 (Figs. 1.1a, b). This definition is adopted by physical geography publications, including middle school geography textbooks.

However, more generally, "Loess Plateau" is synonymous with the phrase "Loess Plateau region," which refers to a larger loess-distribution area designated for integrated control of soil erosion and ecological management by governments and researchers in environmental, ecological, agricultural, and economic fields (e.g., Yang et al. 1988; CAS-CSTLP 1990; Li et al. 2008; NDRC et al. 2010). This coverage connects the eastern slopes of the Riyueshan and Helanshan mountains in the west, and the western piedmont of Taihangshan Mountain in the east (approximately 101°–114° E). It extends from the northern slope of Qinling Mountain to the southern foothills of Yinshan Mountain (approximately 34°–41° N), with a total area about 640,000 km^2 (Fig. 1.1c). It covers portions of seven administrative divisions of the nation, including small areas of Henan Province, Qinghai Province and the Inner Mongolia Autonomous Region, in addition to those covered by the typical Loess Plateau. Geographically, the northern part outside the Great Wall is called Ordos Plateau and is covered by areas with less loess, including the Mu Us Sandy Land, Kubuqi Desert, and Hetao Plain. The phrase "Loess Plateau region" is often used instead of "Loess Plateau" to emphasize that the range is expanded. However, the word "*region*" may be omitted but with the same coverage in many publications, particularly those in environmental and social sciences (including this book).

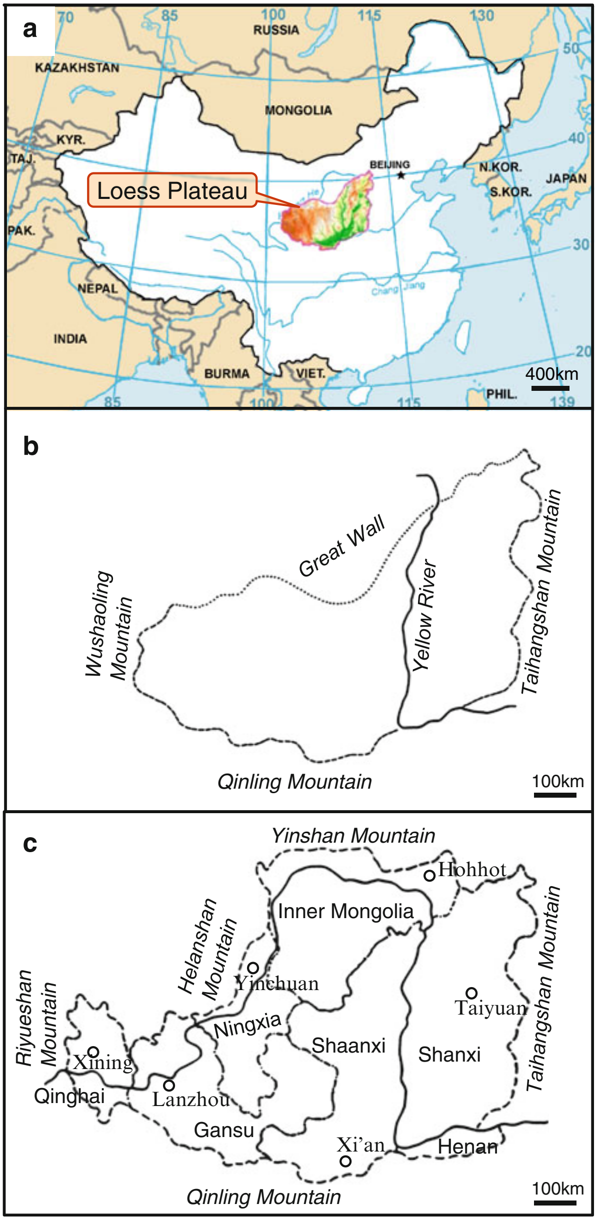

Fig. 1.1 Maps showing location and coverage of Loess Plateau and *Region* of Loess Plateau. (**a**) Its location in north-central China. (**b**) Geographical unit Loess Plateau and its four outer boundaries. (**c**) Coverage of Loess Plateau *Region* and seven provinces and autonomous regions

1.2 Geology of Loess Plateau

Loess layers in the middle Loess Plateau generally have thickness 80–120 m (300–400 m in typical highland areas) and are the thickest known loess deposits in the world, much thicker than those in Europe and the Americas. Loess Plateau deposits in China were transported by fierce wind storms from distant northwest locations, mainly during the Quaternary period (Liu 1985). These homogenous deposits mask the detailed relief of underlying surfaces. Paleolandforms under the loess layers are rock mounts, intervals, basins and lakes (CAS-EBCNG 1980).

The age of loess deposits has long been disputed, and estimates have been updated frequently (e.g., Heller and Liu 1982; Liu 1985; Zhu and Ding 1994; Guo et al 2002). Loess does not form discrete layers by itself, but typical deposits consist of alternating silty loess layers that developed in cold and arid climatic conditions, and clayey loess or paleosoil beds that are indicative of a warm and humid climate. Alternating beds of loess-soil-loess sediments, serving as stratigraphical marker horizons, can be recognized and correlated over large distances. The generally accepted age for loess deposits is 2.5–2.6 million years (Myr), as identified by various methodologies. This refers to the well-known loess-soil sequences containing more than 30 major soil units interbedded with loess (Liu 1985; Kukla et al. 1990; Zhu and Ding 1994).

The typical loess deposit has been subdivided into several main stratigraphical units—Malan Loess of the late Pleistocene age, Lishih Loess of the middle Pleistocene, Wucheng Loess of the early Pleistocene, and late Pliocene Red Clay underlying some localities (Fig. 1.2).

Based on a 160 m-long core from the southern Loess Plateau, known as the Baoji loess sequence, 32 pairs of loess–paleosoil have been identified (Table 1.1). This suggests 32 transitions over the past 2.6 Myr period, from warm and humid to cold and arid climatic conditions.

The Loess Plateau is a vast geological museum. It provides long records of past climate change through sediments that have not been disturbed for millions of years. The most complete loess sequence is of 253 m thickness and is known as the Qinan sequence, obtained on the southwestern plateau (Guo et al. 2002). It contains 231 visually definable reddish layers, interbedded with yellow-brown or brown silty layers. The oldest geomagnetic boundary yielded a basal age of 22 Myr. This evidence indicates large source areas of aeolian dust and energetic winter monsoon winds that transported this material to the Asian interior by the early Miocene epoch; it also pushes the onset period of loess deposits in the Loess Plateau back, from 2.6 to 22 Myr ago. The early Miocene loess deposits further imply that 22 Myr ago the southern margin of the Tibetan Plateau was sufficiently elevated to cause year-round drying and desert formation in the Asian interior, and to produce northwest winds strong enough to carry aeolian particles southeast to the Loess Plateau. The Loess Plateau dust even offers a unique perspective on the uplift of the Himalayas (Langenberg 2002).

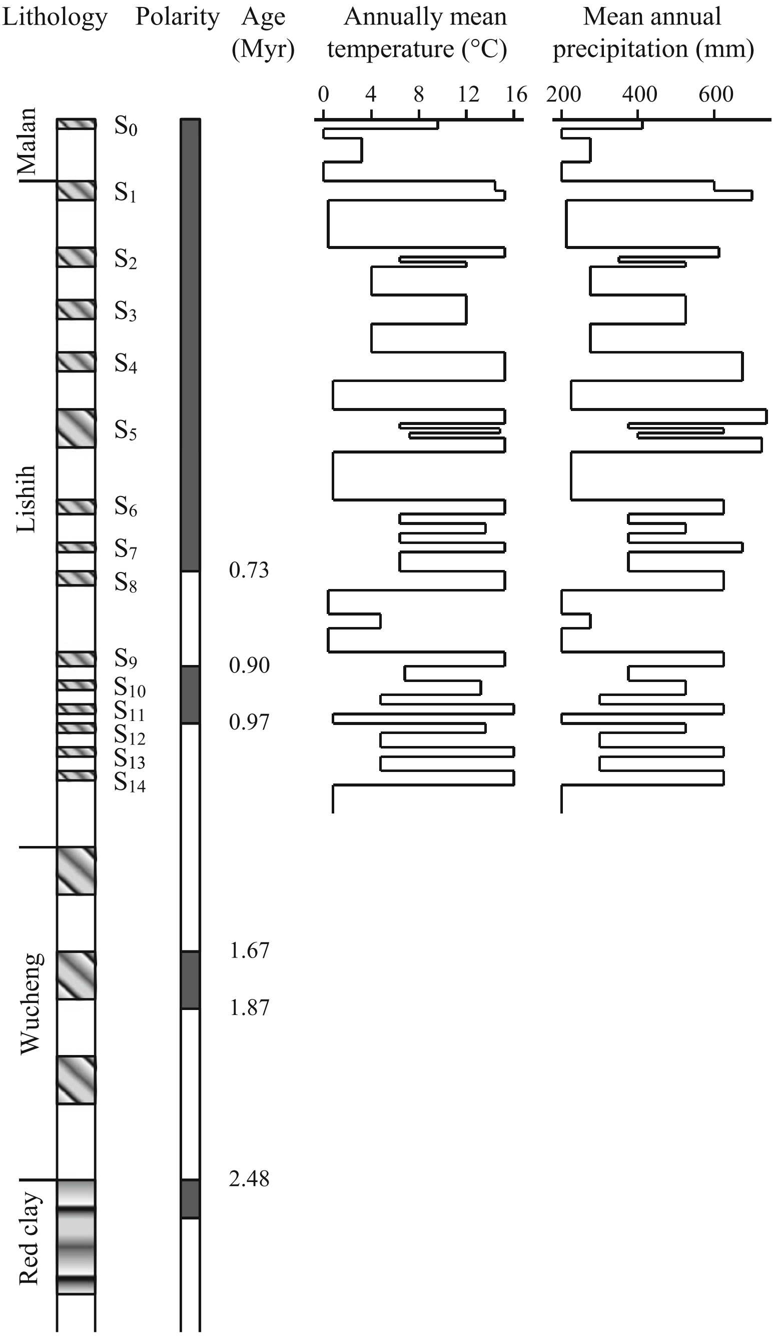

Fig. 1.2 Lithology and ages of paleosoil layers and represented climate changes from Luochuan bore hole (in middle Loess Plateau). Paleomagnetic analysis was applied to a 136 m thick loess sequence. Based on Liu (1985)

Table 1.1 Depth and ages of loess deposit in Baoji sequence

Name of stratigraphical unit	No of paleosoil layer	Paleosoil unit	Depth (m)		Age (Myr)	
			Upper boundary	Lower boundary	Top	Bottom
Malan loess	1	S0	0	8.75	0	0.01
Lishih loess	2	S1	8.75	19.05	0.092	0.127
	3	S2-1	19.05	21.45	0.185	0.22
	4	S2-2	21.45	26.45	0.225	0.242
	5	S3	26.45	34.75	0.272	0.33
	6	S4	34.75	42.25	0.375	0.422
	7	S5-1	42.25	45.15	0.468	0.505
	8	S5-2	45.15	45.85	0.512	0.526
	9	S5-3	45.85	53.2	0.538	0.6
	10	S6	53.2	58	0.68	0.695
	11	S7	58	61.65	0.723	0.745
	12	S8	61.65	70.8	0.762	0.788
	13	S9-1	70.8	72.8	0.852	0.865
	14	S9-2	72.8	75.25	0.89	0.907
	15	S10	75.25	78.2	0.927	0.943
	16	S11	78.2	79.75	0.96	0.986
Wucheng loess	17	S12	79.75	83.65	1.011	1.043
	18	S13	83.65	87.75	1.105	1.126
	19	S14	87.75	93.65	1.142	1.152
	20	S15	93.65	96.55	1.176	1.197
	21	S16	96.55	99.45	1.218	1.237
	22	S17	99.45	100.15	1.259	1.291
	23	S18	100.15	103.75	1.307	1.325
	24	S19	103.75	107.35	1.395	1.411
	25	S20	107.35	108.85	1.425	1.44
	26	S21	108.85	111.05	1.471	1.495
	27	S22	111.05	113.65	1.513	1.54
	28	S23	113.65	120.85	1.551	1.573
	29	S24	120.85	125.05	1.637	1.648
	30	S25	125.05	128.15	1.677	1.718
	31	S26	128.15	135.95	1.785	1.873
	32	S27	135.95	137.35	2.037	2.048
	33	S28	137.35	139.85	2.07	2.091
	34	S29	139.85	142.95	2.119	2.138
	35	S30	142.95	145.85	2.152	2.19
	36	S31	145.85	154.75	2.247	2.256
	37	S32	154.75	158.8	2.417	2.462

From Zhu and Ding (1994)

1.3 Land Morphology of Loess Plateau

China's Loess Plateau is unique in the world, not only in the large area of loess but also its thickness, which can reach 400 m in some places. Since loess is highly subject to erosion, the region has evolved into various eroded landforms throughout its existence, depending on surface cover and erosion intensities (Fig. 1.3). These landforms can be classified into three categories, i.e., landforms between valleys, dissected valleys with various scouring extents, and micro-landforms with loess specialties (CAS-EBCNG 1980).

1.3.1 Landforms Between Valleys

This category of loess landscape can be divided into three major types: loess Yuan, Liang, and Mao.

Loess Yuan are high, flat tableland that more or less retains its original landscape. As loess piled up on placid paleolandforms, a great loess plain was formed.

Fig. 1.3 Large-coverage, bird's-eye photo of northern Shaanxi province, showing eroded loess landforms with hills and gullies. Photo courtesy of Tadaomi Saito

Fig. 1.4 Intact loess Yuan with slight erosion. Photo courtesy of Tadaomi Saito

Such flat plains are of various sizes in the present day. The Dongzhi Yuan in Gansu Province and Luochuan Yuan in Shaanxi Province are famous large plains, covering tens to hundreds of square kilometers. Loess Yuan is characterized by a thick loess accumulation. Numerous ravines formed around the loess Yuan, and some cut gradually into the interior (Figs. 1.4 and 1.5).

Because of headward erosion and incision of modern ravines, the edges of loess Yuan are ragged and fractured, and are even divided into several masses in places where ravines cut into the Yuan. Further headward erosion has broken and reduced the broad and flat surface of a Yuan; thus, the verge area is usually disintegrated. As a result, small pieces of residual loess Yuan are found in the border area between light-erosion and intense-erosion regions.

There is also very thick loess deposit on the terraces along some large river valleys at the plateau edge. The thick loess covers the terrace surface, and the plateau surface descends towards the river valley, in the shape of a bar along the valley. This kind of loess countertop is called terrace-like Yuan. Typical terrace-like Yuan can be

Fig. 1.5 Broken loess Yuan with serious erosion. Photo courtesy of Tadaomi Saito

found along the Weihe River, and are important and highly productive for agriculture.

Loess Liang refers to a landform of elongated loess mound that appears as long stripe-like landforms parallel to ravines. A Liang is hundreds to thousands of meters long, and the breadth varies from tens to hundreds of meters depending on the degree of erosion. Loess Liang is usually formed following further erosion and incision of a residual Yuan landform. Thus, there are frequently distributions of residual loess Yuan and relatively flat lands atop Liang landforms (Fig. 1.6). With the development of erosion, the ridge area gradually narrows (Fig. 1.7). In some cases, the ravines have eroded and incised both sides of a Liang landform, nearly penetrating it to form a very narrow saddle.

Another major type of loess landform is loess Mao, an isolated loess mound with a round top (Fig. 1.8). Slopes incline all around, usually scattered with trees and shrubs. Gentle slopes may be directly used for agriculture. To conserve soil and water for farming, terraced fields can be prepared on the slopes (Fig. 1.9). Since most of loess Mao evolved from loess Liang under further erosion, Liang and Mao

Fig. 1.6 Flat loess Liang with residual loess Yuan. Photo courtesy of Tadaomi Saito

coexist in many areas that are termed loess Liang-Mao areas. The frequency of appearance for Liang and Mao forms varies with intensity of erosion.

Across the entire Loess Plateau, the area of loess Yuan distribution is small. In higher mountains such as Liupanshan and Lüliangshan, the soil horizon is thin and naked rock appears extensively. Liang and Mao formations are the most common landscapes on the plateau.

1.3.2 Landforms Resulting from Runoff Scouring (Valleys)

Valleys formed by runoff scouring are very common landscapes on the Loess Plateau. According to development and characteristics of the eroded form, they can be classified into rill, shallow gully, deep gully, and others.

Rill is the form of the initial stage of water erosion on slopes. A rill usually has depth about 20 cm and width ranging from several centimeters to 1 m (Figs. 1.10 and 1.11). Rills are commonly found in cultivated land after heavy rain events.

Fig. 1.7 Long loess Liang. From Zhu (1986)

A shallow gully is a transitional landform type from rill to gully, and is defined as having 1–3 m width and about 0.5 m depth. These usually form on long-lasting slopes (Figs. 1.12 and 1.13). With accumulation of runoff along the slope, the scouring force becomes more powerful.

With further increase in erosion intensity, a gully with depth exceeding 1 m forms (Fig. 1.14). The location is nearly fixed in this stage of development. The gully extends its length and depth following repeated erosion (Fig. 1.15). The upside and head of a deep gully is generally a shallow gully. A large gully can be as deep as tens to hundreds of meters, with length up to several hundred meters, in which runoff can be very high during heavy rain.

Besides the general eroded landforms mentioned above, there are also wide valleys with or without inflowing streams. For agriculture, terrace fields are often built on slopes, and check dams constructed in gullies and valleys (Fig. 1.16). A large valley may cut through the entire loess layer and become a river tributary (Fig. 1.3).

Fig. 1.8 Loess Mao. Photo by Sheng Du

Fig. 1.9 Cropland made by terracing loess Mao. Photo by Sheng Du

Fig. 1.10 Rill beginning to develop under sheet erosion. From Zhu (1986)

Fig. 1.11 Developed rill. From Zhu (1986)

The riverbed is on the bedrock surface, and the width of the bottom can be as wide as dozens of meters.

Fig. 1.12 Developing shallow gully. From Zhu (1986)

Fig. 1.13 Development from shallow gully to minor gully. From Zhu (1986)

Fig. 1.14 Gully at the edge of a flat land. From Zhu (1986)

Fig. 1.15 Developed deep gullies forming a narrow blade back similar to a loess Liang. From Zhu (1986)

Fig. 1.16 Terrace land on slopes along a wide valley. Photo courtesy of Junliang Tian

Fig. 1.17 Loess bridge. From Zhu (1986)

Fig. 1.18 Loess column formed by landfall. From Zhu (1986)

Fig. 1.19 Loess collapse caused by road scouring. From Zhu (1986)

Fig. 1.20 Loess landslide after rainfall. Photo by Sheng Du

1.3.3 Micro-Landforms with Loess Specialties

Because of its unique structure and texture, certain micro-landforms are found on the Loess Plateau. These include loess bridges, loess columns, formations caused by loess collapse and landslides, as well as other formations (Figs. 1.17, 1.18, 1.19, and 1.20).

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Chapter 2
Climate of the Loess Plateau

Reiji Kimura and Naru Takayama

Abstract The Loess Plateau in China covers an area of ca. 640,000 km^2, extending between 34° N and 40° N/100° E and 115° E, which is the middle region of China's Yellow River. The climate of Loess Plateau is strongly influenced by latitude, longitude, and topography. It has a typical continental monsoon climate. Winters are cold and dry, and most rainfall occurs during the summer (June to September). Annual precipitation is approximately 400 mm (minimum 150 mm, maximum 750 mm). Under China's physical geography classification, the Loess Plateau is classified as the Loess Plateau sub-region in the North China region. The most significant aspect of its climatological characteristics is the distinct seasonality of temperature and precipitation distribution. According to the aridity index (the value obtained when dividing annual precipitation by potential evapotranspiration) (Millennium Ecosystem Assessment (2005) Ecosystems and human well-being: desertification synthesis. World Resource Institute, Washington, DC), the Loess Plateau belongs to a semiarid area.

Keywords Aridity index • Asian dust • Jet-stream • Monsoon • Semiarid

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2.1 Climatic Features

The Loess Plateau climate is strongly influenced by latitude, longitude, and topography (Takayama and Kimura 2008). It has a typical continental monsoon climate. Winters are cold and dry, and most of the annual precipitation is concentrated during the summer rainy season, which occurs mainly from June to September (Table 2.1). The Loess Plateau has been classified as a semiarid area, a classification that was obtained when dividing annual precipitation by potential evapotranspiration, as defined by the Millennium Ecosystem Assessment (MA 2005). Under China's geographical classification (Ren 1982), the Plateau was classified as the Loess Plateau sub-region in the North China region, where the most significant of its climatological characteristics is the distinct seasonality of temperature and precipitation distribution.

The temperature in winter is lower than those of other areas located at the same latitude because the Siberian high weather system dominates the plateau. Conversely, the summer monsoon flows into the low pressure system which occurs on the continent via the Qinling Mountains. This results in a rapid rise of air temperature with the occurrence of the Foehn wind across the Weihe Plain. This plain is located between the southern tip of the Loess Plateau and the Qinling Mountains. For this reason, Xian has recorded a maximum temperature of 45.2 °C, which is one factor in creating the dry climatic conditions of the plateau in the northern area of the Qinling Mountains. The line from the Qinling Mountains to the Huai River is an isopleth with an aridity index of 1.0. This is an important boundary in the physical geography classification for China. Specifically, in the region north of this boundary, the amount of moisture is considered the limiting factor that determines plant productivity.

Figure 2.1 shows the spatial distributions of normal of annual precipitation (mm), annual mean of temperature (°C), annual cumulative sunshine duration (h) and annual cumulative effective temperature (°C) (the value obtained by integrating the portion exceeding the daily average reference temperature of 10 °C) in the Loess Plateau. On the plateau during summer and winter, there is a gradual decline in mean air temperature with decreasing latitude. In Yanan, located in central Shaanxi

Table 2.1 Annual precipitation (Pr), annual potential evapotranspiration (ETp) and aridity index (AI) of representative cities on the Loess Plateau, China (averages from 1970 to 2000)

City	Latitude	Longitude	Pr (mm)	ETp (mm)	AI
Xian	34°18′	108°56′	545	962	0.57
Tongchuan	35°05′	109°04′	563	1,007	0.56
Yanan	36°36′	109°30′	495	1,021	0.48
Yuling	38°14′	109°42′	358	1,063	0.34
Taiyuan	37°47′	112°33′	428	1,042	0.41
Ertuokeqi	39°06′	107°59′	253	1,188	0.21
Yinchuan	38°29′	106°13′	184	1,072	0.17
Langzhou	36°03′	103°53′	310	933	0.33

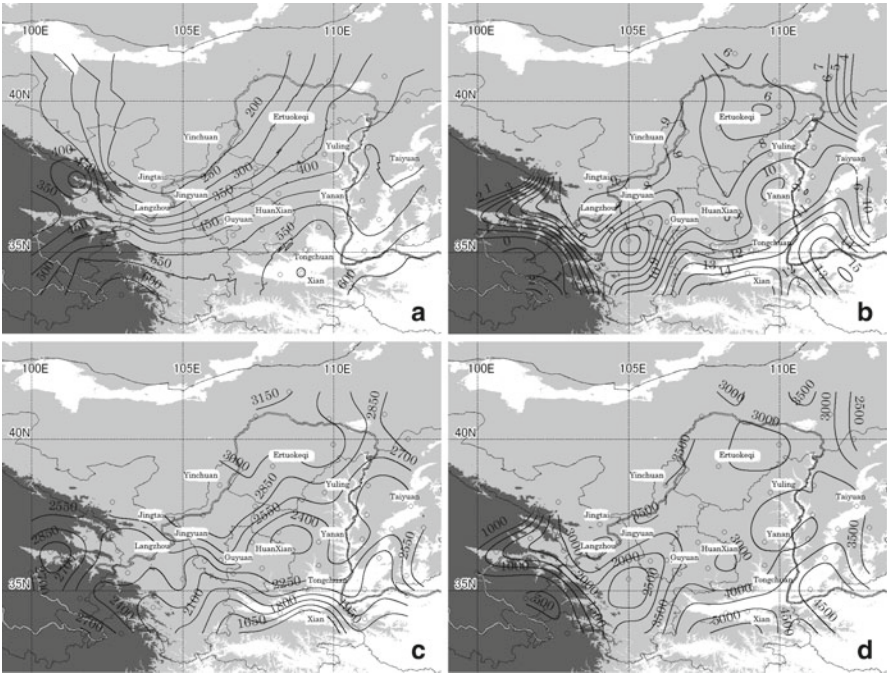

Fig. 2.1 Spatial distributions of (**a**) annual precipitation (mm), (**b**) annual mean of temperature (°C), (**c**) annual cumulative sunshine duration (h) and (**d**) annual cumulative effective temperature (°C) on the Loess Plateau (Normals of climate element up to year 2000). *Light gray* indicates areas with elevations of 1,000–3,000 m, and *dark gray* indicates areas with elevations of over 3,000 m

Province (lat 36°36′N, long 109°30′E), the maximum summer temperature and the minimum winter temperature are ca. 35 °C and −20 °C, respectively. The mean of diurnal air temperature ranges from 10 °C to 16 °C in the southeast and 15 °C to 25 °C in the northeast, with the mean annual temperature across the plateau ranging from 3 °C to 15 °C. The diurnal air temperature range at each city is relatively large, as is the seasonal air temperature range. The cumulative effective temperature, which is an indicator of the heat resources required for crop growth, ranges from 3,000 °C on the western side of the plateau that include Shaanxi and Shanxi provinces, to 4,000–4,500 °C on the Weihe Plain. Adequate heat resources exist on the plateau to grow a crop during the growing season except in the mountainous area, where the risk of frost damage is high. However, the soil freezes from late November to March in most areas on the plateau.

Climate seasonality on the Plateau is caused by the Asian summer monsoon and the Siberian high on Eurasian continent at the synoptic-scale. In winter, the westerly jet-stream is divided into the polar jet stream and the subtropical jet stream at 59° N and 25° N, respectively. The Loess Plateau which occurs on the southern side of the polar jet-stream is dominated by the Siberian high. Extremely dry conditions occur as the precipitation is less than 5 mm because of the influence of the Siberian high in the Eurasian continent. Therefore, the climatic conditions tend towards strong winds, low temperature and low precipitation. During the winter season on the plateau, December to February, there is relatively little precipitation (less than 10 mm). In the spring, the continental winter monsoon weakens, and synoptic disturbances frequently occur. However, because the air mass is very dry, it does not generate large amounts of precipitation. Moreover, the extremely dry air and soil conditions are maintained because of the long-term influence of the continental Siberian high. The resultant spring drought seriously impacts agricultural production in the region, including crop growth during the sowing season. The dry soils combined with the strong winds during spring create the Asian dust events or so-called “Yellow Sand”.

The onset of the Asian summer monsoon (June to August) causes the prevailing wind direction to change from the northwest to a southerly direction in the lower atmosphere on the plateau. Owada (2001, 2002), suggested that the main cause of summer rains on the plateau are driven by a combination of low pressure systems near the ground and subtropical high pressure systems at higher altitudes. The lower-atmosphere southwesterly winds resulting from the Indian monsoon, the southwesterly winds that blow down from the upper-atmosphere of the edge of North Pacific high pressure system and the lower-atmosphere northwesterly winds from low-pressure systems formed on the northern side of the plateau converge three-dimensionally, creating localized fronts against the continental dry air mass. Additionally, cumulonimbus clouds are formed by meanders of the westerly air mass in the upper atmosphere which facilitate the southward movement of cold air from the polar air mass. The Indian summer monsoon moving from the south and the southward movement of the jet stream in the upper-atmosphere could play important roles for summer rains on the plateau, depending on the comparison between rainy years and dry years. Asian summer monsoons begin in response to a phenomenon in which the subtropical jet stream jumps to the north side of the Tibetan Plateau in response to the development of the Tibetan high pressure system (Ogura 1984). At the time of the Asian summer monsoon, the low-pressure circulation appearing over the Indian subcontinent merges with air currents forming in conjunction with the southwest Indian monsoon. These air currents flow into the Bay of Bengal, and part of it can reach the plateau (Ninomiya and Kobayashi 1998). Takayama et al. (2004a) suggested that the westerly wind at 25–30° N in the lower atmosphere could disappear in June, with the counterclockwise air-mass circulation on the Indian subcontinent and the clockwise air-mass circulation on Sea of India appearing simultaneously. The Indian summer monsoon caused by the clockwise air-mass circulation could promote the formation of air currents that flow into Bay of Bengal. These air currents may reach the Loess plateau. However, the mean altitude of the Tibetan Plateau is above 5,000 m. Therefore it seems probable that the southwesterly air current from the Indian summer monsoon is deflected around the southeastern edge of the Tibet Plateau.

In summer, the ground surface temperature can rise rapidly causing the formation of atmospheric convection currents creating localized heavy rain events. Takayama et al. (2004a) proposed using mesh maps (30″ grid scale) of monthly normal precipitation to consider the effects of synoptic climate and local topography.

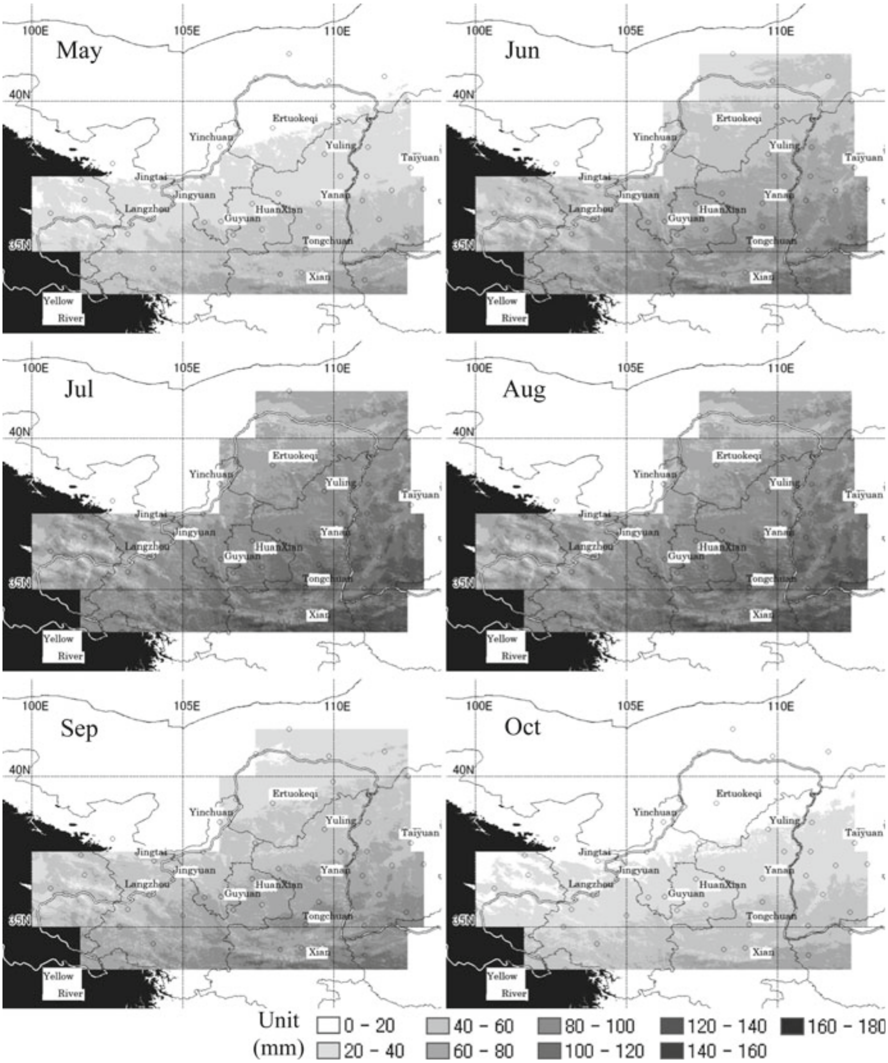

Fig. 2.2 Grid-map of the Loess Plateau's normal monthly precipitation from May to October. *Black areas* are montane regions with elevations of ≥3,000 m

They assumed that the rainfall distribution on the plateau would be dominated by elements including: the change of the prevailing wind with the monsoon, the turbulence associated with westerly winds and the effect of aspect for rainfall.

Figure 2.2 shows the monthly normal precipitation from May through October in the Loess Plateau. The mean monthly precipitation gradually decreases from south to north in May and October, with rainfall distribution exhibiting significant geographical disparity during summer. In other words, that rainfall may be dominated by the position of the prevailing westerly jet-stream in spring and autumn. Conversely, during the summer there are frequent local rainfall events influenced by the topography and the monsoon system. However, the influence of topographical effects on climatological factors is not limited to precipitation. The other influencing factors include: air temperature, insolation, soil temperature, and soil moisture. For example, depending on whether the slope aspect is north- or south-facing, there are large differences in insolation, soil temperature, and soil moisture (Takahashi et al. 2002). Therefore, on the rugged plateau, it is essential to consider topographical factors when planting vegetation such as trees, grass or agricultural crops.

The mean annual precipitation on the plateau ranges from 150 to 750 mm (Fig. 2.1). The annual precipitation on the Weihe Plain in the plateau's southeast and in the loess hills in southern Shanxi Province and western Henan Province is 600–750 mm, giving these areas the highest precipitation rates on the plateau. In contrast, the western and northwestern Ningxia, the Yellow River catchment, the western part of the Ordos Plateau of Inner Mongolia, and the Jingyuan–Jingtai–Yongdeng region of Gansu Province, have an annual precipitation rate of 150–200 mm. The 400 mm annual precipitation isopleth passes through Yulin, Jingbian, Huanxian, and northern Guyuan, dividing the Loess plateau into two distinct areas, the southeast and northwest.

Precipitation rates gradually decline from the southeast to the northwest. Sixty to eighty percent of the plateau's annual precipitation occurs in the 3 months of July to September. Conversely, winter precipitation rates are ca. 5 % of the annual precipitation rate, resulting in significant seasonal variation. The rate of variation in annual precipitation is also significant. Takayama et al. (2004b) analyzed climate data (1980–2000) from 53 monitoring stations of the China Meteorological Administration. They found that the relative annual rate of variation in precipitation was ±30 % [(each year's precipitation amount—average annual precipitation)/average annual precipitation ×100]. Thus, in terms of the ratio between mean annual precipitation rates between wet years and dry years, the plateau's annual precipitation shows a 60 % mean difference. Considering the large amount of variability in precipitation rates—a common characteristic of semiarid areas—the median value of the 95 % estimation interval (the range where the mean value will likely be within a 95 % probability) was used for the mean annual precipitation rate at each location. The value of the mean deviation of each year's precipitation rate was then given an upper or lower bound of the 95 % estimation interval of mean annual precipitation. This was subtracted from each year's precipitation rate and for years in which precipitation was within the 95 % estimation interval, the relative annual rate of variation was set to zero. Figure 2.3 shows the spatial distribution of [highest value—lowest value] for the relative annual rate of variation in precipitation in the period of 1980–2000. The places with greater than 100 % annual rate of variation in precipitation were Linhe, Zhongning, with other areas near the Mu Us Desert, Ulan Buh Desert, and Tengger Desert in the northwestern part of the plateau (Fig. 2.2). A comparison of the western and eastern sides of the plateau reveals that precipitation variation is greater in the eastern region.

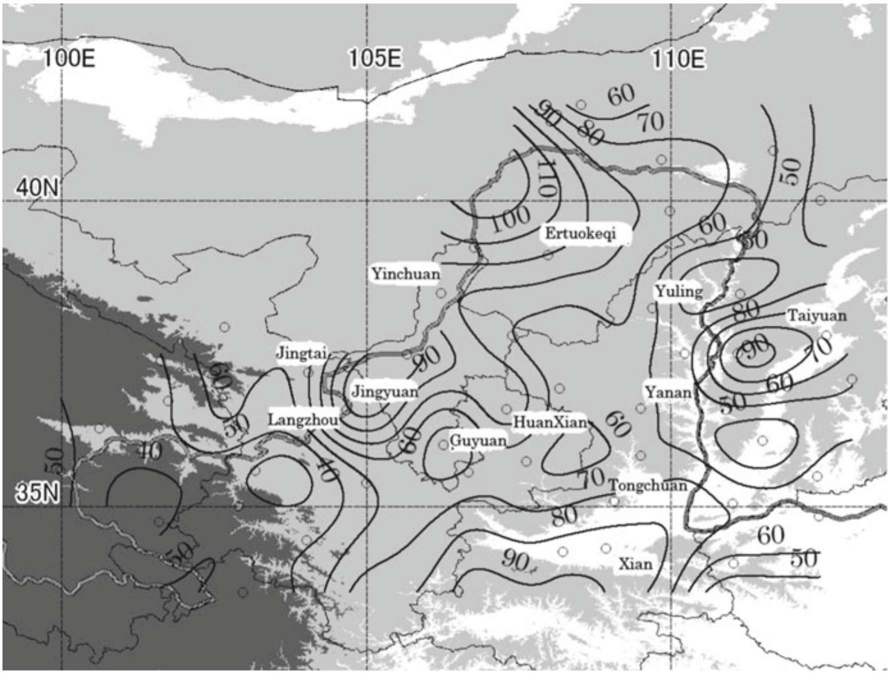

Fig. 2.3 Spatial distribution of the percentage range in the relative annual rates of variation in precipitation during the period of 1980–2000 in the Loess Plateau

The reasons for the stable rainfall on the western side of the plateau are assumed to be caused by the warming of the mid-atmospheric layers in spring and summer. This occurs when the montane regions warm including the Tibetan Plateau, resulting in inflows of compensating currents from the periphery becoming slope updrafts (Takayama et al. 2004a).

Takayama et al. (2004b), found that averaging precipitation rates across the entire Loess Plateau failed to find a significant time-series trend during the 1980–2000 period. However, they found a significant trend of decline in the annual precipitation rate in Yanan. Yasunari (2004) demonstrated a declining trend in precipitation rates in the Yellow River catchment over a 20-year period (1979–1999). Moreover, the main source of precipitation in the Yellow River catchment is evapotranspiration from the ground layer, implying a relatively close quantitative negative association between precipitation and evapotranspiration. This suggests that changes in the vegetation and the state of the ground surface in the Yellow River catchment, including the Loess Plateau, could directly affect the decrease in precipitation.

2.2 Heat and Water Balance

Figure 2.4 (Kimura et al. 2005) shows the spatial distribution of the annual mean sensible and latent heat fluxes (W m^{-2}) of the Loess Plateau in 1998, calculated using a heat balance simulation model (Kimura et al. 2004a, b). On the Loess Plateau the role of sensible and latent heat fluxes are important factors that influence the area's climate. The land surface is assumed to consist of bare soil, with calculations taking into account the physical properties of the five soil types on the plateau. Over most of the plateau, sensible heat flux is greater than latent heat flux, affecting annual precipitation and runoff from the plateau in 1998 (Fig. 2.4; Kimura et al. 2005).

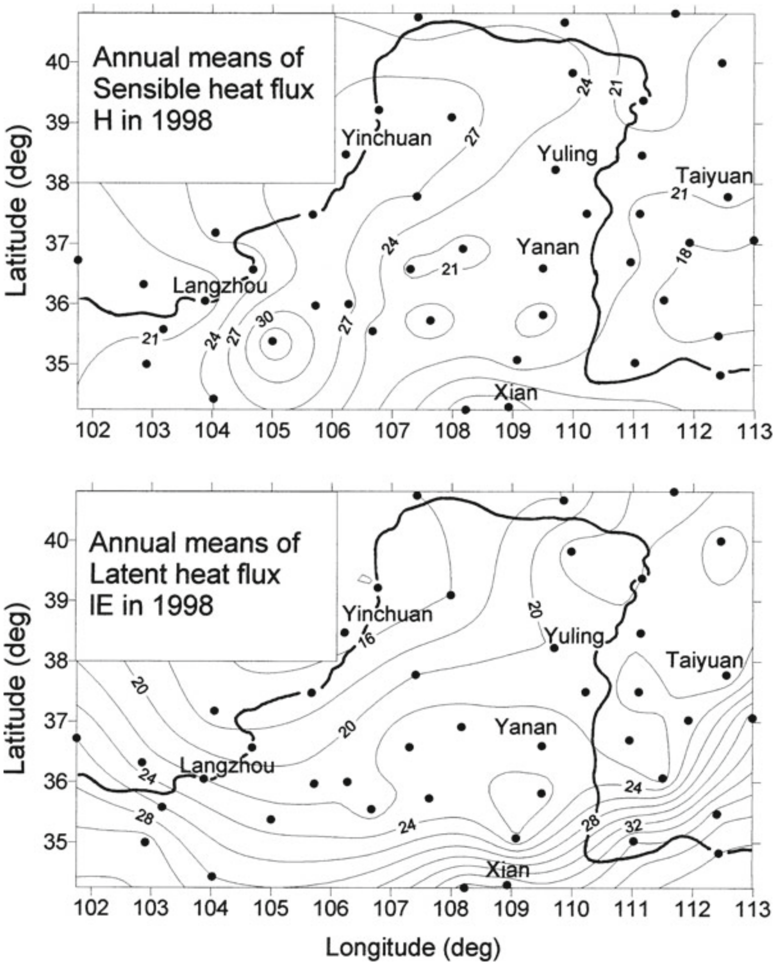

Fig. 2.4 Spatial distribution of annual mean sensible and latent heat fluxes in 1998 on the Loess Plateau (Kimura et al. 2005)

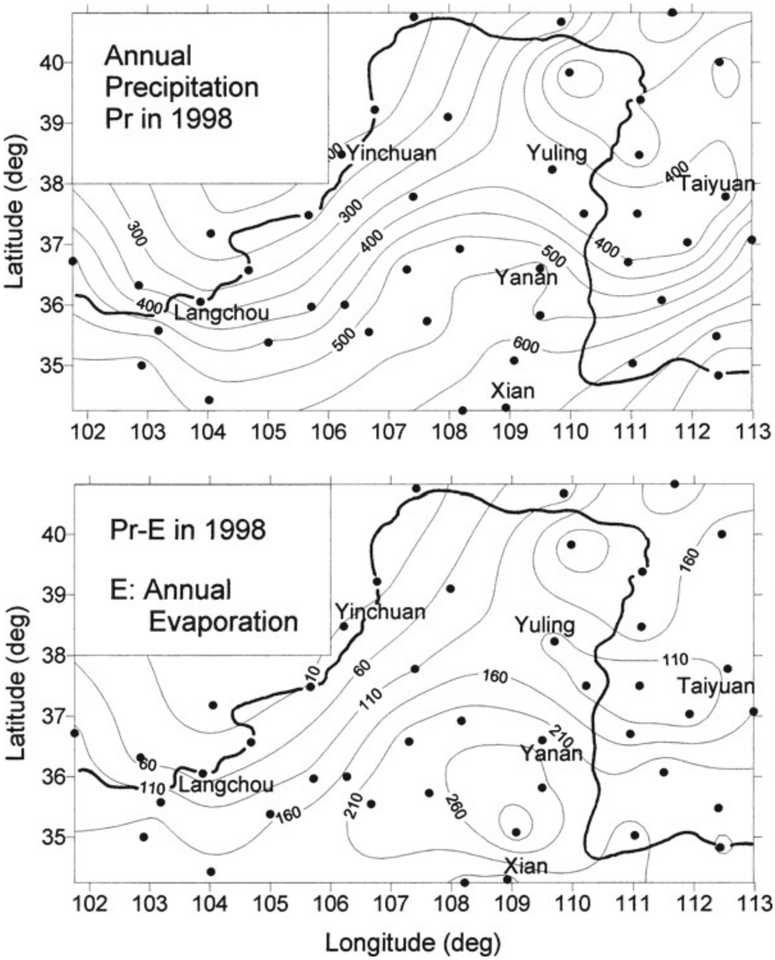

Fig. 2.5 Spatial distribution of annual precipitation and runoff in 1998 on the Loess Plateau (Kimura et al. 2005)

It is evident that runoff gradually declines toward the northwestern area although there is significant runoff that occurs in the plateau's southeastern area, coinciding with comparatively higher rainfall (Fig. 2.5; Kimura et al. 2005).

The seasonal change in volumetric soil water content on the Loess Plateau is highly variable (Fig. 2.6; Kimura et al. 2005). The mean soil water content for different surface layers has been documented using soil depths of 2 cm (θ_1, the first layer), 2–22 cm (θ_2, second layer) and 22–70 cm (θ_3, third layer). The soil water content of the first layer is relatively sensitive to rainfall events. Since the infiltration rate of rainfall is low in Xian and Tongchuan, there were days when the value was near the saturated soil water content level. Focusing on the soil water content of the second and third layers "good water retention of loess" can be observed. There is no

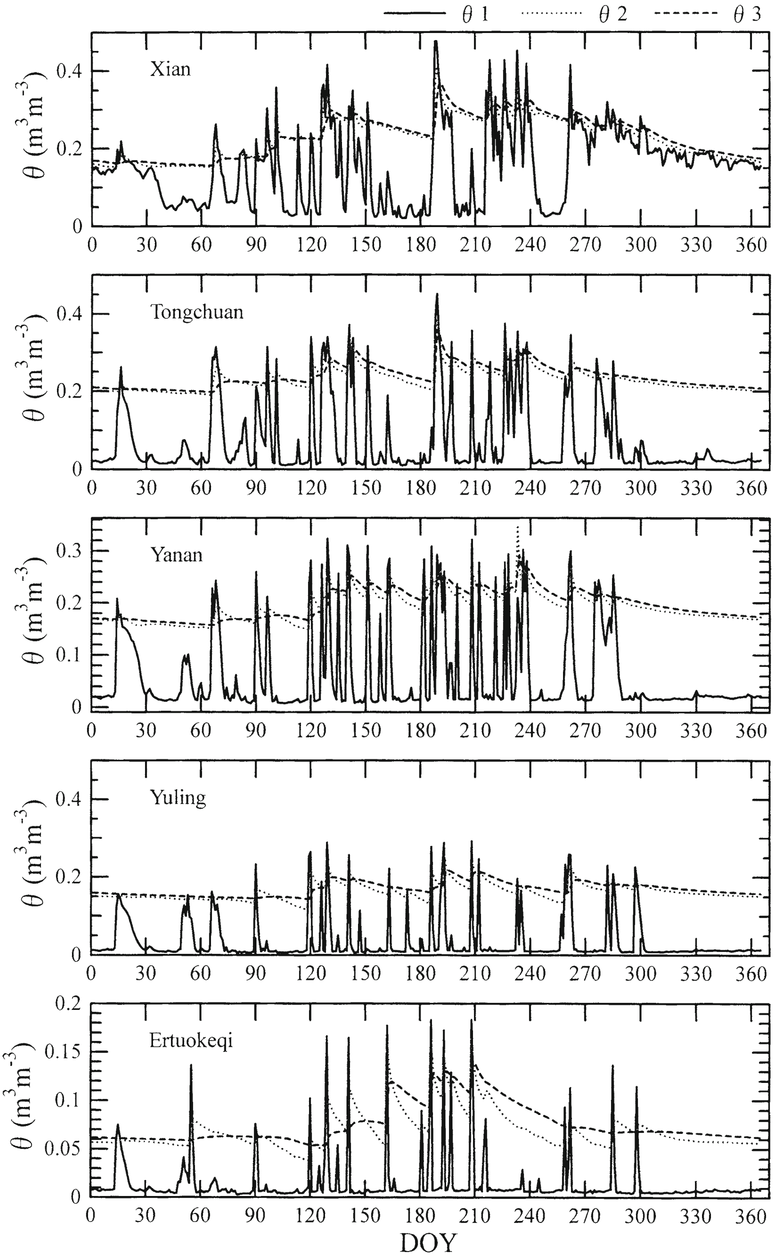

Fig. 2.6 Seasonal change in soil water content at Xian, Tongchuan, Yanan, Yuling, and Ertuokeqi (Kimura et al. 2005)

significant decline in water content even during the dry season. In contrast, the town of Ertuokeqi situated in the desert has poor soil water content resulting in a soil water deficit that is often below the wilting point of plants.

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Chapter 3
Soils on the Loess Plateau

Sadahiro Yamamoto and Tsuneyoshi Endo

Abstract Morphological characteristics of soils on the Loess Plateau are products of its distinctive physical properties and behavior of water and salt in soil profiles. Various types of soils are distributed across the plateau, where rapid environmental changes occur because of long-term artificial contributors to loessial sediments. Soil health in this region has declined, owing to the fragile environment. In a case study of the Luohui Irrigation Scheme, soil morphological characteristics and soil salinization were related to the topographic sequence of the soils. Soil salinization differed within this scheme and subsoil texture was a useful indicator of the state of salt accumulation. This information may help develop guidelines for agricultural soil management that are based on underground water dynamics and soil morphological properties. A proper conservation strategy is necessary to achieve an optimal combination of land use for soils on the Loess Plateau.

Keywords Loess • Soil management • Soil morphology • Soil salinization • Topography

3.1 Introduction

Loess consists of aeolian sediments and windblown silt, and has been accumulating in central China for the past 22 million years (Guo et al. 2002). Loess deposits in northern China accumulated under an arid climate in the Pleistocene (Yang et al. 2006), and soils in areas of loess deposition are immature. Typically, loess sediments on the Loess Plateau are loessial substances. These substances include Asian

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dust transported by spring westerly winds, which are deposited in various regions of China, Korea, and Japan.

The Loess Plateau region has a fragile environment, shortage of farmland, low grain production, natural disasters and poverty. Because of long-term artificial contributors to loessial sediments, various types of soils are distributed across the plateau, where rapid environmental changes occur. The plateau is losing an average of 1 cm of soil each year, owing to erosion and related environmental problems (Gregory et al. 1995).

It is widely believed that forest clearance for agriculture, as practiced on the Loess Plateau, decreases biodiversity, limits naturally adapted vegetation, and simplifies ecosystem structure. However, the impacts of human activities on the plateau have been characterized as continuous and widespread stresses, such as overgrazing and the production of large-scale monoculture. Recently, inappropriate agricultural practices have led to environmental deterioration and poor land productivity on the plateau (Lal 2002; Jin et al. 2008). Because of a combination of long-term human activities and frequent summer rainstorms, steep landscape and highly erodible loessial soil, the plateau has become one of the most severely eroded areas in the world, with a loss of soil and water leading to widespread land degradation. To overcome these problems, the Chinese government has attempted to control soil erosion and develop sustainable agriculture over the past 30 years (Gao and Li 2003; Huang et al. 2008). Soil conservation practice on the plateau has been urgent and indispensable in attacking the aforesaid problems.

3.2 Soil Formation

Loess consists of coarse-to-medium silt that is made up mainly of quartz particles, and is generally poor in clay. Aeolian deposition of most loess results in very high porosity in the youngest loess and low bulk density. During the soil formation process, the constituents of Loess Plateau soil that make it fertile are clearly affected by the loessial substances present, or by the base material in the soil. Consequently, after the deposition of loessial substances, various types of soils are formed that depend on environmental conditions.

Soils with loessial sediments are classified as Los Orthic Entisols, and they have the lithological characteristics of loessial sediments. Los Orthic Entisols are generated from the maturation process in which natural loessial sediments are directly cultivated. However, they readily induce soil and water runoff, and have a poor ability to supply nutrients essential for plant growth (Nanking Institute of Soil Science 1980). Hence, use of these soils for agricultural purposes calls for careful review of soil constituents. Grassland soils (Isohumisols) are found in areas where grasslands form on loessial sediments. Long-term use of such soils causes organic matter that is present in plant roots, leaves, and plant residues to be deposited in the soil. Release of nutrients such as potassium and phosphorus from black organic matter forms black Cumulic Ustic Isohumisols. In regions where forest develops on loessial sediments, brown forest soil called Ustic Luvisol is produced. In addition, after reclamation of land rich in loessial sediments and subsequent cultivation and fertilization, fertile soils called Earth-cumulic Orthic Anthrosols are formed. Soil color and texture vary with environmental conditions after surface deposition of loessial substances.

3.3 Distribution of Principal Soils on Loess Plateau

Los Orthic Entisols contain hydromica as the main clay mineral, whose properties are the same as those of the base material, or loessial substances. This soil type is widely distributed in the northern part of Shaanxi Province, as well as in Gansu, Shanxi and Qinghai provinces, Ningxia Hui Autonomous Region, and Inner Mongolia (Nanking Institute of Soil Science, Academia Sinica 1980). The soil is loose and has relatively high resistance to erosion. In addition, because of its strong permeability, it can store a significant amount of available water. Moreover, it has a significantly high gas phase ratio and softness, and is therefore easily cultivated. Soil fertility is increased by the frequency of cultivation and manuring toward increasing agricultural productivity. The soil surface layer contains a relatively large amount of nutrients. Therefore, the thicker the cultivated soil layer, the greater the soil fertility. Nevertheless, the soil profile that becomes mature after cultivation has not been well understood. Because of its uniform particle size, the soil easily hardens, preventing root swelling. The components of Los Orthic Entisols, which contain only loessial sediments, cannot be ionized by microbial decomposition, and the supply of nutrients to animals and plants is not facilitated. Hence, this soil type is unsuitable for agriculture. Consequently, its use for agricultural purposes requires proper soil management, with application of water and fertilizer for plants.

Dark and solid Cumulic Ustic Isohumisols, which are found in northern Shaanxi Province, northwest Shanxi Province, and eastern Gansu Province, form a thick and black humus layer (Nanking Institute of Soil Science, Academia Sinica 1980). The profile of Isohumisols on the plains of the Loess Plateau and high terraces on both banks of the Yellow River shows clear stratification, with a dark and relatively firm layer, a calcification layer, and base material layer. Root systems of crops and herbs penetrate loose and porous soil layers, and accumulated organic matter is evenly distributed in both the surface layer and deep soil layer. This accumulated humus layer assumes a dark gray color and reaches a depth of 1 m or more. The properties of Isohumisols are affected by carbonate content of the constituent layers. Decayed plant remains and humic substances generated after decomposition combine with calcium to form a film on the outer surface of the soil, which is distributed around a pore. This soil usually has organic content 1–1.5 % or less (at most 2 %). Because of the low organic content, soil hardening occurs and the supply of inorganic nutrients becomes ineffective. As a result, crop yield is reduced and vegetation is poor.

Ustic Luvisols, which mature after cultivation and long-term management of former forest areas, are distributed in the southern part of the Loess Plateau.

The humus layer in Ustic Luvisols is thin, but relatively rich in organic matter and nitrogen (Huang et al. 2007). A lime accumulation layer observed in lower layers beneath the humus layer has smaller organic matter and nitrogen contents than upper layers.

In the valleys of the Fen River in Shanxi Province and Weihe River in Shaanxi Province, many Earth-cumulic Orthic Anthrosols are produced after long-term cultivation (Sun et al. 2005). Anthrosols are very fertile soils generated after long-standing repeated cultivation and fertilization; the soil profile has a distinct thick and mature layer.

3.4 Characteristics of Soils on the Loess Plateau

The Loess Plateau contains Pleistocene aeolian sediments, with thicknesses from several dozen meters to 400 m. These sediments are composed of loess from adjacent desert areas. Fine soil particles are observed in the northwest and southeast plateau regions. The low permeability and high water resistance of the soil facilitates formation of a muddy structure or hardpan. In addition, the plateau receives almost 80 % of annual rainfall between August and September, and rainfall intensity is very high during the crop-growing season. Under these environmental conditions, soil erosion becomes extremely strong. This delivers a large amount of sediment to the Yellow River.

Loess is silty soil derived from unconsolidated rocks, and consists of neutral to slightly alkaline calcareous particles. A significant amount of carbonate is contained in consolidated Asian dust. Flooded soil, and subsequently dissolved carbonates, can prevent consolidation of soil particles and cause dispersion of soil aggregates. Soil particles dispersed after collapse of such an aggregate structure first dry up and form a surface duricrust (crust), which subsequently becomes a hardened structure similar to adobe. The flooding capability is thereby reduced. As a consequence, there is surface runoff with heavy rainfall and the soil is liquefied and easily eroded. This gully erosion causes deep sculptures on the earth surface. In some regions, tops or slopes of hills dissected by gully erosion and slopes near rivers are used for agriculture.

Most of the plateau area receives annual rainfall 300–600 mm, but annual potential evaporation is 1,000–1,500 mm or greater (see Chap. 2 for details). Rainfall varies widely on a seasonal basis, and during part of the year it is dry. For this reason, regional soils differ markedly from those in humid areas. Formation of salt-affected soils is less likely in areas with rainfed agriculture. Some agricultural lands where irrigation is carried out to achieve higher and more stable yields suffer severe soil salinization. In such areas, salty water is used to some extent, because there are no other options. If farmland with poor drainage is excessively irrigated, groundwater level increases and water is incessantly supplied to the soil surface or underlying layers. This eventually leads to surface evaporation and capillary rise of water that contains salts. Consequently, soluble salts in soil are transported to the soil surface, where they accumulate to form salt-affected soils. If significant amounts of such salts accumulate on the surface layer, the soil surface is covered with salt crust, which may decrease land productivity. Although irrigated agriculture can produce a temporary significant increase in crop yield, it brings a high risk of soil degradation that precludes sustainable use of the land.

The Loess Plateau has favorable drainage capacity because of terrain roughness, and is relatively resistant to salt accumulation because of deep groundwater level. However, with progress of waterlogging-induced soil salinization, Stagnic Anthrosols are distributed across irrigated agricultural lands within low-lying areas along rivers, or on flat, high plains on river lower reaches. The high salt concentration in irrigation water causes secondary soil salinization in some agricultural lands. Furthermore, salt accumulation, which eventually makes the ground barren, is a serious problem in low-lying depressions. In a river valley district, the groundwater level is very deep because of deepening by rivers and gullies; however, saline soils containing accumulated salt are formed. Water discharged from such irrigation fields into low-lying areas has high salt concentration. Salt-affected soils form in and around these low-lying areas after soil particles are dried and consolidated, or after the water recedes. As a result, significant salt crystal amounts are deposited both on the surface layer and in lower layers.

The impacts of salt-affected soils on Loess Plateau crop production, the cause of salt-affected soil formation, and methods for soil amelioration and soil erosion control vary widely. Hence, for efficient soil management, it is important to thoroughly understand the various stages of soil salinization and causes of salt accumulation in farmlands.

3.5 Soil Salinization

Because the Loess plateau has a dry climate, irrigated farmland has a high risk of soil salinization. This salinization, which influences the movement of salt and water in soil, is caused by natural factors such as climate and geographic features. As summarized by Ci and Yang (2010), annual precipitation, precipitation pattern, and soil freezing influence salt buildup in soil, resulting in various states of salt accumulation. Moreover, topographic features are major influences on the formation of salt-affected soils. Farmland irrigated by river water is widely distributed across the southern Loess Plateau. A river terrace system is frequently developed within a large irrigation scheme, and there are diverse states of salt accumulation on various terraces. This is because different characteristic soils have been developed on different terraces. Since the formation process of salt-affected soil is altered by soil toposequence, soil and hydrologic characteristics of topographic features should be considered for effective soil salinization management. As a study case, the influence of soil toposequence on soil salinization in the irrigation scheme at the southernmost end of the plateau is shown below (Endo et al. 2012). This is the Luohui Irrigation Scheme, which was established 70 years ago in the cotton production centre of Shaanxi Province.

3.6 Soil Salinization Related to Soil Characteristics Affected by Topographic Features

3.6.1 Outline of Irrigation Scheme

The Luohui Irrigation Scheme has been facing increasing salinization problems, and management is required to limit further salinization and rehabilitate salinized areas. Salt-affected areas in the scheme expanded from 1,140 ha in 1953 to 4,410 ha in 1974 (Li 1995). After identifying problems and installing drainage facilities, the affected area decreased to 3,000 ha by 1980. However, it increased to 3,910 ha by 1987 because of a lack of effective maintenance of drainage structures (Li 1995). The study area (31 km longitudinally × 16 km latitudinally) is in the eastern block of the Luohui Irrigation Scheme (34°45′23″N—34°56′05″N and 109°45′22″E—110°10′23″E), and covers an area about 32,000 ha. The area is on the left bank of the Luohe River near its confluence with the Wei River (a tributary of the Yellow River) in Shaanxi province, and is situated at the foot of the Loess Plateau (Fig. 3.1). The scheme uses irrigation water diverted from the Luohe River to meet the crop water requirements. This water is mainly applied using furrow or border irrigation systems. The study area has a semiarid climate with annual average rainfall 513.6 mm. Average potential evaporation (1,689.3 mm) is approximately three times the annual rainfall. Soils in the irrigation scheme are loams of loessial origin. The scheme is situated on a north-south elevation gradient of about 40 m, and includes a river terrace system divided into three levels: a high terrace (HT; 370–390 m) in the north, intermediate terrace (IT; 360–370 m) in the central area, and low terrace (LT; 344–360 m) in the south near the Luohe River. There are about 80 underground water wells for various purposes, including supplemental irrigation and drinking water.

3.6.2 Irrigation Water Quality

Electrical conductivity of irrigation water (ECw) from the Luohe River, which is the main source of this water, was within a limited range of 1.3–1.6 dS m^{-1}. Underground water (UW) is also used for supplemental irrigation, and had a much wider range between 0.5 and 21.0 dS m^{-1}. In general, higher underground water tables and larger ECw values were observed for water under the HT than under the IT or LT. Sodium and magnesium were the two main cations and sulfate and chloride the two main anions in UW.

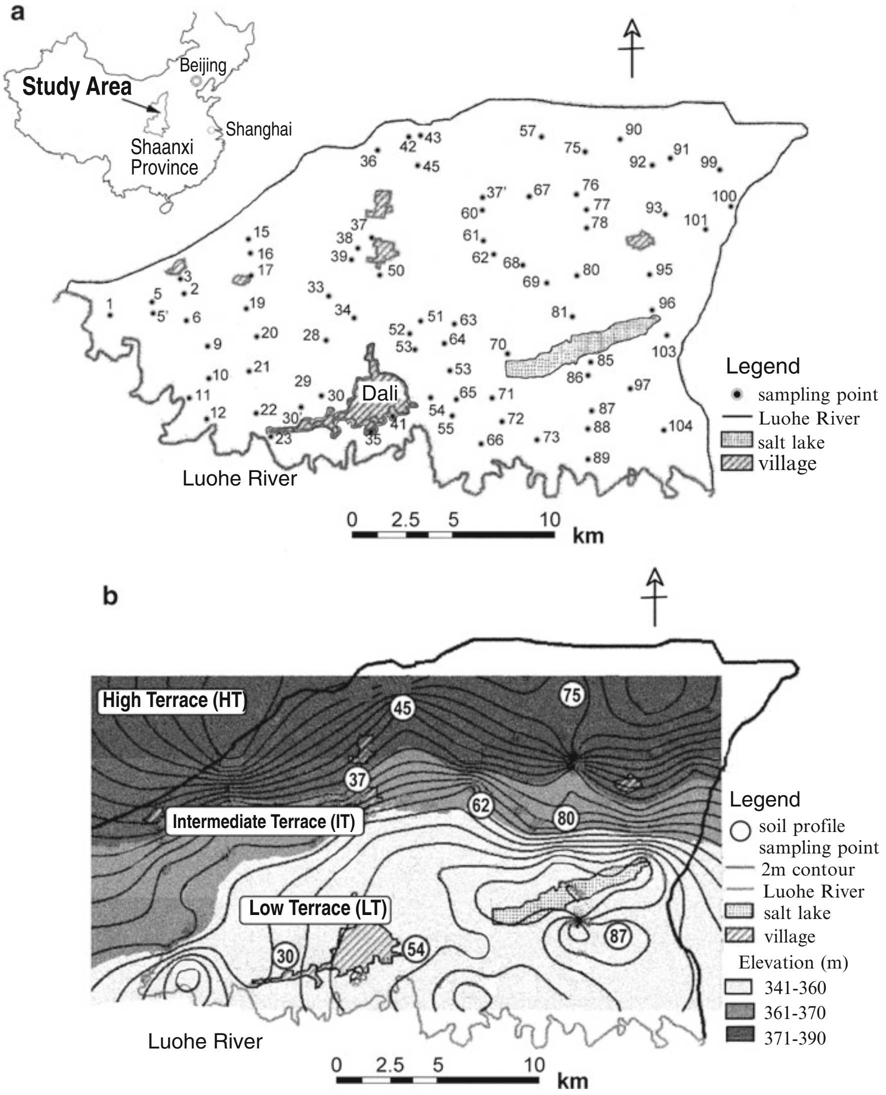

Fig. 3.1 Location of study site and (**a**) sampling points of underground water and surface soils, with well numbers; (**b**) soil profile sampling points and elevation in Luohui Irrigation Scheme, China

3.6.3 Soil Characteristics of Different River Terraces

Morphological properties of soil profiles from the various terraces and pedon descriptions are shown in Table 3.1. The low humus content of surface soils and bright yellowish-brown soils are features of Loess Plateau soil profiles. Calcareous

Table 3.1 Field profile description and physicochemical properties of selected soil profiles (Endo et al. 2012)

			Particle size distribution (%)						The amount of soluble salts in saturated extract (cmolc kg^{-1})										
									Cations					Anions					
Soil horizon	Depth (cm)	Soil color	Coarse sand	Fine sand	Silt	Clay	pH	ECe (dS m^{-1})	Ca^{2+}	Mg^{2+}	K^+	Na^+	Total	SO_4^{2-}	NO_3^-	HCO_3^-	Cl^-	Total	SAR
No. 75, High Terrace • Calciustepts • Hapic Calcisols • Orchard (Lat. 34°54′43.4″N., Long. 110°02′58.3″E.: Elevation 379.4 m)																			
Ap	0 – 10/20	7.5YR4/3	0.2	32.6	37.9	29.3	8.4	0.5	0.07	0.06	0.02	0.16	0.30	0.06	0.00	0.20	0.01	0.27	2.74
B11	10/20 – 20	10YR 4/4	0.2	33.7	37.1	29.0	8.5	1.1	0.09	0.07	0.01	0.46	0.64	0.21	0.01	0.28	0.22	0.71	6.98
B12	20 – 30	10YR 4/4	0.1	37.0	37.1	25.8	8.2	1.9	0.19	0.10	0.02	0.83	1.13	0.04	0.56	0.15	0.41	1.17	9.39
B2	30 – 49	10YR 4/3.5	0.1	36.7	35.7	27.5	8.2	2.7	0.21	0.10	0.01	1.17	1.50	0.15	0.75	0.12	0.53	1.56	12.84
2Bk1	49 – 65	7.5YR4/3	0.0	27.8	39.5	32.7	8.4	2.1	0.09	0.06	0.01	1.12	1.28	0.66	0.01	0.13	0.65	1.46	18.39
2Bk2	65 – 90+	7.5YR 3/4	0.0	34.2	34.8	31.0	8.0	3.4	0.33	0.14	0.01	1.68	2.16	1.24	0.02	0.09	1.24	2.59	14.84
No. 45, High Terrace • Calciustepts • Hapic Calcisols • Bare land (Lat. 34°54′13.8″N., Long. 109°57′28.1″E.: Elevation 371.2 m)																			
A	0 – 13	10YR 4/3	0.1	51.9	31.2	16.8	8.0	4.8	0.63	0.91	0.04	2.30	3.88	2.04	0.02	0.15	1.82	4.03	11.29
BC	13 – 34	10YR 4/3	0.1	54.8	30.8	14.3	7.9	3.1	0.53	0.60	0.02	1.25	2.40	1.54	0.00	0.11	0.78	2.44	7.20
2Bk	34 – 59/65	7.5YR 4/4	0.1	35.8	40.1	24.0	7.7	4.7	1.51	1.10	0.02	1.77	4.40	3.27	0.01	0.07	0.87	4.21	6.60
3BC1	59/65 – 85	7.5YR 4/4	0.0	24.5	44.1	31.4	7.8	4.1	0.80	0.88	0.02	2.16	3.86	2.58	0.01	0.09	1.10	3.79	9.43
3BC2	85 – 110	7.5YR 4/5	0.0	44.5	33.9	21.6	7.7	6.8	1.76	1.39	0.02	3.50	6.67	4.31	0.02	0.05	1.89	6.26	11.91
3BC3	110 – 130+	7.5YR 4/6	0.0	20.6	47.9	31.5	7.7	12.2	1.71	2.31	0.02	7.41	11.45	6.91	0.05	0.07	6.19	13.22	21.19
No. 37, Intermediate Terrace • Calciustepts • Hapic Calcisols • Orchard (Lat. 34°54′16.4″N., Long. 109°57′32.8″E.: Elevation 367.9 m)																			
Ap1	0 – 15	10YR 3.5/3	0.5	50.4	31.5	17.6	8.4	1.0	0.21	0.14	0.03	0.22	0.60	0.14	0.13	0.19	0.09	0.54	2.34
Ap21	15 – 30	10YR 5/3	0.1	50.2	32.4	17.2	8.4	0.8	0.10	0.06	0.02	0.29	0.47	0.16	0.00	0.13	0.20	0.49	4.64
Ap22	30 – 46/55	10YR 4/3	0.1	45.9	34.1	19.9	8.5	0.8	0.09	0.05	0.01	0.30	0.45	0.17	0.00	0.13	0.15	0.46	5.32
BC	46/55 – 65	10YR 4/6	0.0	45.6	19.8	34.6	8.6	1.0	0.10	0.07	0.02	0.34	0.53	0.21	0.00	0.13	0.21	0.56	5.59
2B	65 – 89	7.5YR 4/4	0.1	35.5	34.6	29.9	8.5	1.2	0.12	0.09	0.01	0.46	0.68	0.29	0.00	0.11	0.30	0.70	6.48
2Bk1	89 – 105	7.5YR 4/4	0.1	37.7	34.4	27.8	8.2	1.4	0.16	0.13	0.01	0.53	0.83	0.40	0.04	0.11	0.41	0.96	6.08
2Bk2	105 – 110+	7.5YR 4/4	0.0	40.0	35.0	25.0	8.3	1.7	0.18	0.16	0.01	0.74	1.08	0.53	0.05	0.10	0.54	1.22	7.67

No. 80, Intermediate Terrace • Calciustepts • Hapic Calcisols • Orchard (Lat. 34°51′20.7″N., Long. 110°02′41.6″E.: Elevation 365.4 m)																					
Ap	0	–	15	10YR 3.5/4	0.1	53.8	30.0	16.1	8.2	0.8	0.27	0.10	0.02	0.07	0.46	0.12	0.12	0.10	0.04	0.38	0.75
Ap21	15	–	25	10YR 5/4	0.1	50.6	31.7	17.6	8.2	0.4	0.09	0.04	0.01	0.06	0.19	0.02	0.01	0.08	0.03	0.13	1.13
Ap22	25	–	27/41	10YR 5/4	0.0	46.3	34.3	19.4	8.5	0.4	0.03	0.02	0.01	0.12	0.17	0.01	0.00	0.09	0.01	0.11	4.12
2Bk1	27/41	–	53	7.5YR 5/4	0.0	44.2	23.9	31.9	8.8	0.4	0.02	0.01	0.01	0.18	0.21	0.02	0.00	0.17	0.01	0.21	7.82
2Bk2	53	–	82	10YR 5/4	0.1	50.0	29.1	20.8	8.8	0.5	0.04	0.01	0.01	0.19	0.25	0.06	0.00	0.17	0.01	0.24	6.70
2Ck	82	–	110+	10YR 4/6	0.1	53.4	28.8	17.7	8.8	0.6	0.03	0.01	0.01	0.23	0.27	0.10	0.00	0.16	0.02	0.28	9.47
No. 62, Intermediate terrace • Calciustepts • Hapic Calcisols • Orchard (Lat. 34°51′52.6″N., Long. 110°00′08.3″E.: Elevation 360.0 m)																					
Ap1	0	–	10	10YR 4/4	0.1	38.5	37.7	23.7	7.9	2.7	0.59	0.28	0.04	0.83	1.73	0.35	0.80	0.13	0.29	1.56	5.37
Ap21	10	–	20	10YR 4/6	0.1	39.4	36.8	23.7	7.7	4.4	1.06	0.53	0.03	1.27	2.89	0.34	1.48	0.10	0.65	2.57	6.14
Ap22	20	–	29	10YR 4/6	0.1	40.6	36.2	23.1	7.8	3.6	0.73	0.52	0.02	1.27	2.53	0.22	1.24	0.11	0.61	2.19	6.65
BC1	29	–	40	10YR 4/6	0.1	37.9	35.5	26.5	8.1	3.0	0.28	0.26	0.02	1.10	1.67	0.11	0.81	0.14	0.50	1.56	9.08
BC2	40	–	55	10YR 4/6	0.1	42.5	34.3	23.1	8.1	2.4	0.22	0.19	0.02	0.83	1.26	0.17	0.53	0.16	0.32	1.19	8.09
2BCk1	55	–	70	7.5YR 4.5/4	0.0	46.3	32.3	21.4	7.9	3.1	0.39	0.34	0.02	0.96	1.71	0.28	0.75	0.10	0.36	1.49	7.35
2BCk2	70	–	100+	7.5YR 4/4	0.0	41.4	33.1	25.5	8.0	1.9	0.09	0.10	0.01	1.38	1.57	0.20	0.22	0.11	0.26	0.79	21.23
No. 30, Low Terrace • Typic Ustorthents • Calcic Regosols • Cotton field (Lat. 34°47′24.7″N., Long. 109°53′47.4″E.: Elevation 353.1 m)																					
Ap1	0	–	10/17	10YR 3/4	0.4	52.7	27.7	19.2	8.3	1.1	0.25	0.12	0.02	0.23	0.62	0.16	0.17	0.10	0.13	0.57	4.41
Ap2	10/17	–	21	10YR 3.5/4	0.4	51.9	27.8	19.9	8.1	1.7	0.47	0.30	0.02	0.24	1.03	0.19	0.38	0.09	0.38	1.04	1.75
Ap3	21	–	31	10YR 4/4	0.2	55.2	26.5	18.1	8.1	1.9	0.56	0.36	0.02	0.21	1.15	0.17	0.50	0.08	0.38	1.13	1.41
C	31	–	38	10YR 4/6	0.1	63.3	21.2	15.4	7.9	1.3	0.32	0.22	0.01	0.17	0.73	0.11	0.28	0.06	0.23	0.68	1.56
2C	38	–	41	10YR 5/3	0.1	47.8	33.8	18.3	8.0	1.2	0.33	0.23	0.01	0.19	0.75	0.12	0.26	0.08	0.25	0.71	1.57
3C1	41	–	63	8.75YR 5/4	0.4	59.0	24.2	16.4	8.2	0.7	0.11	0.09	0.01	0.31	0.53	0.05	0.09	0.09	0.11	0.34	4.65
3C2	63	–	78	10YR 4.5/4	0.2	66.8	19.2	13.8	8.6	0.4	0.03	0.02	0.01	0.12	0.18	0.05	0.00	0.09	0.02	0.16	4.13
3C3	78	–	90+	10YR 5/4	0.2	61.9	20.8	17.1	8.7	0.5	0.02	0.02	0.01	0.16	0.21	0.08	0.00	0.12	0.02	0.22	6.01

(continued)

Table 3.1 (continued)

			Particle size distribution (%)						The amount of soluble salts in saturated extract (cmolc kg^{-1})										
									Cations					Anions					
Soil horizon	Depth (cm)	Soil color	Coarse sand	Fine sand	Silt	Clay	pH	ECe (dS m^{-1})	Ca^{2+}	Mg^{2+}	K^+	Na^+	Total	SO_4^{2-}	NO_3^-	HCO_3^-	Cl^-	Total	SAR
No. 54, Low Terrace • Calciustepts • Hapic Calcisols • Orchard (Lat. 34°47′55.1″N., Long. 109°58′02.0″E.: Elevation 351.6 m)																			
Ap	0 – 7	10YR 5.5/3	0.2	83.9	9.7	6.2	8.1	1.0	0.08	0.10	0.01	0.28	0.48	0.11	0.14	0.12	0.03	0.40	4.62
2Ap1	7 – 17	10YR 4/3	0.6	63.7	22.3	13.4	8.3	3.0	0.14	0.15	0.01	1.28	1.58	0.89	0.06	0.23	0.61	1.79	15.82
2Ap2	17 – 27	10YR 4/3	0.5	62.9	23.0	13.6	8.0	5.8	0.76	0.67	0.02	2.56	4.00	1.77	0.01	0.13	2.00	3.91	13.96
2BC1	27 – 40	10YR 4/3.5	0.5	54.3	27.3	17.9	7.9	3.2	0.51	0.54	0.01	0.85	1.91	0.59	0.06	0.08	1.22	1.95	5.52
2BC2	40 – 49/64	10YR 5/4	0.2	67.5	19.6	12.7	8.2	1.0	0.07	0.08	0.01	0.35	0.51	0.12	0.01	0.11	0.23	0.47	6.65
3BCk1	49/64 – 75	10YR 4/6	0.3	60.2	23.5	16.0	8.2	0.9	0.04	0.06	0.01	0.35	0.46	0.12	0.00	0.13	0.17	0.41	7.50
3BCk2	75 – 100+	10YR 4/6	0.0	60.1	23.1	16.8	8.5	0.8	0.02	0.03	0.01	0.43	0.50	0.08	0.00	0.17	0.08	0.33	12.48
No. 87, Low Terrace • Typic Ustorthents • Calcic Regosols • Orchard (Lat. 34°47′37.7″N., Long. 110°03′20.6″E.: Elevation 351.0 m)																			
Ap1	0 – 10	10YR 5/4	0.1	52.4	29.9	17.6	8.3	1.1	0.07	0.03	0.03	0.38	0.51	0.14	0.37	0.16	0.16	0.83	7.99
Ap2	10 – 24	10YR 5/3	0.1	49.2	31.6	19.1	8.2	0.7	0.10	0.04	0.03	0.27	0.44	0.12	0.00	0.13	0.13	0.39	4.53
Ap3	24 – 38	10YR 5/4	0.0	53.6	27.9	18.5	8.4	0.6	0.08	0.03	0.02	0.22	0.35	0.10	0.00	0.11	0.12	0.33	4.57
C	38 – 52	10YR 5.5/4	0.2	57.2	26.6	16.0	8.4	0.7	0.06	0.02	0.01	0.26	0.35	0.07	0.01	0.11	0.11	0.30	6.37
2Ck1	52 – 64	10YR 5/4	0.0	57.6	27.1	15.3	8.6	0.7	0.03	0.02	0.01	0.26	0.31	0.06	0.00	0.11	0.08	0.26	8.86
2Ck2	64 – 75	10YR 4.5/4	0.0	56.0	27.5	16.5	8.3	0.7	0.04	0.02	0.01	0.23	0.30	0.08	0.00	0.10	0.08	0.27	7.66
2Ck3	75 – 90	10YR 4/5	0.0	56.4	25.2	18.4	8.5	0.8	0.05	0.03	0.01	0.29	0.38	0.11	0.00	0.14	0.09	0.34	7.37
2Ck4	90 – 100+	10YR 4/6	0.0	56.1	25.1	18.8	8.3	0.6	0.04	0.03	0.01	0.21	0.29	0.11	0.00	0.10	0.06	0.28	5.39

material was present from the surface down to lower horizons. Master soil horizons on the HT and LT were A-B or A-BC, and A-BC or A-C, respectively. The morphological properties of soil profiles on the terraces in the irrigation scheme reflect their various depositional and soil development characteristics. The soil profile descriptions suggest that the terraces had differences in extent of soil development. Soil sediment varied according to soil deposition because of geographic features and degree of soil pedogenesis, which is reflected in subsoil textures. Weathering and pedogenic processes appeared to have progressed further on the HT than the LT.

Soils on the HT are classified as Calciustepts and Haplic Calcisols, according to Soil Taxonomy (Soil Survey Staff 2010) and World Reference Base for Soil Resources (WRB) classification (IUSS Working Group WRB 2006), respectively. Soils of the LT, with the exception of No. 54, are classified as Typic Ustorthents and Calcic Regosols, according to the same respective sources.

Physicochemical properties of selected soil profiles are also presented in Table 3.1. The soils consisted of 20–84 % sand, 10–50 % silt, and 6–35 % clay. Soils on the HT were rich in relatively fine fraction (high clay plus silt contents), while LT soils had comparatively high contents of sand fraction, which is attributed to deposition of sandy material by flooding of the Luohe River. In particular, lower soil horizons on the HT had a clay plus silt content of 60–80 %. On the LT, the fine sand fraction dominated and was about 60 % of total content in the lower horizons. There was a clear relationship in the irrigation scheme between soil characteristics and topographic position, that is soil toposequence.

3.6.4 Levels of Accumulated Salts in Soil Profiles of Terraces

Different levels of soil soluble salts were observed on the terraces (Table 3.1). Salt accumulation in the soil profile was strongly dependent on soil properties of the terrace, especially subsoil properties. Soils on the IT and LT had lower electrical conductivity values of a saturated soil extract (ECe) levels with depth. There was no evidence of salt accumulation in profiles with mostly sandy texture. Thus, it appears that risk of salinization on the IT and LT was less than that on the HT. However, there were several sites on the LT where the subsoil pH exceeded 8.5, that is, soils on LT have high risk of soil sodication and/or alkalization. The coarser texture of subsoils on the IT and particularly LT might lead to better hydraulic properties and cause low salinity and high sodicity of soils. On the other hand, there was greater soil salinity on the HT relative to the IT and LT, and soil salt content on the HT increased with depth (Table 3.1). A heavy texture layer was observed below 60 cm in the central part of the HT, which was a typical location for severe salt accumulation. That is, the heavier texture of subsoil causes poor permeability and high soil salinity level. The risk of soil salinization is increased by subsoils with heavy textures, whereas the risk of soil sodication is increased by sandy subsoils. Subsoil texture may therefore be a useful indicator of the risk of salt accumulation.

The study area was subdivided into two salt-affected areas according to the potential of soil salinization and sodication—the northern part of the HT with high risk of salinization, and the northeast area of the LT with high risk of soil sodication. Because soil salinization and sodication are different processes, management methods to control them also differ. Therefore it is necessary to clearly diagnose the state and/or risk of the two types of soil degradation caused by salt. According to the present findings, subsoil texture influences the state of salt accumulation. That is, soil salinization risk is enhanced by clay-rich subsoil, whereas soil sodication risk is increased by sandy subsoil with good permeability. Subsoil texture may be a good indicator for forecasting the state of salt accumulation. However, determination of soil texture by mechanical (particle-size) analysis demands much time and effort.

To establish appropriate soil management methods for particular irrigation schemes, we suggest that three assessments based on soil properties be adopted. First, soil textures, including clay content, can be assessed by the simple and easy procedure of hand texturing using the fingers. Second, the spatial distribution of clay contents or subsoil texture should be mapped for the entire area and correlated with spatial variability of salt accumulation. Finally, other soil characteristics and area topography should be assessed, and their relationships with the presence of saline or sodic soils examined. Information from these assessments can help manage the land to minimize further soil salinization and sodication.

3.7 Conclusions

Because of pressure from increasing population and economic development, soil degradation and desertification are widespread problems in China. The Loess Plateau has been facing increasing soil degradation from human activities. To develop appropriate soil management approaches, it is necessary to consider local farming situations. The case study of the Luohui Irrigation Scheme indicates that subsoil texture and soil hydraulic properties influence salt build-up processes. Although a variety of conservation measures has been practiced for many years on the Loess Plateau, a method to achieve optimal combination of land use and conservation strategies should be made available.

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Chapter 4
Vegetation of the Loess Plateau

Norikazu Yamanaka, Qing-Chun Hou, and Sheng Du

Abstract Natural vegetation on the Loess Plateau has been suffering gradual degradation over a long period, owing to human activities. As a result, hardly any original vegetation remains.

The potential natural vegetation is divided into five vegetation zones—forest, forest steppe, steppe, desert steppe and desert. These vegetation zones change from forest to desert with a declining precipitation gradient from southeast to northwest on the plateau.

In the forest and forest steppe zones, the dominant tree species is *Quercus liaotungensis*, which is considered the climax species in this area.

In terms of artificial forest, the most important and widely planted tree species on the plateau is *Robinia pseudoacacia*, a deciduous tree species belonging to the family of Leguminosae. Another such species is the conifer *Pinus tabulaeformis*. In contrast to *R. pseudoacacia,* which is alien to China, *P. tabulaeformis* is indigenous and its natural forests are widely distributed in central and northern China.

This chapter describes the features of natural and artificial vegetation on the Loess Plateau.

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Keywords Natural vegetation • Vegetation zones • Artificial forest • Forest structure

4.1 Climate and Vegetation Zones

Natural vegetation on the Loess Plateau has been deteriorating for a long period as a result of human activity. Therefore, little of the original vegetation remains. However, the potential natural vegetation can be estimated based on the remaining vegetation. This potential vegetation can be divided into five zones, namely forest, forest steppe, steppe, desert steppe and desert. These zones change with decreasing precipitation from southeast to northwest on the plateau (Cheng and Wan 2002) (Fig. 4.1).

The forest zone (I) is mainly in the southeast part of the Loess Plateau. It is also found in mountainous regions near the boundaries with Henan, Shanxi, Shaanxi and Gansu provinces. However, hardly any natural forest remains because of intense destruction by human activity and conversion to farmland. Natural forests are restricted to a small area that remains at the edge of the plateau and on steep slopes.

Elevation of the forest zone ranges from 800 to 2,000 m above sea level. Average annual precipitation of the zone is 500–650 mm, and average annual daily temperature is 11–14 °C. Broad-leaved deciduous forest is the dominant vegetation type.

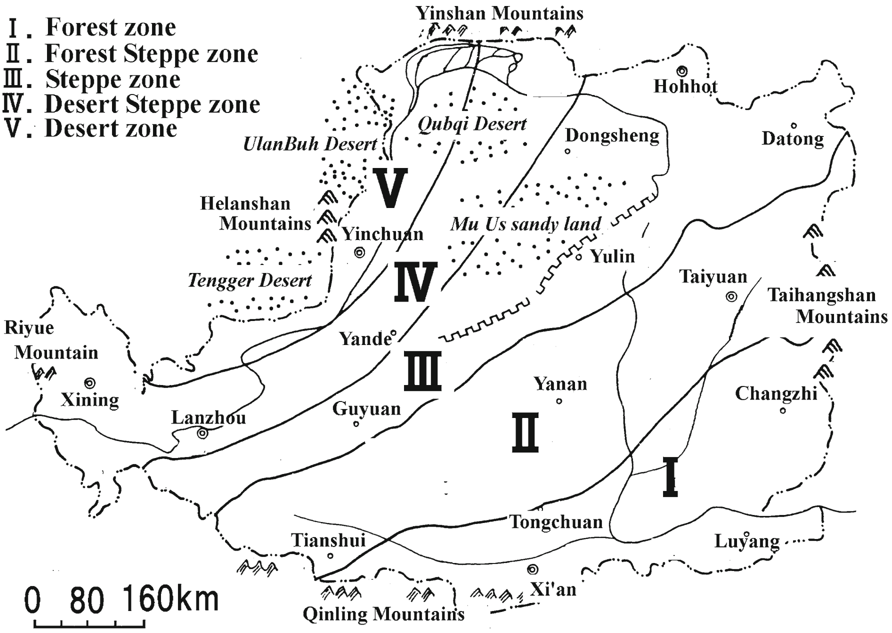

Fig. 4.1 Vegetation zones in Loess Plateau region (based on Cheng and Wan 2002)

The dominant tree species in this type of forest are oak (*Quercus* spp.), poplar (*Populus* spp.), birch (*Betula* spp.), maple (*Acer* spp.), elm (*Ulmus* spp.) and *Tilia* spp. In the shrub layer, *Vitex chinensis*, *Rosa xanthina*, *Cotoneaster* spp., *Syringa* spp., *Berberis amurensis*, *Spiraea* spp., *Clematis fruticosa*, and *Sophora davidii* are frequent. On the forest floor, there are herb species such as *Bothriochloa ischaemum*, *Themeda triandra*, *Dendranthema indicum*, *Pedicularis* spp., *Artemisia sacrorum*, *A. giraldii*, *Melampyrum roseum*, *Stipa bungeana*, *S. sibirica*, *Spodiopogon sibiricus*, and *Arundinella hirta*. There is subtropical broad-leaved evergreen forest in the southern Qinling Mountains, which is at the southern limit of the Loess Plateau region.

The forest steppe zone (II) is the transitional zone, which is adjacent to the steppe zone in the northwest and to forest zone in the southeast. Zone II includes the upper basins of the Luohe and Jinghe rivers, middle basin of the Weihe River, and the Lüliangshan, Ziwuling and Liupanshan mountains. Geographic features of this zone comprise complex loess hills and gullies. The zone is within an elevation range 1,000–1,600 m above sea level. Average annual precipitation is 450–550 mm, and average annual temperature 8–10 °C. Vegetation is sparse because of destruction by human activity and drought. Dominant vegetation is grassland or shrubland established under drought stress. Secondary forests remain only in mountainous areas. The main difference with the forest zone is the increased types of steppe vegetation in the forest steppe. Tree species such as *Pinus tabulaeformis*, *Quercus liaotungensis*, *Populus davidiana*, *Betula platyphylla* are mainly distributed in the mountainous areas. Shrub species such as *Buddleja alternifolia*, *Sophora davidii*, *Prinsepia uniflora*, *Hippophae rhamnoides*, *Ostryopsis davidiana*, *Corylus heterophylla*, *Lonicera* spp., *Spiraea* spp. are dominant on sunny hills. Grasses and herbs, such as *Bothriochloa ischaemum*, *Stipa bungeana*, *Artemisia sacrorum*, *A. giraldii*, *Lespedeza* sp., comprise the several types of steppe vegetation.

The steppe zone (III) is adjacent to the desert steppe zone in the northwest and forest steppe zone in the southeast. The upper basins of the Wudinghe, Jinghe, Qingshuihe and Zulihe rivers are included in this zone. Areas of the Baiyunshan and Quwushan mountains are also included.

Average annual precipitation is 300–450 mm and average daily temperature is 8–9 °C. *Liang*, a gentle ridge of loess, is a typical geomorphology in this area. Vegetation of the steppe zone mainly consists of grasses, herbs and shrubs (Fig. 4.2).

Gramineae and Asteraceae are the dominant plant families in this zone. *Lespedeza* spp., *Thymus* spp. and *Potentilla* spp. are also common. With respect to grassland vegetation, *Stipa bungeana* is widely distributed and frequently dominant. *Artemisia sacrorum*, *A. giraldii*, *Stipa grandis*, *S. gobica*, *A. frigida*, and *Thymus mongolicus* are also distributed widely. The remaining natural forests are partially distributed across mountainous areas 2,000 m above sea level or more. *Picea* spp., *Pinus tabulaeformis*, *Populus davidiana*, *Betula platyphylla*, *Quercus* spp. and thorny shrubs are found in these natural forests.

Desert steppe zone (IV) is in the northwest part of the Loess Plateau, and the southeast district is adjacent to the steppe zone. The area of this zone is comparatively small. Average annual precipitation is 200–300 mm, and annual average temperature 8–9 °C.

Fig. 4.2 Grasslands of Yunwu Mountain, Ningxia (photograph by Norikazu Yamanaka)

As for vegetation, graminaceous species are dominant here. *Artemisia* spp. and small thorny shrubs are also predominant. Many desert vegetation elements are present in this zone. The most typical vegetation is *Stipa breviflora* grassland, which is widely distributed in the hilly loess area of Ningxia and Gansu provinces and in low-elevation areas of Qinghai Province.

The desert zone (V) is on the edge of the northwest Loess Plateau. The area of this zone is comparatively small within the plateau region. The Hetao Plain of western Inner Mongolia, Yinchuan Plain, downstream areas of the Qingshuihe River, and areas between Jingyuan and Baiyin of Gansu Province are included in this zone. Average annual precipitation is around 200 mm, and annual average temperature 9–10 °C. Vegetation consists chiefly of xerophytes (Fig. 4.3). *Kalidium* spp., *Sympegma regelii* and *Anabasis brevifolia* are typical plants here.

4.2 Forest Vegetation on Loess Plateau

Among the vegetation zones of the Loess Plateau described above, vegetation in forest and forest steppe zones are historically destroyed by human activities. Remaining forests are very limited, as most have been completely destroyed or

Fig. 4.3 Desert vegetation dominated by xerophytes near Wuhai, Inner Mongolia (photograph by Norikazu Yamanaka)

converted to farmland. However, forests can potentially be reestablished in forest and forest steppe zones. In the present forest distribution of Shaanxi Province, which covers the major part of forest and forest steppe zones in the Loess Plateau region, forests are in the upstream region of the Luochuan River, which flows in the central portion of Shaanxi Province.

The area in which forests remain on the eastern side of the Luochuan River is called the Huanglongshan forest district; that of the western side is called the Qiaoshan forest district. In the former district, there are cities and towns such as Yan'an, Ganquan, Yichuan, Fuxian, Luochuan, Huanglong, and Hancheng. Average elevation of this district is 1,000–1,700 m above sea level, with Daling the summit at 1,783 m. Average annual temperature of this forest district is 8.6 °C and average annual precipitation 611 mm. Temperature and precipitation decrease northward. Precipitation in the vicinity of the city of Yan'an is about 500 mm, and there are few forests north of the city because of aridity.

Forest vegetation in this district is classified as warm-temperate deciduous broad-leaved, and the most dominant forest species is *Quercus liaotungensis* (Fig. 4.4). This is considered the climax species of this area; however, most *Q. liaotungensis* forests in this district are secondary, and there are few forests with large trees (ECFSP 1989). Areas of *Quercus liaotungensis* forests are also limited, and most are fragmented. *Quercus liaotungensis* forests with slightly larger area exist only in

Fig. 4.4 *Quercus liaotungensis* forest in southern part of Yan'an, Shaanxi (photograph by Norikazu Yamanaka)

Nanniwan Town and Yichuan County of Yan'an. In addition to *Q. liaotungensis*, *Populus davidiana*, *Betula platyphylla*, *Pinus tabulaeformis* and *Platycladus orientalis* forests are also found in this district.

The geography, climate and vegetation of the Qiaoshan forest district are similar to those of Huanglongshan district. In the city of Yan'an, a region where forest growth is limited by aridity, forest vegetation varies with slope direction. On south-facing slopes, soil tends to be dry, owing to a large amount of solar radiation. In contrast, soil tends to be moist on north-facing slopes. Figure 4.5 shows that the difference in environmental conditions corresponding to slope direction are reflected by vegetation type. In the southern part of Yan'an, *Quercus liaotungensis* forest develops on north-facing slopes, and *Platycladus orientalis* coniferous forest on south-facing slopes.

As for the structure of natural forest remnants in southern Yan'an, the most dominant tree species is *Quercus liaotungensis* (Fig. 4.6). Other predominant species are *Cotoneaster multiflorus*, *Caragana microphylla*, *Spiraea pubescens* and others. These species, however, are small in height (about 1–2 m) and constitute the understory vegetation. The dominant *Quercus liaotungensis* occupies the canopy. Our study found that the average tree diameter at breast height (DBH) of *Q. liaotungensis* was 8.8–12.1 cm, and the largest was 38.5 cm. The tallest *Quercus liaotungensis* were 10–14 m in height. Other tree species in the canopy layer were *Acer*

Fig. 4.5 Difference of vegetation between north- and south-facing slopes in southern Yan'an, Shaanxi (photograph by Norikazu Yamanaka)

Fig. 4.6 *Quercus liaotungensis* growing in southern Yan'an. This species is described as *Quercus mongolica* var. *liaotungensis* in Huang et al. (1999) (photograph by Norikazu Yamanaka)

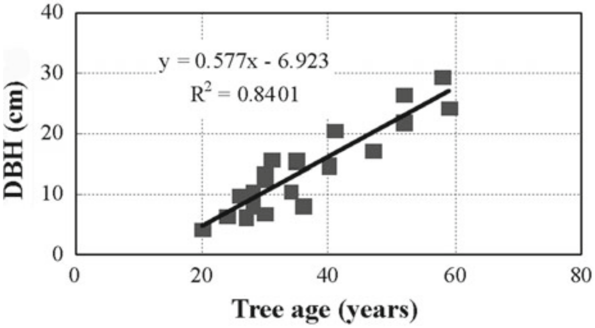

Fig. 4.7 Relation between age and DBH of *Quercus liaotungensis* growing on a ridge in southern Yan’an (Yamanaka 2008)

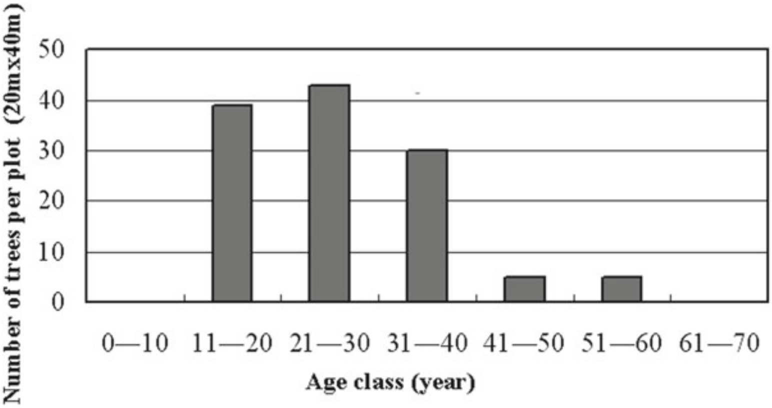

Fig. 4.8 Age class distribution of *Quercus liaotungensis* growing on a ridge in southern Yan’an (Yamanaka 2008)

stenolobum, *Syringa oblata*, *Prunus armeniaca*, *Pyrus betulaefolia*, *Acer ginnala*, *Platycladus orientalis*. Small numbers of other species were also found.

All forests investigated in the southern part of Yan’an City were secondary forests, composed of young trees. In forests on the ridge where a number of young trees grew, the oldest tree was 59 years old; strong correlation between DBH and age was found (Fig. 4.7) (Yamanaka 2008).

Even in the Yan’an region within the zone of limited growth caused by aridity, *Quercus liaotungensis* grew up to 30 cm in DBH by the age of 60 years. Figure 4.8 shows the age distribution of *Q. liaotungensis* calculated by an equation describing the relationship between DBH and age, and is shown in Fig. 4.7 (Yamanaka 2008). The L-shaped distribution of age implies that many young *Quercus liaotungensis* grow in the stand and sequentially succeed the forest itself. Many seedlings less than 1 cm in DBH grow in this stand, which also indicates the sequential regeneration of *Quercus liaotungensis*.

Fig. 4.9 *Betula platyphylla* forest in Yichuan, Shaanxi (photograph by Norikazu Yamanaka)

Regarding forest succession, species characteristics related to the reaction of trees to the light environment is important. In particular, shade tolerance indicating an ability to endure weak light makes it possible to forecast future forest succession.

Figure 4.9 shows *Betula platyphylla* forest of the Huanglongshan district in Yichuan County. This forest consists of *B. platyphylla* with DBHs about 15–20 cm; *Betula platyphylla* trees occupying the canopy layer had been withering. There were no young *Betula platyphylla* trees, whereas there many young *Quercus liaotungensis* trees on the forest floor. These results imply that *Q. liaotungensis*, with its stronger shade tolerance, should succeed this forest.

A relation similar to that mentioned above was also reported for major tree species grown on the Loess Plateau in Shanxi Province, which is adjacent to Shaanxi Province. Yamanaka et al. (2000) indicated that: (1) *Quercus liaotungensis* had stronger shade tolerance than *Pinus tabuliformis*; (2) shade tolerance of *Betula platyphylla* and *Populus davidiana* were considerably weaker because they only existed in well-lit spaces; and (3) the descending order of shade tolerance was *Quercus liaotungensis*, *Pinus tabuliformis*, *Betula platyphylla* and *Populus davidiana*.

4.3 Artificial Forests on Loess Plateau

Afforestation of the Loess Plateau is chiefly conducted under the framework of the "Three North Shelterbelt Construction Project" and "Grain-for-Green Project" launched by the Chinese government in the late 1970s and late 1990s, respectively. Through implementation of various national ecological projects, many plant species have been planted on the plateau. In the 1950s, many *Armeniaca sibirica* were cultivated. In the 1960s, however, large numbers of black locust (*Robinia pseudoacacia*) were planted. In the 1970s, poplar (*Populus* spp.) was established in addition to black locust. In the 1990s, *Pinus tabulaeformis* and apples (*Malus pumila*) began to be cultivated (Xue and Hou 2008).

Among these species, *Robinia pseudoacacia*, a deciduous tree species belonging to the Leguminosae family, is the most important and widely planted tree species on the Loess Plateau. This species is native to North America and was introduced to Qingdao from Europe at the beginning of the twentieth century.

After the establishment of the People's Republic of China in 1949, afforestation of *R. pseudoacacia* has been advanced on a large scale in various parts of China (Fig. 4.10).

Plantations of *Robinia pseudoacacia* on the plateau are mainly in Shaanxi, Gansu, and Shanxi provinces, as well as in Pengyang County in the southern part

Fig. 4.10 *Robinia pseudoacacia* planted in a fish scale-like micro catchment at Yan'an, Shaanxi (photograph by Norikazu Yamanaka)

Fig. 4.11 Degraded *Robinia pseudoacacia* plantation caused by water deficit in northern part of Yan'an, Shaanxi (photograph by Norikazu Yamanaka)

of Ningxia Province. Among these provinces, the planted area of Shaanxi is the largest, and *R. pseudoacacia* is especially cultivated in the region between the Weihe River and southern part of Yan'an. However, planted area and biomass decrease with decreasing temperature and precipitation northwestward of Yan'an. It becomes impossible for *R. pseudoacacia* to grow normally in the vicinity of the Great Wall, which is at the northern limit of Shaanxi Province (Xue and Hou 2008).

In Hequ County, in the northern part of Shanxi Province, growth of *R. pseudoacacia* is good on the south slope relative to the north slope, because of low temperature. Moreover, the growth of *R. pseudoacacia* planted at the bottom of a slope is superior to those planted on a ridge. In the northern part of Shaanxi Province, plantations on ridges are frequently degraded because of water deficit (Fig. 4.11).

Another widely planted species on the Loess Plateau is the conifer *Pinus tabulaeformis* Carr. In contrast to *R. pseudoacacia*, which is alien to China, *P. tabulaeformis* is indigenous and its natural forests are widely spread across central and northern China, including the provinces of Liaoning, Inner Mongolia, Hebei, Beijing, Tianjin, Shanxi, Shaanxi, Ningxia, Gansu, Qinghai, Sichuan, Hubei, Henan, and Shandong (Xu 1993). As a major distribution zone of natural *P. tabulaeformis*, the mountainous areas of the Loess Plateau have long been forested with this species. There are large areas of *P. tabulaeformis* plantations in the Hanglongshan and Qiaoshan forest districts of the plateau. The plantations grow well and can naturally regenerate on shady, partially shady, and partially sunny slopes at low and mid elevations (800–1,600 m) of mountainous regions (ECFSP 1989). Even in the northern plateau with its relatively low precipitation, *P. tabulaeformis* is widely planted and has high adaptability to soil drought.

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Chapter 5
Agriculture on the Loess Plateau

Ping An, Tomoe Inoue, Mingqing Zheng, A. Egrinya Eneji, and Shinobu Inanaga

Abstract The Loess Plateau is considered the cradle of agricultural cultivation in China. The climate, ecology and geography of the area have created a unique farming system on the plateau. Agricultural output in the area increased 25-fold from 1980 to 2008, with more profound increases during the last 5 years because of the adoption of modern farming techniques. However, the rapid advances of technology and drastic societal changes (urbanization) have posed new challenges to agriculture on the plateau, such as shortages of water for irrigation and reductions in cultivable land from urbanization and soil erosion. Hence for sustainable agriculture on the plateau, measures such as terraced farming, use of supplemental irrigation, better farm inputs, crop rotation with legumes, and organic farming are recommended.

Keywords Loess Plateau • Agriculture • Farming system • Constrains • Measures

5.1 Introduction

The Loess Plateau (LP) is one of the birthplaces of agricultural civilization in the world, and is the cradle of agricultural cultivation in China. Agriculture has been practiced on the plateau for over 6,000 years, and the farming system is well established.

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Given its unique location and climate, agriculture on the plateau is essentially semiarid farming.

During the second half of the twentieth century, rapid population increase on the LP led to conversion of large areas of land to agricultural use, including those areas unsuitable for cultivation. This resulted in severe water scarcity and soil erosion, which in turn reduced soil productivity and prompted a shortage of food supply. Agricultural development on the plateau has fallen behind other areas in China. Recently, with the promotion of agricultural technologies and improvements in the farming system, agriculture on the LP has made tremendous progress.

5.2 Agriculture on the Loess Plateau

5.2.1 General Background

The LP covers parts of the autonomous regions of Inner Mongolia and Ningxia, and the provinces of Qinghai, Gansu, Shaanxi, Shanxi and Henan. Because the areas in Inner Mongolia, Qinghai and Henan that form part of the LP are relatively small or less important to agriculture (Table 5.1), discussion in this chapter mainly focuses on Gansu, Ningxia, Shaanxi and Shanxi Provinces. Without specific indication, all data used in this chapter are from these four provinces.

Agricultural land (cultivated land, garden plots, forestland and grassland) accounts for about 75 % of the total land area of the LP (Table 5.2). About 70 % of the cultivated land is on slopes of varying degrees, which is a significant feature of these lands relative to other cultivated farmland in arid and semiarid areas of China. Among these areas of sloping farmland, only 23 % are terraced.

General information of agriculture on the LP is shown in Figs. 5.1, 5.2, 5.3, and 5.4. To better understand the agricultural situation on the plateau, relevant data for the Huabei Plain (HP) are given for comparison. This plain is adjacent to the LP, to its east.

Table 5.1 Component administrative regions and their respective sizes in the Loess Plateau

Administrative area (province)	Area forming part of the Loess Plateau (km^2)	Area of province (km^2)	Proportion of Province (%)	Proportion of the Loess Plateau (%)
Shanxi	154,366	156,000	99	24
Ningxia	51,954	66,400	78	8
Shannxi	109,573	205,800	63	20
Gansu	51,954	454,430	24	17
Inner Mongolia	147,146	1,183,000	12	23
Henan	21,656	167,000	13	3
Qinghai	34,258	721,000	5	5

Source: National Development and Reform Commission of China (NDRC), The Ministry of Water Resources of China (MWR), Ministry of Agriculture of China (MOA), State Forestry Administration of China (SFA), 2010

Table 5.2 Land use in the Loess Plateau (2008)

	Land-use type					
	Cultivated land	Garden plot	Forest land	Grass land	Idle land	Others
Total area (10^4 ha)	1,458	122	1,667	1,650	1,107	483
Percentage (%)	22	2	26	25	17	7

	Within cultivated land						
	Degree of slope						
	<5°	5–15°		15–25°		>25°	
			Terraces		Terraces		Terraces
Area (10^4 ha)	455	372	243	215	68	91	15
Percentage (%)	31	25	17	15	5	6	1

Source: NDRC, MWR, MOA, SFA, 2010. Data in this table are of the whole Loess Plateau

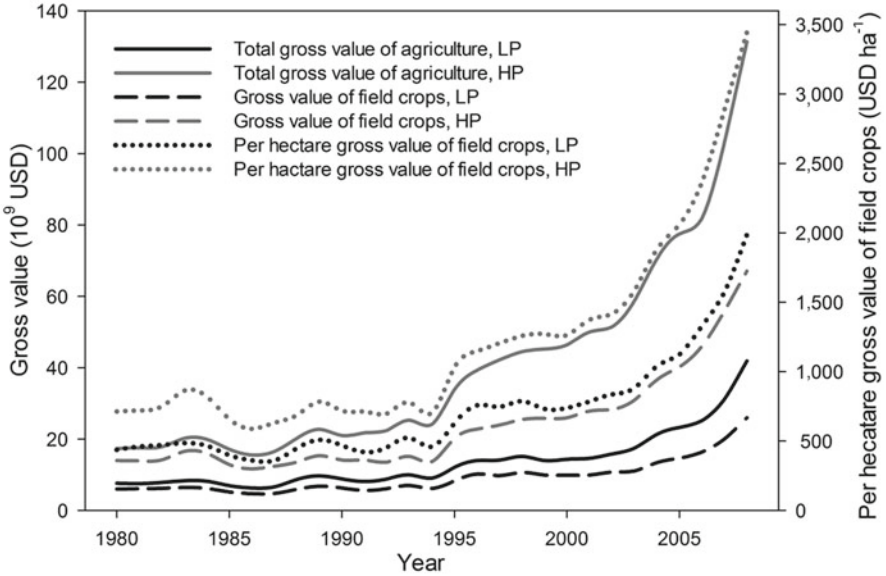

Fig. 5.1 Total gross value of agricultural production (field crops, forestry, animal husbandry and fishery), gross value of field crops and per hectare gross value of field crops in the Loess Plateau (LP) and Huabei Plain (HP) of China (1980–2008) (MOA 2009). Data in this figure were calculated at current prices and exchange rates

It is an important national agricultural area, with relatively developed agriculture. Data for Hebei and Shandong Provinces are used to represent the HP, since they are its main constituents. Annual precipitation in these two provinces ranges from 400 to 700 mm, from west to east (Du and Tang 2004).

The total gross value of agricultural production (field crops, forestry, animal husbandry and fishery) of the LP increased 25-fold from 1980 to 2008, and there has been a dramatic increase in the last 5 years (Fig. 5.1). The gross value of field crops

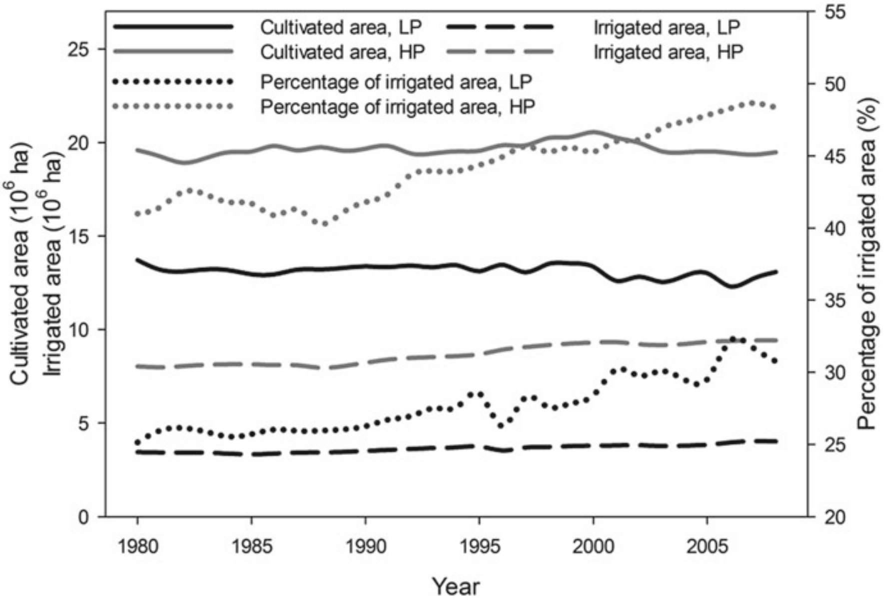

Fig. 5.2 Total cultivated and irrigated areas and the proportion of irrigated to cultivated areas in the Loess Plateau (LP) and Huabei Plain (HP) of China (1980–2008) (MOA 2009)

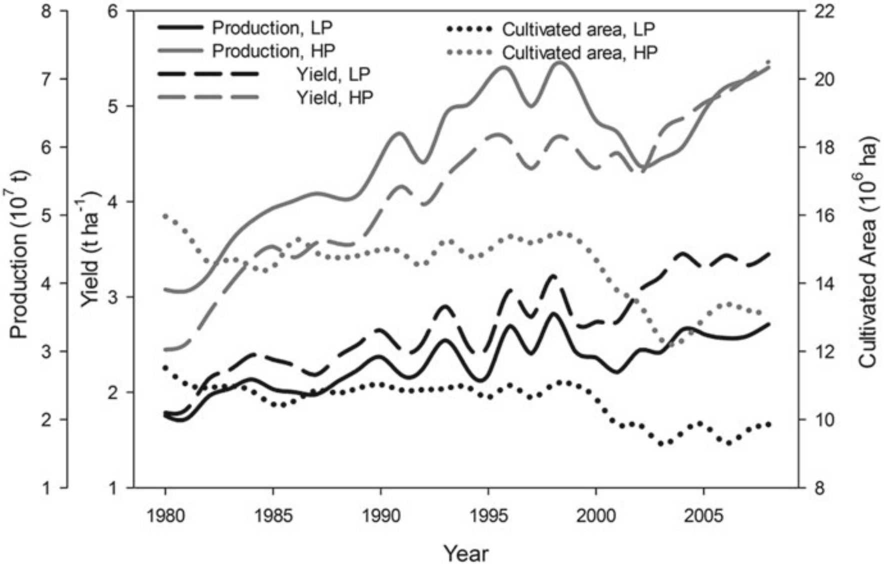

Fig. 5.3 Cultivated area, production and yield of grain crops in the Loess Plateau (LP) and Huabei Plain (HP) of China (1980–2008) (MOA 2009)

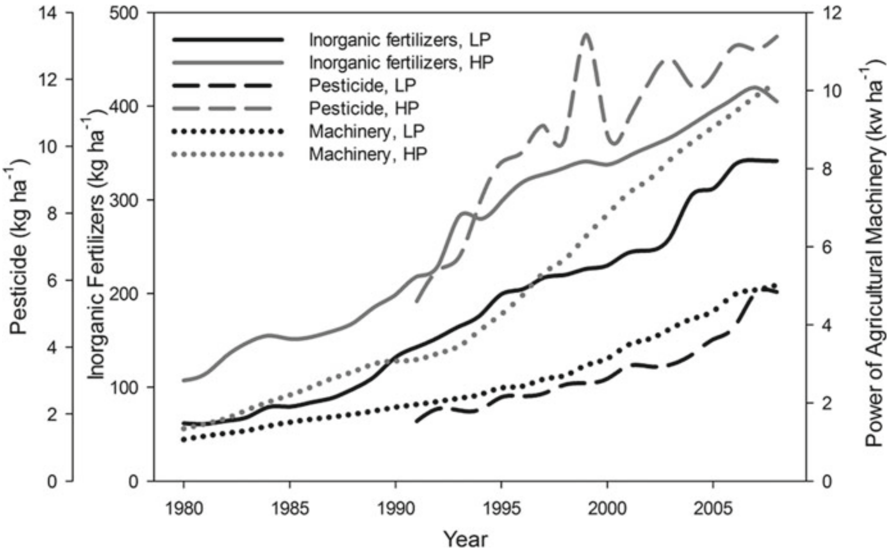

Fig. 5.4 Per hectare consumption of pesticides, inorganic fertilizers and power of agricultural machinery in the Loess Plateau (LP) and Huabei Plain (HP) of China (1980–2008) (MOA 2009)

has also increased proportionally with total agricultural gross value. However, outputs on the plateau were only about one-third of those on the HP, where agricultural output increased 35-fold over the same period. The farm output per unit of cultivated area was also lower on the LP relative to the HP (Fig. 5.1).

Cultivated area on the LP slightly decreased, except for a sharp decrease from 1999 during onset of the “Grain for Green” policy (Fig. 5.2). This project was launched by the Chinese government in 1999 to help restore ecological balance in the western region by turning low-yield farmland, much of it on steep slopes, back into forest and pastureland. See Chap. 10 for the details of this policy. The total area of irrigated land also did not change much over the last 30 years. The proportion of irrigated area to all cultivated area increased, especially over the last 10 years. However, the irrigated area is still small, covering only 30 % of all cultivated land, whereas that of the HP is about 50 %.

Grain crop cultivation area has decreased since 1999, while the total amount of production has increased because of an increase in yield per unit area on the LP (Fig. 5.3). However, the current grain yield remains lower on the LP (3.5 ton ha^{-1}) than the HP (5.5 ton ha^{-1}). Inputs of fertilizer, machinery and pesticides per unit of cultivated area increased during the past 30 years on the LP, especially in the last 10 years (Fig. 5.4). However, they are still lower than those on the HP.

Significant features on the LP are increases in planting area and production of fruit trees since the Grain for Green policy began. The total area of fruit trees was about 1,284.6 × 10^3 ha in 1999, increasing to 1,722.7 × 10^3 ha in 2008. Production was 8,346 × 10^3 ton in 1999, and 17,053×10^3 ton in 2008. The most significant increase was for apple trees in Shannxi Province (MOA 2009).

5.2.2 Classification of Agriculture on the Loess Plateau

Agricultural areas on the LP can be generally divided into rainfed and irrigated.

Rainfed agricultural areas cover about 70 % of total cultivable land, and are mainly distributed in mountainous and hilly areas (National Development and Reform Commission of China et al. 2010). Therefore, agricultural lands in this area are mostly on slopes (Table 5.2). These areas lack water resources, or significant elevation differences between land and river makes it difficult to use river water. Agriculture in these areas depends on rainfall, and only a small portion has supplemental irrigation using harvested rain water. Because of water scarcity, crop yield is very low (e.g., wheat yield is 2,505–3,117 kg ha^{-1}). With the recent popularization of rainwater harvesting, cultivation under supplemental irrigation has been increasing. This harvesting on the LP is mainly achieved by constructing underground water cellars. By using supplemental irrigation, crop yield has increased considerably.

Irrigation agriculture accounts for about 30 % of total cultivable land, and is mainly distributed along rivers and areas of flat terrain on the Hetao Plain and Fenwei Plain. Because of relatively high inputs, crop yield in these areas is usually 1.5–2 times that in rainfed areas (Wang and Wang 2009).

5.2.3 Crops and Cropping Systems on the Loess Plateau

Crops grown on the LP are very diverse, owing to the long history of agriculture in the area. Most cultivars have high tolerance to drought and other abiotic stresses, such as heat, cold and low fertility. More than 20 crops are presently cultivated on the plateau. These are winter wheat, spring wheat, maize, millet, sorghum, rice, pearl millet, soybean, barley, highland barley, hulless oats, buckwheat, oats, pea, hyacinth bean, broad bean, mung bean, adzuki bean, frijole, cowpea, green pea, hyacinth bean, potato, sweet potato, and others. Crops with high economic value and oil crops include rape, *Perilla frutescens*, flax, hemp, cotton, beets, and others. Fruits include apple, pear, jujube, apricot, plum, and peach.

Wheat and maize are the two major crops on the LP, accounting for about 35 and 30 % of total cultivated area and 30 and 40 % of total crop production, respectively, in recent years (NDRC et al. 2010). Meanwhile, a large cultivation area (more than 20 % of the national area) of minor grain crops is a significant feature of LP agriculture (Table 5.3). Cultivated areas of potato and buckwheat account for about 25 and 50 % of those crops in China, respectively.

In rainfed agricultural areas, single cropping is the dominant cropping system. It involves 3 or more years of continuous wheat, followed by 2 or more years of continuous maize. In some places with better water and temperature conditions, double cropping is also practiced. In irrigated areas, rotation of winter wheat—summer maize is the main cropping system, and this has the best yields.

Table 5.3 Average cultivation area of minor crops in the Loess Plateau (1998–2000)

	Total cultivation area (10^4 ha)	Cultivation area of main minor crops (10^4 ha)								
		Millet	Potato	Buck wheat	Barley	Oats	Mung bean	Red bean	Board bean	Total
Loess Plateau	1,189	46	110	20	5	7	12	2	7	208
Nation	11,180	138	440	44	84	42	71	23	112	954
Percentage (%)	11	33	25	44	6	17	17	10	6	22

Source: Zhang (2007)

5.3 Constraints to Agriculture on the Loess Plateau

Although the traditional agricultural system has been well developed, there are still certain constraints on further agricultural development.

5.3.1 Rainfed Farming

5.3.1.1 Shortcomings of Sloping Fields

The typical landscape in rainfed areas is loess hills; agricultural fields are mostly on slopes of varying degree. Because of this sloping landscape, water and fertilizer applied to fields are easily washed off, leading to low crop yields. Production in this area is usually 25–50 % of that in terraces and 10–20 % of that in irrigated fields (Shan and Chen 1993).

5.3.1.2 Shortage of Water

Annual precipitation in the rainfed area varies from 300 mm in the west to 500 mm in the east. Because about 80 % of the precipitation falls between July and September, crops (especially spring crops) suffer from water shortage. Average water use is 3,720 m^3 ha^{-1}, only 14 % of that nationwide (Li et al. 2007). Differences in potential yields of most crops between two outputs, calculated by solar radiation and precipitation (Table 5.4), indicate that the limiting factor on crop yield in this area is the shortage of irrigation water.

5.3.1.3 Insufficient Inputs

Because of severe erosion, soil fertility in this area is very poor (Table 5.5). In addition, the small income of farmers leads to low input to fields (Fig. 5.4), resulting in low yield (Fig. 5.3) and low efficiency in production of agricultural commodities (Fig. 5.1).

Table 5.4 Potential yield of crops calculated by solar radiation and precipitation

Crops	Potential yield based on solar radiation (kg ha^{-1})	Potential yield based on precipitation (kg ha^{-1})	Difference (%)
Winter wheat	11,486	6,790	41
Spring wheat	11,677	3,759	68
Spring corn	16,403	8,747	47
Summer corn	16,309	10,363	36
Millet	12,106	8,668	28
Potato	54,859	37,276	32
Sweet potato	77,692	63,442	18

Source: Wang and Wang (2009)

Table 5.5 Fertility of cultivated soils in the Loess Plateau and Huabei Plain

	Organic matter (%)	Total N (%)	Soluble P (mg kg^{-1})	Soluble K (mg kg^{-1})
Loess Plateau	0.66–1.14	0.049–0.071	4.1–6.8	105.5–66.4
Huabei Plain	1.35	0.088	9.56	127.7

Source: Wang and Wang (2009), Hu et al. (2002)

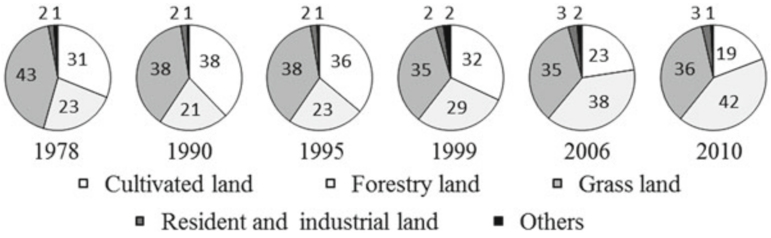

Fig. 5.5 Land use changes in Ansai County from 1978 to 2010 (Zhou et al. 2011)

5.3.1.4 Decrease in Area of Cultivable Land

With industrialization and urbanization, the area of cultivable land is decreasing rapidly. It has been reported that cultivated land decreased at yearly rates of 0.44–1.91 % in rural areas and 2.28–3.30 % in urban areas from 1996 to 2007 (Zhu and Huang 2007). In Shanxi Province, this decrease was 5.4×10^5 ha over the same period, accounting for 12.7 % of total cultivated land; per capita, it decreased by 21.4 % (Ma 2009). The Grain for Green policy also reduced cultivated land. Figure 5.5 shows land use changes in Ansai, a typical county in the rainfed agricultural area of the LP (Zhou et al. 2011). Because of the decrease in land available for cultivation, food production may not meet future demand as the population grows. Therefore, a large increase in crop yield per available land is a critical need in this area.

5.3.1.5 Soil Degradation in Agricultural Fields

Because most agricultural fields are on slopes, surface soils with relatively high fertility and organic matter content are easily eroded by water and wind (see Chap. 6 for details of soil erosion on the LP). The concentrated rainfall in summer and strong wind in early spring often remove surface soils from agricultural fields. It has been reported that 0.2–1 cm of surface soils on cultivated sloping land have been eroded by water; some areas may reach 2–3 cm every year. Total N and P were about 1.2 and 1.5 kg/ton, respectively, in the soils lost (NDRC et al. 2010). Further, the low organic and inorganic fertilizer inputs (Fig. 5.4) leads to soil degradation, and hence low productivity of agricultural fields (Fig. 5.3).

5.3.1.6 Low Diversity in Cropping Systems

Excessive emphasis on high crop yield has historically compromised diversity in crops and cropping systems. In this area, cropping accounts for over 60 % of the total agricultural (including animal husbandry and forestry) output value (Fig. 5.1). These areas are not naturally suitable for sole cropping, because most of the lands are hilly with low precipitation (400–600 mm). Continuous cultivation with improper land management causes low agricultural productivity and rapid land degradation. Because of the limited availability of grasslands and small proportion of animal husbandry, the contribution of livestock to the agriculture sector on the plateau is less important.

Spring crops (winter wheat, spring wheat, and others) are more favored than summer ones (maize, soybean, and others), as reflected by the larger cultivation area and more intensive management of spring crops than summer crops. However, because rainfall is concentrated in summer, this is not suitable for spring crops but rather summer ones. The eschewing of summer crops has resulted in low total crop production and precipitation use efficiency.

5.3.2 Irrigated Farming

Irrigated farming areas on the LP are usually characterized by readily available water resources and developed irrigation systems. These areas are mainly found on the Hetao Plain and Fenwei Plain. However, because of inappropriate water management, breakdown of irrigation facilities, and increasing water demand by industries and people, these areas are facing severe problems (Li et al. 2007).

5.3.2.1 Soil Salinization

The Hetao Plain is in the Ningxia and Inner Mongolia autonomous regions. It is famous for irrigation agriculture. Its total area is 25,000 km^2 with irrigated agricultural land about 9,840 km^2. With abundant water recourses, excess water is used for irrigation (about 8,000 m^3 ha^{-1}; Li et al. 2007). This has led to lowered elevation of the underground water table (by about 1–1.5 m). Since this area has a dry continental climate with very high evapotranspiration (2,100–2,300 mm) and low annual precipitation (187–231 mm), soil salinization has become a serious problem. Salt content is about 0.1–0.5 % in underground water and 0.2–0.7 % in soil. It has been estimated that about 70 % of cultivated land has secondary salinization and 20 % has been abandoned because of severe salinization (Xin and Wang 1998).

5.3.2.2 Low Efficiency in Agricultural Production

On the Fenwei Plain in Shaanxi and Shanxi Provinces, favorable farming conditions have attracted settlers. As a result, the population is higher than in other locations. Recently, rapid development of industry and urbanization has taken up a large area of cultivated land (e.g., 15,200 ha in Xian, capital of Shannxi Province, from 2005 to 2010, accounting for 5.7 % of total cultivated land; this is expected to increase to 15.3 % by 2020; The Bureau of Land and Resources of Xian 2005). This has caused a sharp decrease in total area of cultivable land. Thus, arable land per capita is very small. Further, damage to irrigation facilities has produced low irrigation efficiency and decreased irrigated area (Li et al. 2007). In severely dry years, the actual irrigation area is only about half the area with irrigation facilities. Moreover, competition for water among agriculture, industry and homes is becoming increasingly serious. It is predicted that shortage of irrigation water will challenge future agricultural development in this area (Li et al. 2007). Therefore, increasing the efficiency of agricultural production for high yields is an urgent issue.

5.4 Measures for Sustainable Agriculture on the Loess Plateau

Agriculture on the LP varies significantly with topography and water availability, as well as the needs and awareness of farmers. Constraints on agriculture vary with different agricultural areas and farmers' economic conditions. Therefore, measures to overcome constraints on crop production must be considered based on specific areas and farmers.

5.4.1 Rainfed Agricultural Area

5.4.1.1 Extensive Construction of Terraces

Low production in sloping farmland is a common feature of rainfed agriculture on the LP. It has been reported that yield increased by two to four times in terraced versus sloping lands on the plateau (Shan and Chen 1993). With terraces, there is less water runoff and soil erosion. However, only 22 % of the sloping lands are terraced (Table 5.2). Therefore, converting large-scale sloping farmland to terraces would benefit crop production and conserve soil and water.

5.4.1.2 Popularization of Supplemental Irrigation

Supplemental irrigation refers to applying limited amounts of water to rainfed crops when precipitation fails, to provide essential moisture for normal plant growth. With this type of irrigation, crop yield increases and water use efficiency improves (Deng 2004). For example, 60 mm of supplemental irrigation for spring wheat roughly doubles the yield, and water use efficiency increases by 30 % (Deng 2004). This type of irrigation should be widely applied on the LP, since the limiting factor of rainfed agriculture is water shortage, and it is possible to harvest rainwater for agricultural use there. Therefore, collecting rainwater for use in supplemental irrigation should be popularized on the plateau. Moreover, pitcher irrigation with buried clay pots beside crops and trees can be used to complement this irrigation, although this may not appropriate for irrigating large areas.

5.4.1.3 Increasing Agricultural Inputs and Land Management

Low inputs to agricultural fields is one of the limiting factors of agricultural production in the area. To increase use of inputs, increasing the farmer's income should be considered. Cultivation of cash crops usually provides farmers with greater economic benefit. On the LP, many indigenous plants could be grown as cash crops. For example, medicinal plant species, such as *Cistanche deserticola*, *C. tubulsa*, *Glycyrrhiza uralensis*, and *Lycium barbarum* are widely distributed on the plateau. Cultivation of these plants not only has high economic value, but also contributes to environmental conservation. Biofuel plant production is another option. Several plant species have been selected for the plateau, such as *Sapiam sebiferum*, *Xanthoceras sorbifolia* Bunge, *Vernicia fordii*, *Sapiam sebiferum*, and *Pistacia chinensis*. However, water relationships of these species need to be evaluated before their planned cultivation in the region. Species with high yield and low water demand are desirable.

Organic agriculture adds value to products. In arid areas like the LP, disease levels and nitrogen requirements for crops are generally low. Therefore, cultivation without chemicals like pesticides, herbicides and inorganic fertilizers is a possibility for achieving high-value agricultural products. Organic agriculture in the rainfed area of Australia has been successful. With improved economic conditions for farmers, greater inputs to farmlands can be expected.

On the other hand, conserving water and nutrients on cultivated land has the same effect as agricultural inputs. On the LP, the typical agricultural system consists of conventional tillage practices with three to four deep ploughings per year, which lead to soil loosening and runoff loss. Moreover, there is removal of all residues from the field at harvest, leaving the field without cover for 3–8 months.

All these practices readily predispose soil to erosion. Thus, reduced tillage with stubble and straw retention on the soil surface (i.e., conservation tillage) must be introduced in these areas. Conservation tillage has been evaluated in long-term field trials. These have demonstrated its advantages in semiarid areas of countries such as Australia (Turner and Asseng 2005), the USA (Martens et al. 2005), Spain (Cantero-Martínez et al. 2007), Kazakhstan (Suleimenov et al. 2004), and the LP (Wang et al. 2007; Huang et al. 2008; Jin et al. 2008; Bai et al. 2009). Conservation tillage reduces surface runoff and evaporation, and thus stores more water in the soil, improves soil chemical and physical properties, allows earlier planting, increases crop yield, and conserves energy and labor resources. For gullied hills, conservation tillage is more desirable. Mulches with gravel, sand, crop residues and films can also be associated with conservation tillage.

5.4.1.4 Improvement of Cropping Systems

Rotation of wheat–maize is the main cropping system in the LP. However, in other rainfed agriculture areas of the world, legume–cereal rotation is very popular. This cropping system increases cereal yield, water use efficiency and soil organic matter (Pala et al. 2004; Turner and Asseng 2005). Trials on the LP showed that this cropping system improved wheat grain yield and water use efficiency relative to standard winter wheat monoculture. Adopting and popularizing this cropping system on the plateau may achieve high crop production. Selection of legume species and cultivars should be based on strong drought tolerance and high water use efficiency.

Strip cropping, the planting of appropriate crops at various places on a slope, is another option to increase yield on sloping fields. Experiments in Tajikistan showed that a combination of winter wheat planted on the top of a slope and alfalfa on the bottom increased soil moisture, soil fertility, and hence winter wheat yield, compared to cropping winter wheat alone (Akramov et al. 2004). This type of planting should also be tried on the LP.

Integration of these practices on the LP may be even more effective. Initial investment in these technologies may be high, but expenses would be recovered because they are more efficient. The most important point is that these measures would ensure sustainable agriculture in this ecologically fragile region.

5.4.2 Irrigated Agricultural Area

The problems of soil salinization and low agricultural efficiency in irrigated areas require extensive and integrated management of agriculture. The favorable natural conditions for agriculture in these areas suggest that they should have high yields and be highly productive and efficient. To reach this goal, efficient cultivation systems including water-saving techniques (micro irrigation such as drip or subsurface irrigation, sprinkler irrigation, soil mulching), greenhouse cultivation, adoption of favorable cultivars, shifting of the cropping system, mechanization and precision management must be enhanced. In addition to technical measures, improvement of capacity-building and technology transfer would generally advance agricultural production on the LP, as in other semiarid regions (An et al. 2008).

5.5 Conclusion

The LP is considered the cradle of agricultural cultivation in China. The unique climate, ecology and geography of the area have created a unique farming system on the plateau. Agricultural output in the area has increased 25-fold from 1980 to 2008, with greater increases during the last 5 years because of adoption of modern farming techniques. However, unfavorable natural conditions and rapid advances of urbanization have posed many challenges to agriculture on the LP, such as shortages of water for irrigation and reductions of cultivable land caused by urbanization and soil erosion. Hence, for sustainable agriculture on the plateau, measures such as terraced farming, supplemental irrigation, better farm inputs, crop rotation with legumes, and organic farming are recommended.

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Part II
Desertification of the Loess Plateau

Chapter 6
Soil Erosion in the Loess Plateau Region of China

Fenli Zheng and Bin Wang

Abstract The Loess Plateau region has experienced severe soil erosion since the Ming Dynasty, and has become one of the most severe soil erosion regions in the world because of complex landforms, high soil erodibility, concentrated and high-intensity rainfall, and long-term human activity. This chapter outlines the general situation and regional distribution of soil erosion in the region. The soil erosion characteristics are described in detail, including water erosion, wind erosion and wind–water coupling erosion. This chapter also highlights the driving factors of water erosion, wind erosion and dust storms, including climate, soil and parent materials, topography and landforms, vegetation, and human activity. Finally, there is a brief treatment of sediment delivery to the Yellow River and its main tributaries.

Keywords Driving factors of soil erosion • Regional distribution • Water erosion • Water–wind coupling erosion • Wind erosion

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6.1 Introduction

The Loess Plateau region and its dusty soil cover almost all of Shanxi, Shaanxi and Gansu provinces, and parts of Qinghai and Henan provinces, and Ningxia and Inner Mongolia autonomous regions. The plateau has the most widely distributed loess on the Earth, and is where the thickest loess-paleosol sequence has developed. The surface is covered by loess-paleosol layers with an average thickness of 100 m (Liu 1984). The loess has been geologically transported from the northwest Gobi Desert by winds, and has accumulated in the region since the beginning of the Quaternary (about 2.5 million years ago) (He et al. 1997). The alternations of loess and paleosols, in conjunction with their enclosed faunas and distinctive mineralogies, have been widely interpreted as reflective of Quaternary glacial/interglacial episodes (Liu 1985).

As one of the most severe soil erosion regions in the world, over 60 % of the land in the Loess Plateau region has had soil erosion, with an average soil loss of 2,000–2,500 tons km^{-2} yr^{-1} (Yang and Yu 1992). For example, the soil erosion rate in some watersheds of the Huangfuchuan basin reached 59,700 tons km^{-2} yr^{-1}, and maximum sediment concentration in the river water measured as high as 1,640 kg m^{-3} (Tang et al. 1993). Soil erosion has seriously depleted land resources and degraded the eco-environment on the plateau, which directly affects sustainable development of the local socio-economy. Furthermore, soil loss in the plateau region is the major source of sediment load in the lower reaches of the Yellow River. Sediment delivery to the Yellow River increases after it crosses the Loess Plateau. Mean annual suspended sediment concentration in the river, measured at Shanxian Observatory, is 37.6 kg m^{-3}. Before 1980, a total sediment load of 1.64 billion tons per year (Sediment Specialty Committee of Chinese Water Resources Association 1989) was observed at the Sanmen Gorge, Henan Province (Table 6.1), which is 9–21

Table 6.1 Sediment and runoff in some world rivers (Jing et al. 2005)

River	Country	Basin area (×10^4 km^2)	Sediment load (×10^8 ton)	Runoff discharge (×10^8 m^3)	Sediment concentration (kg m^{-3} yr^{-1})	Average erosion rate (ton km^{-2} yr^{-1})
Yellow River	China	75.24	16.40	432	37.8	2,480.0
Ganges	India Bangladesh	95.50	15.51	3,710	3.92	1,579.0
Brahmaputra	China India Bangladesh	66.0	7.26	3,480	1.89	1,089.0
Yangtze	China	180.72	4.78	9,211	0.54	280.6
Mississippi	USA	223.0	3.12	5,645	0.53	96.6
Amazon	Brazil	580.0	3.63	57,396	0.063	63.0
Missouri	USA	137.0	2.18	6,160	3.54	159.0
Colorado	USA	63.70	1.35	49	27.5	121.0
Nile	Egypt Sudan	297.8	1.11	892	1.25	37.3

times greater than that of most major world rivers. Of the 1.64 billion tons of annual sediment delivery, 0.4 billion tons was deposited in the downstream river channel, at a sedimentation rate about 10 cm yr^{-1}. Thus, riverbeds in the Yellow River lower reaches are 4–10 m higher than adjacent land. Since the 1990s, sediment delivery has greatly decreased. In recent years, this delivery was about 0.3 billion tons per year.

6.2 Regional Distribution of Soil Erosion

Owing to different climatic conditions, geographic features and human activity, there is a clear regional distribution of soil erosion on the Loess Plateau. Generally speaking, there are three erosion areas—water, wind, and wind–water (Fig. 6.1). Specific and detailed descriptions of each erosion pattern are given in Sects. 6.3, 6.4 and 6.5.

Among the three erosion areas, the water erosion area (area III in Fig. 6.1) is the most important and is the principal sediment source of the Yellow River. Based on

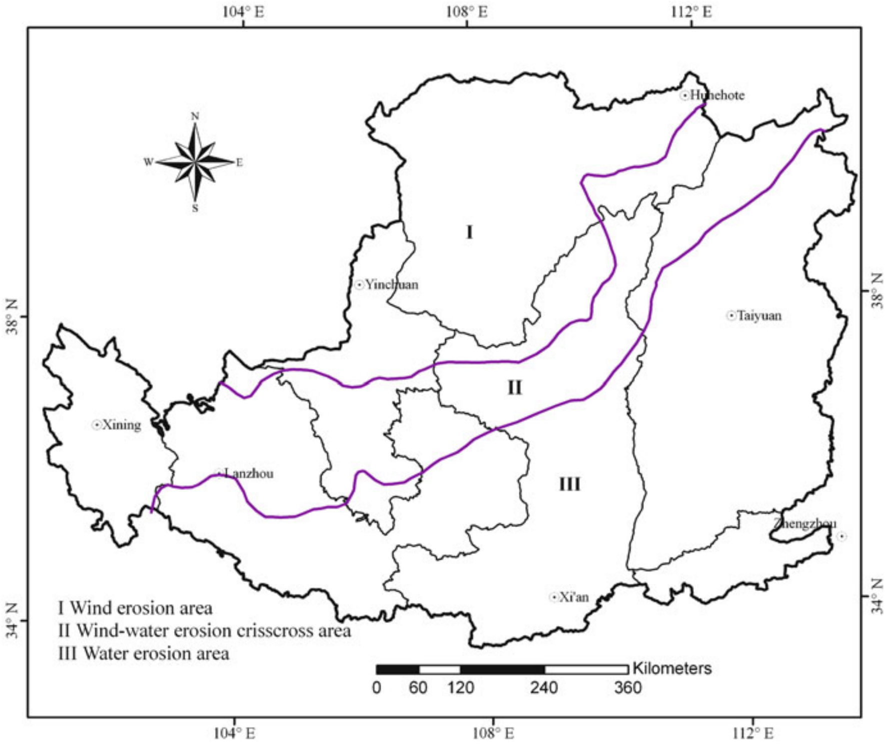

Fig. 6.1 Regional distribution of soil erosion in Loess Plateau region. After Huang (1955)

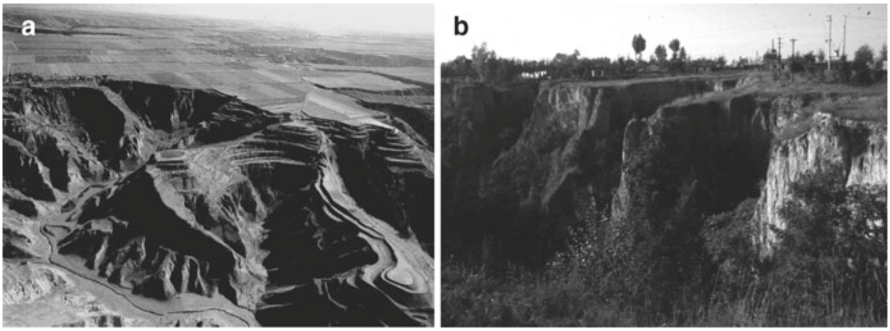

Fig. 6.2 High plain with deep-cut gullies, Loess Plateau. (**a**) High plain. From Zhu (1986). (**b**) Deep gully along high plain edge (Photo by Fenli Zheng)

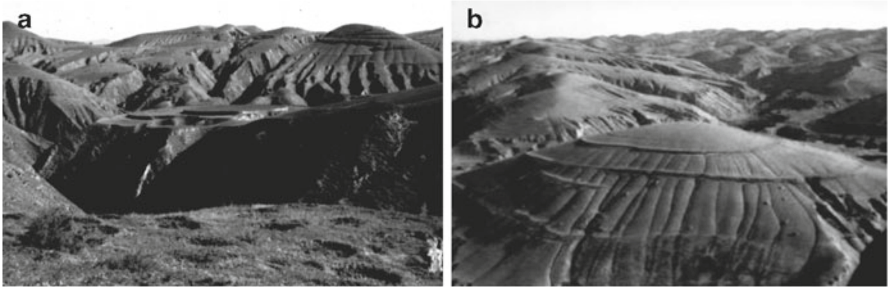

Fig. 6.3 Hill-gully landscapes, Loess Plateau. (**a**) Hill-gully landscape. From Zhu (1986). (**b**) Hillslope landscape. From Zhu (1986)

its distinct geomorphology and erosion patterns, this area is divided into two sub-regions, hill-gully (Fig. 6.2) and high loess plain with deep-cut gullies (Fig. 6.3). Gully erosion accounts for more than 60 % of total soil erosion in watersheds of the hill-gully sub-region, and more than 80 % in the high loess plain with deep-cut gullies. According to a recent gully survey (Gully Erosion Survey 2012), there were about 660,000 gullies with length greater than 500 m and gully channel area larger than 5 km^2. On the Loess Plateau, the area with greatest gully density is near the Yellow River in Shanxi and Shaanxi provinces, the main coarse-sediment producing areas in the middle reaches of the river (Qian et al. 1980). For example, sediment from north Shaanxi Province is responsible for about 50 % of total sediment delivery to the Yellow River.

6.3 Water Erosion

Vegetation removal and agricultural development began about 3,000 yrs ago in the Loess Plateau region. Consequently, soil erosion became increasingly severe. Every year, about 0.01–2 cm of topsoil is washed away. The severest soil erosion on the plateau is in western Shanxi Province and northern Shaanxi Province, where annual

Table 6.2 Sediment concentration and delivery in principal rivers on Loess Plateau (Jing et al. 2005)

River	Observatory	Sediment delivery ($\times 10^8$ ton)	Average sediment concentration (kg m^{-3})	Maximum sediment concentration (kg m^{-3})	Erosion rate (ton km^{-2} yr^{-1})
Yellow River	Shanxian	16.0	37.6	590	2,330
Zuli River	Jingyuan	0.833	493	606	5,600
Qingshuihe	Quanyanshan	0.240	162	323	1,640
Huangfu River	Huangfu	0.614	312	1,480	19,200
Kuye River	Wenjiachuan	1.383	174	1,640	11,800
Wuding River	Chuankou	2.098	135	1,290	7,700
Qingjian River	Yanchuan	0.510	313	1,150	14,700
Yanhe River	Ganguyi	0.649	258	1,210	11,000
Fenhe River	Hejing	0.409	22	286	1,100
Luohe River	Futou	1.058	110	1,190	4,200
Jinghe River	Zhangjiashan	2.709	156	1,040	6,400
Weihe River	Xianyang	2.006	33	67	4,000

sediment delivery to rivers is 1,640–19,200 tons km^{-2} (Table 6.2). Maximum sediment delivery is in the Huangpu River. Average sediment concentration in tributaries of the Yellow River is 67–1,640 kg m^{-3}, and the maximum is in the Kuye River. Due to implementing continuous soil and water conservation measures such as reservoir and dam construction and vegetation rehabilitation, soil erosion greatly decreased after the 1990s. However, soil erosion control is still a priority for regional environmental management.

6.3.1 Vertical Distribution of Water Erosion Patterns

Owing to slope gradient increasing along the slope length, water erosion patterns along the slope are vertically distributed, i.e., the dominant erosion pattern follows a downslope sequence of sheet-rill-ephemeral gully-gully erosion. Figure 6.4 is a typical example of the vertical distribution of water erosion patterns in the hill-gully Loess Plateau zone. With variation of erosion pattern along the slope length, erosion intensity gradually increases. Generally speaking, sheet, rill and ephemeral gully erosion are frequent in cropland. These types of erosion reduce soil quality and crop productivity, thereby affecting vegetation restoration. Sheet erosion occurs with the formation of surface runoff, at an annual rate normally less than 5,000 tons km^{-2}. Rill erosion usually occurs in cropland after rainstorms, especially on sloping land with gradient greater than 10° and less vegetation cover (Fig. 6.5) and on deforested land (Fig. 6.6). Annual rill erosion intensity is 4,000–8,000 tons km^{-2}. Ephemeral gully erosion occurs on steeply sloping land with gradient greater than 15° and less vegetation cover (Fig. 6.7); its annual intensity is 6,000–15,000 tons km^{-2}.

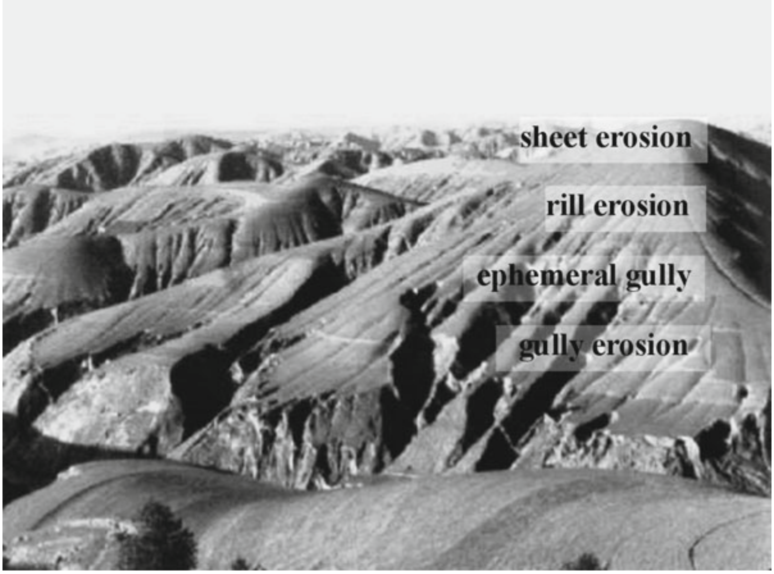

Fig. 6.4 Vertical distribution of water erosion patterns along hillslope. From Zhu (1986)

Fig. 6.5 Rill erosion of fallow land (Photo by Fenli Zheng)

Gully erosion occurs on very steeply sloping land with gradient greater than 25° (Fig. 6.8), and its annual erosion intensity is 8,000–30,000 tons km^{-2}. The area of greatest gully density in the Loess Plateau region is near the Yellow River in Shanxi and Shaanxi provinces.

Fig. 6.6 Rill erosion of deforested land (Photo by Fenli Zheng)

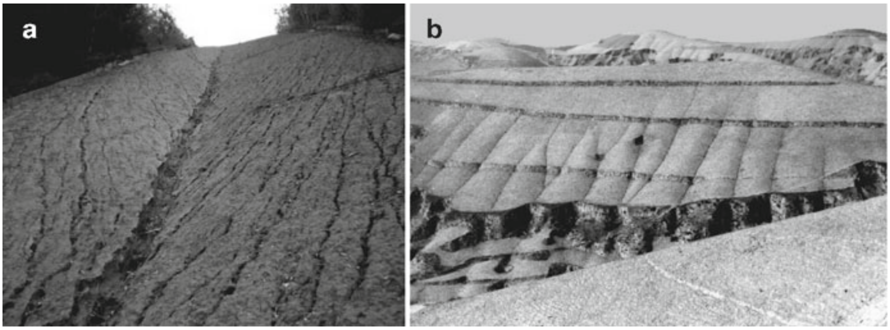

Fig. 6.7 Ephemeral gully erosion of fallow land. (**a**) Ephemeral gully erosion in Ziwuling area (Photo by Fenli Zheng). (**b**) Ephemeral gully erosion in Ansai County. From Zhu (1986)

6.3.2 Driving Factors of Water Erosion

Severe water erosion in the Loess Plateau region is mainly caused by concentrated storms with intense rainfall, high soil erodibility, steep landforms, sparse vegetation cover and intensive human activity.

6.3.2.1 Concentrated Storms with Intense Rainfall

Annual average precipitation in the Loess Plateau region is between 200 and 700 mm, but annual rainfall concentrates in July, August and September,

Fig. 6.8 Gully erosion on the Loess Plateau. From Zhu (1986)

constituting 50 % of total annual precipitation. Most rainfall comes from heavy storms of short duration. Rainstorms during these 3 months often cause intense water erosion, which in turn produces high sediment concentrations and subsequent sediment delivery to the Yellow River and its tributaries. For example, in 1977 in the city of Yan'an, rainfall at a rainstorm center was 228 mm over approximately 30 min, which caused a flood on the Yanhe River. Measured sediment was five times higher than the annual average value. In addition, a maximum single rainfall event was observed in Ordos, Wushenqi County on August 1, 1977, in which the precipitation reached 1,410 mm over 10 h.

6.3.2.2 Steep Topography and Landforms

Steep topography and landforms with widespread gullies in the Loess Plateau region cause serious soil loss. Severe soil erosion forms specific geomorphologic features, with many gullies and fragmented landforms. Measurements from aerial photographs were made during the period 1957–1979 in Guyuan County for 17 gullies of lengths 2,000–10,000 m, widths 100–300 m, and depths 100–300 m. These data showed that the average speed of gully head advance was 5.32 m per year, and maximum was 15.7 m per year (Comprehensive Investigation Group of Guyuan County 1996). Hence, gully density and slope gradient may be taken as indicators for assessing the potential of soil erosion intensity.

Topography is also important to water erosion patterns. Because of the increase of gradient along slope length, the dominant erosion processes vary in the sequence of sheet, rill, ephemeral gully, and gully erosion. Thus, erosion intensity increases along the slope length.

Table 6.3 Soil loss from forestland and deforested land on different landforms (Zheng 2006)

Landforms	Land use type	Erosion rate (ton km^{-2} yr^{-1})	Ratio (times)
Gully slope	Forestland	14.4	1
	Deforested land (fallow)	21,774	1,512
	Deforested land (crop)	13,179	915
Hillslope	Forestland	1.3	1
	Deforested land (fallow)	10,325	7,942
	Deforested land (crop)	9,703	7,464
Gully slope + gully slope (from top to toe)	Forestland	1.0	1
	Deforested land (fallow)	15,286	15,286

6.3.2.3 Sparse Vegetation Cover and Highly Erodible Loess

Natural vegetation on the Loess Plateau has been severely destroyed over several decades. Before the 1980s, forest cover in the Loess Plateau region was only 6.5 %. Less vegetation cover and highly erodible loess cause extreme soil erosion. Soil loss from forestland on hillslopes, gully slopes or their combination, with 5°–35° slopes (from top to toe of the slope) was very low, at 14 tons km^{-2} yr^{-1} (Zheng 2006). However, soil erosion intensity from fallow land or cropland after deforestation sharply increased to 9,703–21,774 tons km^{-2} yr^{-1} (Table 6.3).

Quaternary loess is the most widespread material in the Loess Plateau region, covering more than 40 % of the total area (Liu 1984). Loess is the main source of sediment in the Yellow River, because of its high erodibility. Average erodibility values (universal soil loss equation—*K* or USLE-*K*) of loessial soils vary from 0.005 to 0.049 (ton ha h) • (ha MJ $mm)^{-1}$, and concentrate in the range 0.015–0.023 (ton ha h) • (ha MJ $mm)^{-1}$ (Zhang et al. 2004; Wang et al. 2013). Generally, the coarser the texture of loess, the smaller its natural porosity and strength. This implies a close relationship between particle composition and sediment yield. The erosive potential production by 100 mm runoff per unit area rises with an increase of >0.05 mm particle content, since the material is less cohesive (Cao 1980). Runoff is affected by rainfall factors and soil infiltration capacity. Infiltration is closely related to soil porosity, texture, layer profile, and soil moisture. The infiltration rate is higher for sandy soil than for clayey soil. For soils developed from the same loess parent materials, there are great differences in infiltration capacity, associated with varying intensities of soil formation and profile development. Heilu soil, developed on newly formed loess, has a good profile structure, more root and soil fauna channels, larger non-capillary pores, and greater infiltration capacity. It is less erosion-prone than soil developed on amorphic loess.

6.3.2.4 Human Activities

Soil erosion in the Loess Plateau region is a combination of natural and accelerated erosion processes. Accelerated erosion arises from irrational land use, overgrazing, mining, construction and others. Because of population increases, large areas of forestland and grassland were destroyed, thereby accelerating soil erosion. The historical flood frequency along the Yellow River may explain the relationship between population increase and soil erosion. Before the Sui Dynasty (A.D. 581–618), the Yellow River flooded only 1.1 times per century, while during the Ming Dynasty (A.D. 1368–1644) it flooded 155 times per century (Tang et al. 1994; Zheng et al. 1994). During the 25 years from 1912 to 1936, flooding occurred 103 times. To satisfy food requirements of the increasing population, there was destruction of natural vegetation and an increase of arable land. The result was more severe soil erosion.

Cultivation of sloping land is a major factor associated with serious soil erosion. Fifty percent of total arable land is on slopes of the high plain with deep-cut gully areas, and up to 70 % of arable land is on slopes of the loess hill-gully areas. Research indicates that erosion greatly increases on slopes steeper than 25° (Tang et al. 1998).

6.3.2.5 Mining Activities

Recent development of oil, coal and natural gas industries in the Loess Plateau region, together with construction of energy industries and unregulated accumulation of large amounts of discharged stones and waste, have increased erosion intensity in some areas. During industrial development, large amounts of soil, stone and rock are removed, piled up and disturbed, so their natural stabile state is destroyed. Meanwhile, as mine construction has taken up large areas of agriculture and forest land, forest and grass vegetation has been destroyed. Production-related activities like traffic, construction and mining can cause landslides and soil collapse, leading to serious soil loss.

6.4 Wind Erosion

Wind erosion is the second important environmental problem in the Loess Plateau region, and represents one of the main dust sources for sandstorms in China. The wind erosion area mainly occupies part of the Ordos Plateau (area I in Fig. 6.1). This area is bordered by the Great Wall on the south and extends north to the Yinshan Mountains. It borders the Helan Mountains in the west, and stretches eastward to the Linger-Dongsheng-Yulin line. It includes the Maowusu (Mu Us) Sandy Land, Kubuqi (Hobq) Desert, Hedong Sandy Land and Hetao Plain. The wind erosion area

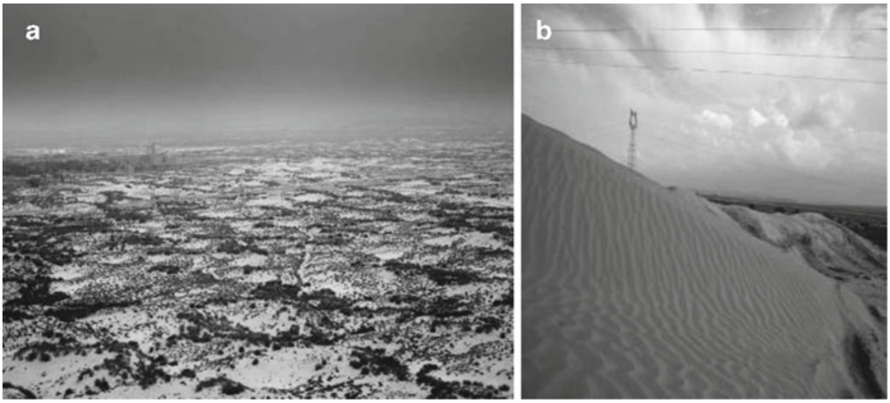

Fig. 6.9 Desert landscape of Mu Us Sandy Land on Loess Plateau. (**a**) The Mu Us Sandy Land. (**b**) Semi-fixed dune in Mu Us Sandy Land (Photo courtesy of Junliang Tian)

is about 180,000 km^2, representing 25.08 % of the Loess Plateau region (Huang 1955; Tang 2000). The dominated terrain is high plains, and the desert (sandy land) landscape is obvious (Fig. 6.9). Annual average precipitation nearly drops below 300 mm, annual evaporation is 2,500–3,000 mm, and the humidity coefficient is 0.23–0.1 or less. The drought environment and geographic attributes make shrub species dominant, and cause vegetation transition from steppe to desert steppe (Tang 2004; Fu 1989).

6.4.1 Driving Force of Wind Erosion

The wind erosion area largely covers the Mu Us Sandy Land. In this region, there are 11–68 gale days (greater than 8° on the wind scale), reaching 147 days in an extreme year (Chen 1988). Gales mainly occur in spring and winter, and are caused by cold snaps. Average annual wind velocity is from 2.7 to 3.3 m s^{-1}, and maximum average velocity is 3.2–4.2 m s^{-1}. The maximum speed can reach 11 on the wind scale (instantaneous wind speed 28.5–32.6 m s^{-1}) (Tang 2004). Given the spare and loose sandy loam cover, and that most gale wind speeds are higher than the threshold velocity (Table 6.4), dust storms are frequent in this area. Annual average dust storm days are from 7.2 to 37.8, and average maximum days about 72 (Table 6.5). Moreover, the spatial difference of dust storm frequency is distinct; damage caused by wind erosion gradually decreases from north to south. The main reasons are: (1) atmospheric moisture south of the wind erosion area is greater than in the north, suppressing dust storm formation (Chen 1988; Tang 2004); (2) soil erodibility decreases from north to south, owing to different parent rocks or soils (Xu 2005).

Table 6.4 Threshold wind velocity for different sand particles

Particle size distribution (mm)	Threshold wind velocity at 2 m (m s^{-1})
0.1–0.25	4.0
0.25–0.5	5.6
0.5–1.0	6.7
>1.0	7.1

Table 6.5 Wind speed, wind direction and gale days in wind area of the Loess Plateau region[a]

	Maximum wind speed and direction		Gale days		
Location	Velocity (m s^{-1})	Direction	Average (day)	Maximum (day)	Minimum (day)
Fugu	24	N NW	29	54	8
Shenmu	19	NW, W	16	44	4
Yulin	21	NNW	13	27	4
Hengshan	26	NW	35	77	8
Jingbian	24	W, WNW	15	73	1
Dingbian	33	NW	25	59	5
Jiaxian	20	NW, WNW	22	64	4
Suide	27	NW	51	102	6
Zizhou	18	WNW	4	10	0

[a]Source: Shaanxi Planning Commission (1986)

6.4.2 *Wind Erosion Patterns*

Wind erosion has two varieties, deflation and abrasion. Deflation erosion occurs when wind picks up and carries loose surface soil particles in the air. Abrasion erosion indicates that soil/rock surfaces are worn down by wind-borne sand. Deflation can be further divided into three sub-processes (Balba 1995; Wiggs 2011): (1) surface creep, during which larger, heavier particles slide or roll along the ground; (2) saltation, during which particles are lifted into the air a short height, bouncing and saltating across the soil surface; and (3) suspension, during which very small and light particles are lifted into the air by wind and are frequently carried long distances. Saltation is responsible for the majority (50–70 %) of wind erosion, followed by suspension (30–40 %) and surface creep (5–25 %).

6.4.3 *Dust Storms in the Loess Plateau Region and Northwest China*

Dust storms are undesirable weather phenomena that are frequent in arid and semiarid areas during spring. In Northwest China, there are three major regions of frequent dust storm occurrence (Qian et al 2002; Tang 2004): the Tarim Basin and

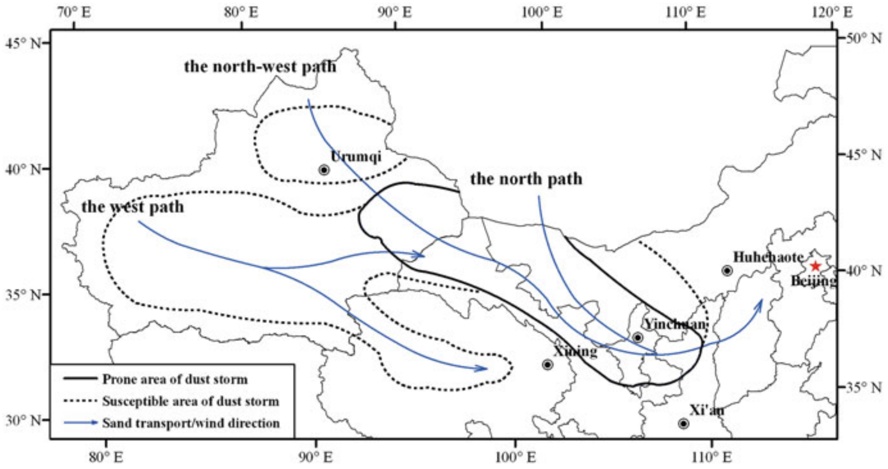

Fig. 6.10 Areas prone or susceptible to dust storms in Northwest China. Distribution of these areas and cold air paths were redrawn based on data of Xu and Hu (1997) and Shi et al. (2000)

surrounding area (e.g., Taklimakan Desert), and the Hexi Corridor-Ningxia Plain-North Loess Plateau and Alxa Plateau-Hetao Plain-Erdos Plateau regions (Fig. 6.10). High-frequency dust storm regions are recognized as the Hexi Corridor-Ningxia Hetao Plain-Hetian area in the Xinjiang Uyghur Autonomous Region, and the Turpan region (Shi et al. 2000). Not surprisingly, these three high-frequency regions are at the three principal entrances of cold air in winter and spring, i.e., paths from the northwest, west, and north (Fig. 6.10). An unstable air column provides the necessary thermal conditions for dust storm formation, causing these regions to become major dust sources.

6.5 Wind–Water Coupling Erosion

Another erosion pattern related to both wind and water erosion that contributes to intense soil erosion is that of wind–water coupling. This erosion occurs in the transition zone between the water and wind erosion areas, and is called the wind–water erosion crisscross area. It extends mainly between 35°25′–40°38′ N and 103°00′–113°53′ E (area II in Fig. 6.1). This area has notoriously dramatic climate changes and frequent natural disasters, such as floods, torrential rain, droughts and sandstorms. Annual precipitation is 250–400 mm and interannual precipitation is irregular, ranging from 2 to 7 times that of a normal year (Tang 2000). Therefore, soil erosion occurs year round. Water erosion dominates in summer and autumn, and wind erosion in winter and spring. Wind erosion stimulates water erosion by providing great quantities of loose material, which increases sediment concentration in surface runoff and sediment delivery to rivers. Water erosion enhances wind erosion via the reshaping of landforms. Because of its complex environmental and geographic attributes, the wind–water erosion crisscross area is the center of extremely severe erosion in the Loess Plateau region; its annual erosion intensity can reach 150,000–250,000 tons km^{-2}. The crisscross area is at the juncture of Shanxi and Shaanxi provinces and Inner Mongolia Autonomous Region (Zhu 1984; Tang 2004; Jing et al. 2005).

6.6 Conclusion

The Loess Plateau region of China, in the middle reaches of the Yellow River, has the most widespread loess in the world. Here, the thickest (50–200 m) loess-paleosol sequence has developed. The loess has been transported from the northwest Gobi Desert by winds and accumulated on the plateau since the beginning of the Quaternary (about 2.5 million years ago). Because of a fragile natural environment and long-term human activity, the plateau region is one of the most severely eroded areas in the world; annual soil erosion intensity is 10,000–15,000 tons km^{-2} in the severe erosion area. Because of the severe erosion, the sediment load in the Yellow River increases after flowing through the Loess Plateau region. Before 1980, mean annual suspended sediment concentration in the river was 37.6 kg m^{-3} and annual sediment delivery 1.6 billion tons, of which 0.4 billion tons was deposited in the downstream river channel. Generally speaking, there is an obvious regional distribution of soil erosion in the region, i.e., water erosion in the southeast, wind erosion in the northwest, and wind–water coupling erosion in their transition zone. The extremely severe erosion center of the region is in the wind–water erosion crisscross area, whose annual erosion intensity can reach 150,000–250,000 tons km^{-2}. Maximum sediment delivery also occurs in that area, where annual sediment delivery to rivers is 1,640–19,200 tons km^{-2}.

Over the past 50 yrs, there have been great achievements in soil and water conservation in the Loess Plateau region. Recently, sediment delivery of the Yellow River declined to 0.3 billion tons per year. Although management practices in the Loess Plateau region have greatly aided the decrease of soil loss over several decades (Xu et al. 1994; Chang et al. 1996) and related sediment delivery to the Yellow River, fragile eco-environmental conditions remain in the region. Therefore, control of soil erosion and improvement of the eco-environment remain core issues in China.

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Chapter 7
Irrigated Agriculture and Salinization

Katsuyuki Shimizu, Shen-Li Yang, and Yoshinobu Kitamura

Abstract The Loess Plateau has complex topography with deep, thick loess, and is poor in water resources. The soil is loose and rich in carbonates, but because these dissolve readily when moistened, the soil is susceptible to subsidence and erosion damage when wet. These natural characteristics have hindered irrigation development on the plateau. Irrigation methods on the plateau can be classified into three categories: (1) gravity irrigation on flat tablelands in the southern region, (2) gravity irrigation on steep topography, and (3) pump irrigation on relatively flat, high plains. Among these three, (1) and a part of (2) have potential salinization hazards, with no such potential for category (3) and most of category (2). We analyzed the relationship between topographic characteristics and potential salinity hazards of irrigated farmlands in the Luohui Irrigation District, a typical large-scale irrigation system located on the southeast Loess Plateau. Based on onsite observation, we summarize current and potential problems of irrigated farmland within a semiarid area. Salinization of irrigated farmland is greatly influenced by water management. The construction, operation, and management of a well-conceived and elaborate water management system is a requirement for sustainable agriculture.

Keywords Irrigation • Drainage • Salinization • Groundwater level • Groundwater quality

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7.1 Characteristics and Forms of Irrigation and Drainage on the Loess Plateau

Located in the midstream Yellow River region, the Loess Plateau has complex topography with deep, thick loess, and is poor in water resources. The soil is loose and rich in carbonates; however, because these dissolve readily when moistened, the soil is susceptible to subsidence and erosion damage when wet (Qian 1991). These natural characteristics have hindered irrigation development on the plateau. Irrigation on the plateau can be divided into the following three categories, based on attributes such as topography, plateau surface size, and the state of water sources (Qian 1991).

7.1.1 Gravity Irrigation on Level Tableland-Like Topography of the South

Principal withdrawal facilities are large- and medium-sized headworks or storage facilities built on river main courses or branches, and many small-scale ancillary hydraulic facilities (Figs. 7.4 to 7.7) are widely distributed in this region. These constitute irrigation projects of various sizes. This type of irrigation system is found on the main body of the plateau, which has a flat tableland-like topography with few valleys. Water use on the Weibei Plateau in Shaanxi Province is typically gravity irrigation. The Weibei irrigation area comprises seven large irrigation districts and a number of small and medium irrigation districts. The irrigated area covers at least 500,000 ha, stretching 300 km from Baojixia in the west to the Yellow River in the east (Nakajima 1995). Of the seven large irrigation districts, Baojixia (112,700 ha), Jinghui (90,000 ha), and Luohui (52,000 ha) use gravity irrigation, and they obtain water from headworks and reservoirs on the Wei, Jing, and Luo rivers, respectively. These three districts have many tube wells with pumps, several small and medium water storage facilities, and pumping facilities. In these districts, the water channels and tube wells are used in conjunction for irrigation; flowing and stored water are managed in an integrated manner. The Fengjiashan (85,000 ha) and Yangmaowan (16,000 ha) irrigation districts use gravity irrigation by means of dams that can impound 389 million m^3 and 107 million m^3 of water (Qian 1991), respectively. In these districts, steps have been taken to prevent seepage so that wet subsidence of soil does not occur when water flows through the channels. Cast-in-place concrete has been used in the primary channels, and U-shaped concrete flumes are widely used in secondary channels and field channels. Because irrigation water carries very large amounts of silt in summer, various measures have been taken to prevent flow blockage by sedimentation. These include constructing channels with a steep incline, lining narrow and deep sections of channels with concrete, and installing sluice gates at drainage inflows. These measures increase channel carrying capacity so that in the Luohui irrigation district, for example, it is possible to withdraw water during floods with a maximum silt content of 59.8 % (corresponding to 900 kg m^{-3}); the yearly average flood withdrawal amount reaches 13 million m^3 (Qian 1991). Floodwater withdrawals make it possible to substantially mitigate water shortages during the summer irrigation season.

7.1.2 Irrigation and Drainage on Steep Slopes

In regions with steep slopes, conservation of water and soil is most important. Trees and herbaceous plants are planted on steep slopes, while terraced fields are built on gently sloping land. Most farmland is in river valleys. Generally, irrigation facilities are for small water storage, and people practice a comprehensive management that harmonizes farmland and forests in watersheds. Land formed when erosion-control check dams are buried is often used as farmland (known as dam farmland) for cultivating crops such as maize, potatoes, sorghum, millet, and fruit. A problem that remains to be solved is safety during flooding.

7.1.3 Pumping Irrigation on Relatively Flat Plateau Surfaces with Deep Ravines

The comparatively flat plateau surfaces in the north, where conditions are drier, are much higher in elevation than rivers. This makes it very difficult to withdraw water from rivers to farmland solely by gravity flow. Thus, it has always been difficult to secure water, not only for irrigation but also for household use and livestock. In such areas, water is obtained essentially by pumping it upward from the Yellow River or its tributaries, necessitating construction of high-lift electric pumping stations. Examples of large irrigation districts using these mechanisms are Jiaokou (75,000 ha) and Donglei (43,000 ha) irrigation districts in Shaanxi Province, Dayudu, Jiamakou, and Zuncun districts in Shanxi Province, Jingtaichuan and Jinghui districts in Gansu Province, and Guhai irrigation district in the Ningxia Hui Autonomous Region (Qian 1991). The lift of pumped irrigation in these districts ranges from 70 to 100 m to as high as 400–500 m. Therefore, they are generally multi-stage. To efficiently lift water from the withdrawal point to farmland, pumping stations are sited from low to high positions based on the arrangement of fields. Other than grains, land uses include cash crops, fruit trees, forests, and livestock. For example, Qian (1991) reported that the first-phase pumped water project in the Jingtaichuan irrigation district (1969–1975) irrigates 20,300 ha by pumping water from the Yellow River main course. Ten pumping stations were built, with a total of 84 pumps. This district's design withdrawal amount is 10.6 $m^3 s^{-1}$, maximum lift 447.9 m, and the pumps consume 63 MW of power. The combined length of primary and secondary water channels is 177 km, which are all lined with concrete. In all irrigation districts, 18,700 ha of degraded land have been opened for cultivation, a 1,300-km sand drift prevention zone established, and 14 million trees planted. This has substantially improved the natural environment. Thanks to this project, wet-rice yield improved five-fold, from 0.75 ton ha^{-1} before the project to 3.75 ton ha^{-1} afterward (Sanmuganathan 2000). The farmers who benefit are now able to provide for their food and clothing, and the project has also been very effective in terms of improving the food situation in China.

7.2 Irrigation and Drainage on Guanzhong Plain (Guanzhong Irrigation Area)

The Guanzhong Plain extends from 33°39′N–35°50′N and 106°18′E–110°37′E. It is a river-valley basin, enclosed by mountains on three sides and open to the east. The Wei River flows from west to east through the approximate middle of the plain, and at its eastern terminus it merges with the Yellow River. On the north and south sides of the Wei, elevation gradually increases with distance from the river. The topography of the river's north bank is level, forming a broad loess tableland whose upper layer is covered thickly by loess. As tributaries join the Wei, they scour the loess tableland to form an alluvial plain, resulting in alternating narrow plains and tablelands whose elevation difference is generally 50–100 m. The Guanzhong Plain is situated along the Yellow River midstream portion, and the main rivers of the plain are the Wei, Jing, and Luo. The Wei is the Yellow River's largest tributary, having a watershed of 135,000 km^2. Annual surface runoff is estimated at 7,440 million m^3. Annual sediment yield is 330 million ton (Zhang, 2009), making this the Yellow's main source of flooding and sediment. Flooding is mainly due to surface runoff from the Qinling Range, which enters from right-bank branches. Sediment is mostly from the Loess Plateau, and enters in large amounts from left-bank tributaries.

Irrigation and drainage projects on the Guanzhong Plain have a long history. During the Qin and Han dynasties at least 2,000 years ago, there was already an irrigation network, mainly around Chang'an (Li 2004). In the twentieth century, a severe drought in the Shaanxi region in the 1920s prompted construction of the Guanzhong Eight Hui irrigation districts (the names of all eight end with the character hui, which means "blessing"). These are Jinghui, Luohui, Weihui, Meihui, Fenghui, Heihui, Ganhui, and Laohui, and are under the guidance of water use expert Li Yizhi. Their completion arguably built the foundation of modern water use advancement in Shaanxi Province (Li 2004).

Large-scale irrigation projects have been promoted since the founding of the People's Republic of China and, by 1990, six large irrigation districts had been completed. These are the aforementioned irrigation districts of Baojixia (irrigated area 196,000 ha), Jinghui (85,000 ha), Jiaokou (75,000 ha), Fengjiashan (85,000 ha), Luohui (52,000 ha), and Donglei (43,000 ha), comprising a total irrigated area of 536,000 ha. There are also 20 irrigation districts, ranging in size from 50,000 to 500,000 mu ($mu = 666\ m^2$; irrigated area 163,000 ha), and 114 districts between 10,000 and 50,000 mu (irrigated area 385,000 ha). This embraces several tens of thousands of small irrigation facilities (Nakajima 1995).

The Guanzhong Plain has 123,000 ha that is waterlogged, 32,000 ha that is saline/sodic, and 74,000 ha that is both. This gives a total farmland of 229,000 ha that is degraded by these two problematic conditions (Nakajima 1995). This farmland is therefore greatly impacted by inadequate drainage systems; it is distributed in areas that include locations where Wei River sediment runoff has accumulated. Nevertheless, 133,000 ha have been improved by providing supplemental pumped irrigation that incorporates vertical drainage using tube wells, and by constructing drainage systems (Nakajima 1995).

Irrigation is of great importance to agricultural production on the Guanzhong Plain. It is said that about 80 % of irrigated land in Shaanxi Province is in Guanzhong, which means that management of Guanzhong irrigation and drainage has a decisive influence on agricultural production in that province. Problems cited for the Guanzhong Plain in recent years include: (1) aging and deterioration of facilities, and delayed repairs; (2) a water shortage and attendant difficulty of securing adequate water; and (3) delayed provision of management facilities. It is currently impossible to keep up with the diversification of water demand (The World Bank 2007; China Papers 2010).

7.3 Irrigation Management and Problems in Luohui Irrigation District

The Luo River is the main water source for the Luohui irrigation district, which comprises Luodong block in the Dali area on the left bank, and Luoxi block in the Pucheng area on the right bank. As shown in Figs. 7.1 and 7.2, the district sits on the Wei River and Luo River tableland in eastern Guanzhong, Shaanxi Province (from 34°45′48″N—35°03′37″N and 109°28′30″E—110°08′31″E). Full-scale irrigation began in 1950, with a history in excess of 60 years. It is one of the primary agricultural production districts of the province.

Principal crops in the area are cotton and maize in summer and wheat in winter. In recent years, farmers have tended to grow less cotton and shifted to cash crops, such as vegetables and fruit. Because of planting rotation, wheat (a winter crop) and maize (a summer crop) are often planted together. Thus, if more winter wheat is planted the previous year, more maize is planted in summer of the following year.

A problem faced by the Luohui irrigation district is farmland deterioration from salinization. For advancement of sustainable agriculture, it is essential to formulate a well-conceived and elaborate water management system. The following sections describe irrigation and drainage systems, water management, changes in groundwater dynamics and saline area size, and other attributes of the Luohui irrigation district, along with the history and problems of irrigation management.

7.3.1 History of District Development and Natural Conditions

As shown in Fig. 7.1, the Luo River begins southeast of Baiyu Mountain's highest point (1,907 m mean sea level (MSL)) in Dingbian County, Shaanxi Province. It then flows through its 680.3 km channel and joins the Wei River. Its watershed covers

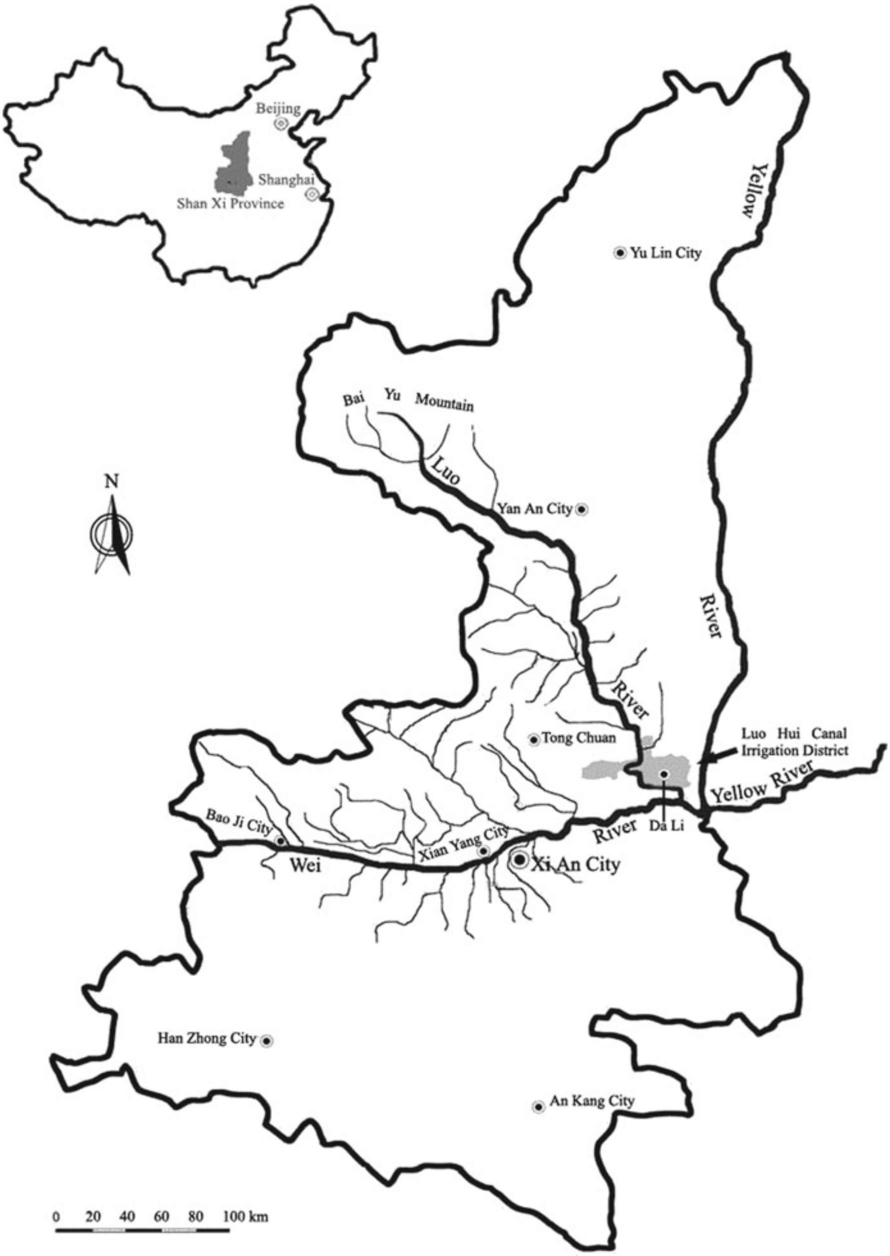

Fig. 7.1 Locations of Luo River and Luohui irrigation district

26,900 km^2, and its average annual flow rate is 26.5 m^3 s^{-1}. Since the watershed contains loess with high erodibility, the Luo has high sediment discharge.

Construction in this irrigation district commenced in 1934, with Li Yizhi in charge of its design. After the 1949 founding of the People's Republic of China,

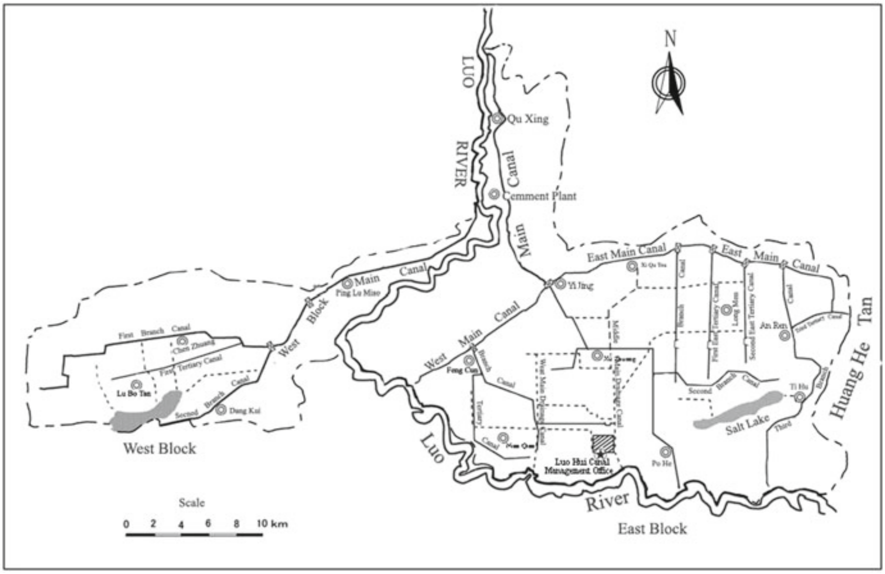

Fig. 7.2 Map of Luohui irrigation district

the Luodong (East) block (total size about 50,000 ha, irrigated area about 32,000 ha) was completed by the People's Government in 1950. In 1966, the Luoxi (West) block was finished, giving the irrigation district a total size of 75,000 ha. The irrigated area is oblong and extends east and west, covering about 52,000 ha (Fig. 7.2). It has an elevation range about 335–400 m MSL.

The Luohui irrigation district is on the tableland just upstream of the junction of the Yellow, Wei, and Luo rivers (Fig. 7.1). Hydrological and geological conditions are strongly affected by Quaternary sediments. Aquifers are thick and flows are slow, making for a long residence time. Additionally, the area is characterized by low availability of good-quality usable groundwater with total dissolved solids (TDS) value less than 1 g L^{-1}, owing to high salt content. The groundwater distribution is shaped by factors including rainfall, irrigation, drainage conditions, and flow regimes of the Yellow, Wei, and Luo rivers.

Ground slope is generally north to south, but groundwater flows from northeast to southwest. In the northern part of Luodong block, the water table is 380–385 m MSL, and in the south it is 335–345 m MSL, giving a decline of 35–50 m. After collecting in a salt lake, the groundwater flows from west to east and out to the Yellow River rapids.

In low-lying places, the water table is 30–50 m below the ground surface, whereas at some locations it reaches the surface.

The Luohui irrigation district has a temperate continental semiarid climate.

Figure 7.3 shows average monthly pan evaporation (E, measured using an evaporation pan that is 20 cm in diameter and 10 cm in depth), precipitation (P), and their difference (E–P), based on records from 1956–1990 (1966–1977 data are missing)

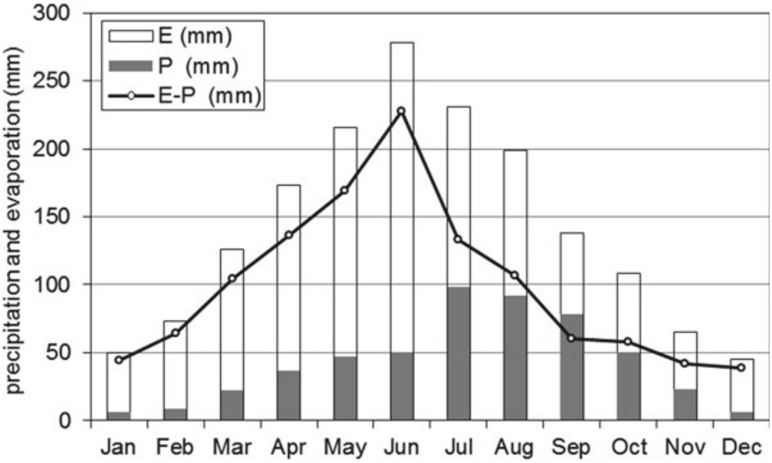

Fig. 7.3 Average monthly change in pan evaporation amount (E), precipitation (P), and their difference (E–P) in Luohui irrigation district (precipitation data: 1950–1990; evaporation data: 1956–1990; data are missing for years 1966–1977) (Luohui Records Editorial Committee 1995)

by the Dali Meteorological Observation Station. Average annual precipitation is 514 mm. Monthly precipitation is least in January at 5 mm, and the highest is in July at 98 mm. July through September precipitation is 266, and 20 mm from December through February. These two periods account for 52 and 4 % of annual precipitation, respectively.

Average annual pan evaporation is 1,690 mm, which is about 3.3 times the average annual precipitation. As shown in Fig. 7.3, average monthly pan evaporation peaks a month earlier than average monthly precipitation. In all months of the year, pan evaporation exceeds precipitation. The difference (E–P) is greatest in June, about 225 mm. During the crop irrigation period (December through June), this difference is especially large (777 mm), while during the harvest period (August through October) it is small (225 mm). From the viewpoint of economic water productivity, this climate condition is disadvantageous for irrigated agriculture (Luohui Records Editorial Committee 1995).

Farmland in Luohui irrigation district has four soil types—Lou, alluvial, saline, and artificially improved or warp soil (soil dressed by warping, i.e., deliberate flooding of land to deposit layers of silt. For details, refer to Chap. 15). Lou (silty clay loam) is the main soil type in this district, covering about 54,000 ha or 72 % of total district size. This soil's parent material is loess, and has been formed by long-term cultivation. It has high organic content and high water- and nutrient-retaining capacity, making it suitable for agricultural purposes (Luohui Records Editorial Committee 1995).

The district's alluvial soil is sticky and is distributed mainly in Luoxi block. Its area is 14,000 ha, or 19.1 % of the irrigation district. This soil is formed from diluvial soil that accumulated in lakes during the Pleistocene. It contains mainly sulfates and chlorides, has low water permeability, and is difficult to cultivate (Luohui Records Editorial Committee 1995).

Saline soil is distributed in lowland portions of the irrigation district. The salts present include sulfates or sodium chloride or magnesium chloride, with content approximately between 1 and 2.5 % (by weight). This soil covers 2,300 ha, or about 3.0 % of total irrigation district size. Its high salt content makes growing crops impossible (Luohui Records Editorial Committee 1995). This is due to an increase in osmotic pressure of the soil water. Since the salts absorb water very strongly, crops cannot remove them and thus appear to be under drought stress, even when adequate moisture is present in the soil.

7.3.2 Irrigation and Drainage System Management, and Appearance of Problems Including Salinization

7.3.2.1 Problems Arising Shortly After Irrigation System Operation Commencement and Remedial Measures

The Luohui Irrigation District irrigation system is composed of a withdrawal facility (Fig. 7.4), a headrace (Fig. 7.5), main water channels (Fig. 7.6), secondary water channels (Fig. 7.7), and branch water channels. Table 7.1 presents physical data on the system as of 1990 (Luohui Records Editorial Committee 1995).

In 1955, the irrigation system was completed, after which the irrigated area increased and water use grew. Inadequate irrigation management just after system inauguration, along with extensive surface irrigation and excessive rainfall during the rainy season raised the water table, resulting in waterlogging and/or capillary rise followed by salinization. Capillary rise of groundwater is regarded as one of the main causes of salinization. When the groundwater table is above the critical water table depth, there is capillary rise, i.e., groundwater can be absorbed and move upward through soil pores. Thus, the most important practice for preventing salinization is to cut off this rise and lower the groundwater level below the critical water table depth. That depth depends on soil texture, and is around 2.5 m from ground level for loess soil. From the time irrigation began until 1965, the water table rose 2–8 m, depending on location. This necessitated measures such as improved irrigation management, more efficient water use, and an upgraded drainage system.

Construction of the drainage system in Luodong block got underway in 1956. By the second half of the 1980s, three main drainage channels (36.5 km in length), 10 secondary drainage channels (64.5 km), and 244 branch drainage channels (388 km) had been completed. The area served covers 18,700 ha. Additionally, beginning in the 1960s, concrete slabs were used to line water channels to improve irrigation efficiency. This reduced conveyance loss from 15 to 5 %.

Construction of the Luoxi drainage system began in 1966. By 1990, a main drainage channel (33.75 km in length), 17 secondary drainage channels (62.2 km), and 298 branch drainage channels (192 km) had been completed. The system serves an area of 3,400 ha.

Fig. 7.4 Luohui irrigation district water withdrawal facilities (upper, before improvement; lower, during improvement. Completed in 2006)

7.3.2.2 Problems After Drainage System Construction

Several decades have passed since the Luohui Irrigation District irrigation and drainage system began operation, and a number of problems have become evident. These include declining irrigation water use efficiency, inadequacies in the drainage system, and impacts on the natural water cycle. In particular, excessive downward infiltration of water has raised the water table, causing salinization and otherwise worsening the local environment.

Draining water into lowlands within the district has aggravated lowland salt damage and worsened crop production. In particular, there is pronounced waterlogging and salinization near the Luodong district salt lake, which is hindering crop

Fig. 7.5 Luohui irrigation district headrace

Fig. 7.6 Luohui irrigation district, Luodong block central main channel (lining is damaged in this section)

cultivation. The Luohui surface drainage system is not managed by the irrigation district but by the Dali County People's Government. Management of the irrigation and drainage systems by different organizations is a major impediment to solving the salinization problem.

Fig. 7.7 Luohui irrigation district, secondary water channel on Luodong block central main channel

7.3.2.3 Problems with Field Water Management and Remedial Measures

Irrigation of fields is generally done between ridges or by border irrigation. Water is taken from the withdrawal point at a field's upstream side, and irrigation is achieved by one-way water flow down the length of the field. Irrigation water is halted when it has reached a point 10 m upstream from the last ridge (short side). This prevents overflow at the bottom end. When these fields were first developed, they had lengths of 200–300 m or more on the long side but, because irrigation efficiency was very low, fields were gradually shortened. In 1963, instructions were given to make fields with sticky soil or loam 100–150 m long, and fields with sandy soil 70–100 m long. Farmers have been encouraged to make fields as short as possible. The recommended length for cotton fields is 30–50 m, and guidance is given to keep fields from exceeding 70 m at maximum. Nevertheless, fields exceeding 200 m are frequent.

Providing crops with sufficient water to satisfy their needs requires irrigation application after having determined appropriate timing and water amount. These depend on factors such as weather (precipitation amount), soil moisture, and the state of crop growth. This determination also makes more efficient water use possible.

Table 7.1 Luohui irrigation water channel system as of 1990

Channel name			Channel length (km)	Design flow rate ($m^3 s^{-1}$)	Channel bottom slope	Irrigated area (ha)
Headrace			21.366	18.5	1/2,800	2,843
Luodong block	East main channel	East main channel upper section	16.195	7.0	1/3,000	5,612
		East main channel lower section	9.655	6.0	1/3,000	
		Secondary channels (3)	40.160	1.6, 1.6, 2.0	1/2,000-1/2,500	8,962
		Branch channels (2)	11.708	2.0, 1.5	1/2,000-1/2,500	2,462
		Subtotals	77.718			17,036
	Central main channel	Central main channel upper section	5.489	15.0	1/1,500	5,037
		Central main channel middle section	6.875	10.0	1/1,500	
		Central main channel lower section	9.375	1.5	1/2,000	
		Branch channels (2)	13.500	1.5, 10.0	1/1,500-1/2,000	2,332
		Subtotals	35.239			7,369
	West main channel	West main channel upper section	7.796	3.0	1/2,500	3,528
		West main channel lower section	4.826	3.0	1/2,500	
		Secondary channel	10.038	1.5	1/2,000	2,301
		Branch channels (2)	15.575	1.5, 1.5	1/2,000-1/1,800	2,441
		Subtotals	38.235			8,270
	Luodong block totals		151.192			32,676
Luoxi block	Luoxi main channel	Luoxi main channel	22.177	7.0	1/2,750	7,334
		Secondary channels (2)	20.340	5.0, 2.0	1/2,750, 1/3,000	4,381
		Branch channels (2)	20.639	5.0, 2.0	1/2,000	4,558
		Subtotals	63.156			16,273
	Luoxi block totals		63.156			16,273
Totals			235.714			51,792

Note: Numbers in parentheses in third column means the number of channel-size involved in each channel category

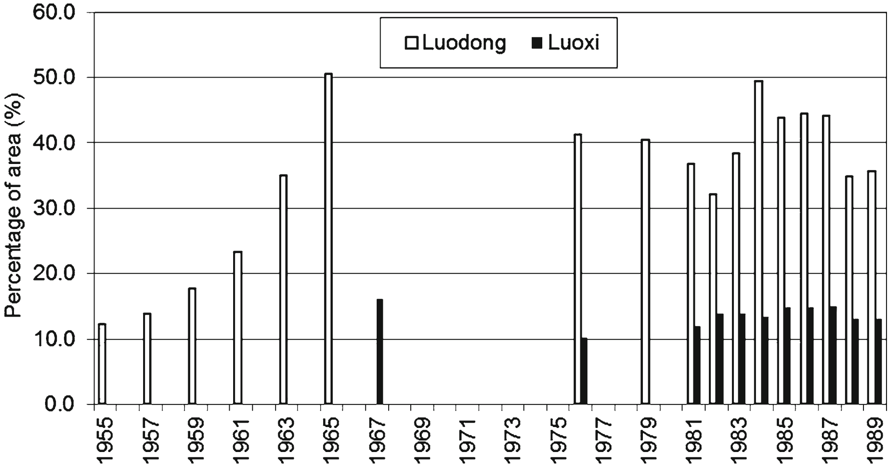

Fig. 7.8 Yearly percentage change of Luodong and Luoxi block total irrigation areas in which water table was 0–3 m from the surface (reliable data are unavailable from the Great Proletarian Cultural Revolution years (1965–1976))

During irrigation, one must not only provide the amount of water needed by crops with consideration of water table level and the extent and characteristics of salinization, but also adjust soil solution concentration. In the Luohui district, irrigation water amount is determined based on the following three zones, categorized in accord with water table depth and salinization (Luohui Records Editorial Committee 1995):

1. Normal irrigation zones: When the water table is below 2.5 m from ground level; irrigation water amount is provided according to crop needs.
2. Irrigation zones requiring caution: When the water table is 1.5–2.5 m from ground level, and soil is not saline or is slightly saline. Irrigation water is provided in appropriately reduced amounts over those of crop needs, and soil salinization is prevented.
3. Irrigation zones requiring improvement: When the water table is within 1.5 m of ground level, and soil is moderately or seriously saline. Fields are managed with care, and irrigation and leaching are conducted simultaneously in accord with drainage conditions and state of salinization.

7.3.2.4 Problems with Irrigation and Drainage System

When the irrigation system began operation from 1954 to 1957, irrigation efficiency was a low 39.7 %, and drainage facilities had yet to be built (irrigation efficiency is the ratio of total amount of water consumed by crops to total amount of water diverted from the source). For that reason, annual average aquifer recharge was as high as ~110 million m^3, and the water table rose by an average 0.57 m each year. Figure 7.8 shows yearly change in the percentage of Luodong block total irrigation area in which the water table was 0–3 m from the surface (that is, the area in danger of salinization). In 1955, this percentage was 12.5 %, but increased to 50.5 % in 1965. After that, a system was adopted that charged for the amount of water use, and in the 1960s irrigation efficiency rose to an average of 52.8 %. This reduced the average annual water table rise from 0.78 m (1959) to 0.26 m (1965) (Luohui Records Editorial Committee 1995). The drainage system was subsequently expanded, along with improvement of the main and secondary channels by lining with concrete. Further, the salt lake drainage system and west main drainage channel were built, and a new drainage management agency (Dali County People's Government) was established. This created a wide-area water management system. As a result, groundwater drainage grew from 4,090,000 m^3 in 1957 to 16,150,000 m^3 in 1964. Also, downward infiltration of irrigation water decreased, and irrigation efficiency improved from 55.0 % in the early 1970s to 59.6 % in the second half of the decade. This reduced the proportion of the district in danger of salinization, from 50.5 % (1965) to 32.2 % (1982) (Luohui Records Editorial Committee 1995). Nevertheless, drainage channel maintenance and management worsened beginning in 1982, and the water table rose again. Because of this, beginning in 1986 maintenance and management were again made more rigorous, and care was exercised in controlling the irrigation district water table.

Managers in the newer Luoxi block learned from the Luodong problems, and drainage channels were constructed soon after the irrigation system began operation. Thanks to this timely measure, water table control proceeded relatively well. Average annual water table ascent in Luoxi block declined drastically, from 0.51 m (1977) to 0.03 m (1979). Subsequently, the proportion of Luoxi block in danger of salinization was maintained between 12 % and 16 %.

As the above discussion shows, management of irrigation and drainage systems by different organizations is undeniably a major impediment to effective water table control in this irrigation district.

7.3.2.5 Trend Toward Deterioration of Groundwater Quality and Associated Problems

Figure 7.9 shows the proportions of land area affected by various concentrations of groundwater salt (TDS), based on groundwater survey results from 1960, 1965, 1973, 1980, 1984, and 1990 (Luohui Records Editorial Committee 1995).

The figure shows the trend in Luodong block of groundwater change, from freshwater to low-concentration saline water. In 1960, groundwater in 7.4 % of the block area had TDS less than 1 g L^{-1}. The proportion was 48.6 % for low- to medium-concentration saline groundwater with TDS 1–3 g L^{-1}, 39.7 % for medium- to high-concentration saline groundwater with TDS 3–10 g L^{-1}, and 4.3 % for high- to very high-concentration saline groundwater with TDS 10–50 g L^{-1}. In 1990, there was no longer any location where groundwater had TDS less than 1 g L^{-1}, while the proportion of the block with 1–3 g L^{-1} had increased to 70.1 %. The proportion with 3–10 g L^{-1} was 28.8 %, and that having high- to very high-concentration saline groundwater with TDS 10–50 g L^{-1} was 1.9 %. During this period, the proportion of groundwater with medium to very high concentrations declined, but high-quality

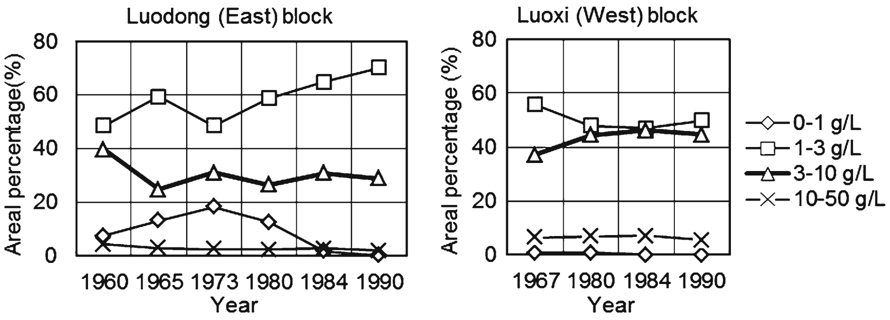

Fig. 7.9 Change in distribution of groundwater salinity concentration in Luohui irrigation district (Luohui Records Editorial Committee 1995)

groundwater with less than 1 g L^{-1} disappeared. Low- to medium-concentration saline groundwater with TDS 1–3 g L^{-1} accounted for nearly all of Luodong block (Luohui Records Editorial Committee 1995).

In the Luoxi block, the proportion of block area with freshwater to medium-concentration saline groundwater having TDS with 3 g L^{-1} declined, from 56.5 % in 1967 to 49.9 % in 1990. The proportion with medium- to high-concentration saline groundwater with TDS 3–10 g L^{-1} increased, from 37.1 to 44.7 %. However, the proportion with high- to very high-concentration saline groundwater with TDS 10–50 g L^{-1} fell slightly, from 6.4 % in 1967 to 5.4 % in 1990 (Luohui Records Editorial Committee 1995).

Under the standard classification of saline water (Rhoades et al. 1992), the Luohui irrigation district has almost no potable groundwater. If the rate of gravity irrigation decreases and frequency of groundwater usage increases, or if the usage cycle shortens, water quality becomes increasingly poor. Irrigation using poor-quality groundwater accelerates soil salinization.

7.3.2.6 Irrigation Management and Size of Saline Area: Change and Current Status

After the irrigation system began operation in the Luohui irrigation district, management of field water and irrigation was deficient, and there was only simple surface irrigation. These factors raised the water table and produced secondary salinization. Figure 7.10 shows yearly change in saline soil area of the irrigation district.

Under the standard classification for saline soil (Luohui Records Editorial Committee 1995), the total area of land with saline soil in Luodong block was 1,140 ha in 1953—750 ha with medium or lower salinity and 390 ha for serious or greater salinity. During the period 1954–1959, the saline soil area in the block increased at an average rate of about 418 ha yr^{-1}. It increased during the Great Proletarian Cultural Revolution (1965–1976), and reached 4,400 ha in 1974. Subsequently, farmland salinization was brought under control in various ways. These included enhanced water management, improved irrigation techniques, construction of drainage facilities,

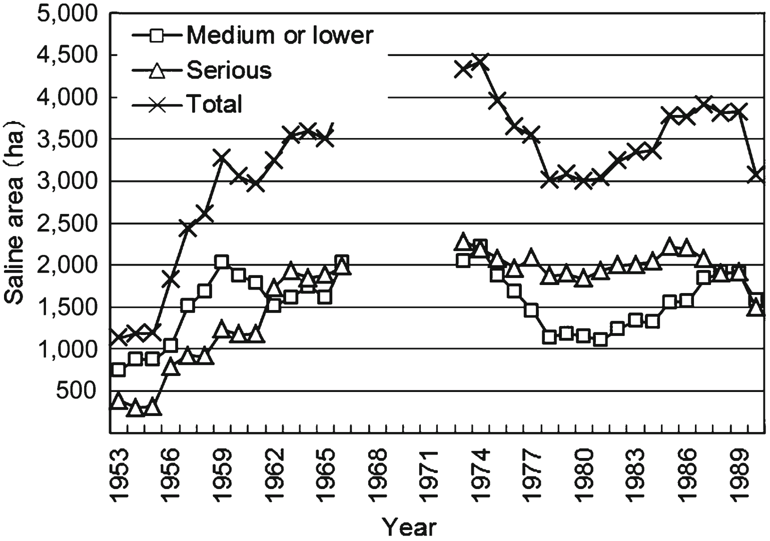

Fig. 7.10 Yearly change of saline soil area in Luodong block of Luohui irrigation district (data are unavailable from the Great Proletarian Cultural Revolution (1965–1976))

lining of water channels and other measures to prevent seepage, and improvement of soil by warping. These measures reduced the area of saline soil to 3,000 ha in 1980. That area increased again in the 1980s, but at the end of the 1990s it fell once more, to 3,070 ha. The increase in saline soil area in the 1980s was due mainly to minor salinization. A potential cause for this was a change in China's agricultural policy in that decade toward promoting agricultural development, which induced a rapid increase in water withdrawals and temporary negligence of irrigation management.

In conclusion, salinization of irrigated farmland is greatly influenced by the nature of water management. The construction, operation, and management of a well-conceived and elaborate water management system is a requirement for sustainable agriculture. Chapter 15 provides detailed discussion of wide-area water management for preventing secondary salinization.

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Chapter 8
Land Use Change and Deforestation on the Loess Plateau

Jing-Feng He, Jin-Hong Guan, and Wen-Hui Zhang

Abstract Tracing the history of land use and vegetation change to the year 221 BC may help understand the environmental evolution of the Loess Plateau. Research has revealed that vegetation on the plateau maintained a natural state during the Zhou Dynasty and Warring States period. Natural vegetation still accounted for a large proportion during the Qin and Han Dynasties. In the Tang and Song Dynasties, natural forests disappeared from valleys and plains, and vegetation in hills and mountainous regions were also destroyed. The northern desert began to expand and the overall natural environment was in a state of deterioration. Serious deterioration of natural vegetation on the Loess Plateau mainly occurred during the Ming and Qing Dynasties (AD 1368–1911). Reasons for the drastic vegetation changes during this era are associated with both natural and human factors, for example forest cutting, land reclamation and overgrazing. In the last half of twentieth century, artificial plantations have been constructed as the primary means of ecosystem restoration on the plateau. A series of ecological projects implemented in recent decades significantly has changed vegetation cover and the environment there. These projects have eventually changed the trend of historical degradation to one of restoration.

Keywords Dynasty • History of land use • Land reclamation • Vegetation change

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8.1 Introduction

As the Loess Plateau covers large geographical and climatic magnitudes, the region has diverse habitat conditions for different vegetation types (Chap. 4). It is suggested that grassland and forest steppe were the dominant vegetation types across the region and forest was dominant at a local scale in mountainous and valley areas in the Quaternary and particularly the Holocene periods (Shang and Li 2010; Sun et al 2010; Zhang et al 2010). Due to increasingly intensive human activities, the natural vegetation has experienced significant degradation (Wang et al 2006; Zhang et al 2010). At the beginning of human history, the Loess Plateau belonged to forest-steppe zones, characterized by widespread forests that are intermingled with grasslands (Shi 1981a). The plateau is suitable for development of agriculture and animal husbandry. With rapid population growth, extensive exploitation of the land led to a decrease of vegetation cover. In particular, deforestation gave rise to desertification, soil erosion and other damage. Deterioration of the ecological environment seriously affected regional economic development and improvement of human life, rapid change of regional resources and the environment, and ultimately the wellbeing of the ecological environment. Therefore, analysis of population, land use and forest vegetation vicissitudes on the Loess Plateau during the historical periods of China has scientific importance for vegetation recovery, rational land utilization, promotion of regional economic development, and improvement of the agricultural ecological environment.

8.2 Loess Plateau Vegetation Changes Over Chinese Historical Periods (Table 8.1)

Vegetation on the Loess Plateau was mainly natural secondary forests. Remnant forests were mainly in the northern Qinling Mountains, Taihangshan Mountains, Lüliangshan Mountains, Huanglongshan Mountain, Ziwuling Mountain, Longshan Mountain, and Liupanshan Mountain. Natural vegetation of the vast loess hill and gully region has been destroyed. Human activity is the main cause of forest change on the plateau. This activity is mainly manifested by the use of land, and its intensity is positively related to population and productivity development. Land use and vegetation change inevitably impact ecosystem structure and function. Shi (1981b) separated the historical change of middle reach forests on the plateau into four periods, according to historical records and archaeological analysis. However, plateau land use over 3,000 years has been very complex. Pastoral boundaries and population increases and reductions may objectively reveal vegetation characteristics of various stages. In accord with the extent of vegetation damage and chronology of human activities, we divided the historical vegetation changes on the plateau into eight periods.

Table 8.1 Dynasties in Chinese history

Dynasty	Period
Xia dynasty	2070 BC–1600 BC
Shang dynasty	1600 BC–1046 BC
Zhou dynasty	1046 BC–256 BC
Spring and autumn/Warring states period	770 BC–221 BC
Qin dynasty	221 BC–207 BC
Han dynasty	202 BC–AD 220
Three kingdoms period	AD 220–AD 280
Jin dynasty	AD 265–AD 420
North–South dynasties	AD 420–AD 589
Sui dynasty	AD 581–AD 619
Tang dynasty	AD 618–AD 907
Five dynasties and ten states	AD 907–AD 960
Liao, Song, Xia, Jin dynasties	AD 916–AD 1234
Yuan dynasty	AD 1271–AD 1368
Ming dynasty	AD 1368–AD 1644
Qing dynasty	AD 1616–AD 1911
Republic of China	AD 1912–AD 1949
People's Republic of China	AD 1949–present

8.2.1 *Before the Qin Dynasty (Prior to 221 BC)*

The Loess Plateau has been said to be the birthplace of the Chinese nation. Cultural relic sites of the Neolithic period are widely distributed on the southern plateau. The densest concentrations of these sites are in the Fenhe and Weihe river valleys and western Henan Province. During the latter period, people fished and gathered to make a living, indicating that the southern plateau maintained a favorable natural ecosystem (Sang 2003).

Written records from the Shang and Zhou dynasties suggest that productivity was greatly improved and agriculture transformed from primitive methods to the traditional style (Yan and Li 2007). Furthermore, backhoe agriculture developed to a respectable degree (Sang 2003). People in the Zhou mainly resided in the counties of Qingyang, Xifeng, Binxian, Changwu, Fufeng, and Qishan. The ancient *Book of Songs* documented that the soil was fertile on the plain, and the people cleared Chinese tamarisk, mulberry, *Cudrania* and other trees in unreclaimed natural wasteland to create farmland. These were small trees and shrubs, but they revealed the abundance of shrub vegetation during the Zhou Dynasty (Wang 2010). China had 13.5 million people during the Xia Dynasty and 13.7 million in the Zhou Dynasty, about half of which were in the Fenhe and Weihe river valleys and western Henan. Population density in these three areas was 30–40 km^{-2}. Even so, it is still evident from the *Book of Songs* that deer, tigers and leopards were living in groups on the southern Loess Plateau, with vast forest area and limited arable land (Zhang 1998).

During the Spring and Autumn and Warring States periods, plough agriculture replaced that of hoeing, and agriculture developed further in the Guanzhong Plain, Fenhe Valley, and Luoyang and Tianshui basins. During the Warring States period, the Qin Kingdom extended its force toward the upper reaches of the Weihe River and northern Shaanxi, while the Zhao Kingdom expanded towards northern Shanxi. In these areas, people built towns and reclaimed farmland to develop agriculture. But until the late Warring States period, agriculture was still mainly in areas of southern Taiyuan-Longmen-Tianshui. Animal husbandry remained dominant in northern areas. Population of the entire Loess Plateau was sparse. In that period, mountain vegetation on the plateau remained in a healthy state (Cheng 2001).

The ancient books of *Shan Hai Jing* and *Xi San Jing* describe the abundance of oak and lacquer trees on Huanglongshan Mountain in Northern Shaanxi, mulberry and lacquer trees in the upper reaches of the Qingjian River, and pine, cypress and oak on Baiyu Mountain. The *Book of Songs* also describes alternating distributions of farmland, mulberry and oak. In Loess Plateau areas, such as east of Liupanshan Mountain, west of the Lüliangshan Mountains, north of Weihe River and south of the Great Wall, there was both expansive grassland and widely distributed shrub land. River valley and mountain land were mainly covered by tree vegetation. An important vegetation dividing line was Lishi-Yan'an-Qingyang. Habitats south of this line also had a large forest area proportion (Wang 1994). Arbors were mainly coniferous and elm. Grasses and shrubs were also important parts of vegetation. All the records above were confirmed by pollen analysis (Liu 1985). Hence, before the Zhou Dynasty, human activity had some effect on vegetation on the Loess Plateau, but was mainly concentrated in river valley plains and the Taiyuan region, and damage was limited. People reclaimed land and cleared trees mainly around settlements and towns. In most plateau areas, vegetation remained in a natural state.

8.2.2 Qin and Han Dynasties (221 BC to AD 8)

During the Qin and Han dynasties, the Loess Plateau was the country's political and economic center, and population and land use changed greatly. In this period, farming culture invaded the plateau, which is clearly reflected from Han Dynasty stone portraits unearthed in Suide and Mizhi counties. After the Qin Kingdom united the entire country, its force expanded north to the Qin Great Wall north of the plateau. Mengtian, a famous general during the Qin Dynasty, led 300 thousand soldiers in building the Great Wall in the north. Forest and grass vegetation was seriously damaged by cultivation and reclamation (Sang 2005). During the Han Dynasty, the ruling force expanded further, toward the north and west. In the time of Emperor Hanwu, it reached the Yinshan Mountains in the north and the Hexi Corridor in the west. The entire plateau was ruled by the Han Dynasty. In that period, the plateau population increased significantly because of immigration and army garrisons. In the late Han Dynasty, the population reached 8.88 million (Guo and An 2007). Because of large-scale immigration, the Guanzhong Plain (around Xi'an) came to have less land and a large population, which resulted in a lack of grain. The government had to lift a prohibition on collecting vegetation in mountain forests and around swampy lakes, an activity that damaged vegetation there. The alluvial plain and loess terraces in forest regions were completely reclaimed as farmland. Forests around agricultural residences were also damaged by wood and firewood collection. Reclamation in the forest zone was most common on the Guanzhong Plain and northwestern Henan Province. Nonetheless, because of the need for hunting and amusement, forests near hills and mountains, swampy lakes, palaces and courier hostels were well preserved. In particular, areas on the northern slope of the Qinling Mountains, Guanzhong Plain and Longxi County were extensively covered by forest.

The ancient counties of Shuofang and Wuyuan in Inner Mongolia, Xihe in Shanxi near the Yellow River and Shang in northern Shaanxi were also areas of vigorous land reclamation. These areas in the steppe zone were suitable for agriculture and animal husbandry; population densities were mostly greater than 10 km^{-2}. From the Qin to Han dynasties, with the progress of immigration and reclamation in the northwest counties, the agricultural economy extended far northwestward and farming areas expanded to the feet of the Yinshan Mountains. South of the Qin Great Wall, farmland and irrigation channels were connected, and villages were in sight of each other. In particular, in the northern Guanzhong Basin and south of the Yellow River, emerging agriculture became very prosperous relative to Guanzhong Plain. In this period, the population in the four counties reached 1.67 million. Assuming such a population, if one person requires 0.7–1 ha of reclaimed farmland, 1.11–1.67 million ha would be needed, or 10 % of the total area of all four counties. Since these regions were mostly mountains, rivers and desert, the proportion of reclamation was very large because flatland was almost totally reclaimed (Guo and An 2007). The consequence of vegetation destruction was serious ecosystem degradation. Many places trended toward desertification. In the late Qin and early Han dynasties, a borderline between agriculture and animal husbandry formed in the northern Loess Plateau.

8.2.3 Late Han Through North–South Dynasties (AD 25–589)

Following the Qin and Han dynasties, population of the Loess Plateau declined owing to frequent wars in the north during the Three Kingdoms Period and Jin Dynasty. The population of Guanzhong Plain was 520 thousand in the final years of the late Han Dynasty, whereas there were only 460 thousand in the Western Jin (AD 280; Xue 2000). During that period the temperature continued to fall, and the boundary line of agriculture and animal husbandry gradually moved south until reaching the Qinling Mountains. Because of agricultural atrophy and weakening of outside forces (e.g., farming), vegetation partially recovered in a situation of positive succession. *Chilege* was a volume of folk songs during the Northern Dynasty, in which grassland scenes on the northern Loess Plateau were described. During the period of the 16 States, Tongwan City was the capital of Xia State. This was located in northern Jingbian County near swampland, which had clear water. Helianbobo was the prince of Xia State. He stated that he had traveled to many places north of Baimaling Mountain and south of the Yellow River, and that the environment of his capital was superior to any others he had visited. The ancient book *Shuijingzhu*, written by Li Daoyuan, recorded that many elms and willows grew in Northeast Yulin (Sang 2005). Overall, though natural vegetation suffered damage in the Qin and Han dynasties and farming continually moved onto the Loess Plateau, this vegetation still composed a large proportion on the plateau until the North–south Dynasties.

8.2.4 Sui and Tang Dynasties (AD 581–907)

China was reunited, the society stabilized, the economy prospered, and the country entered a golden age of agricultural development. With economic development and expansion of agricultural areas, the population of the Loess Plateau increased (Xue 2000). By the Tang Dynasty, the population of the capital city of Chang'an in Shaanxi was over a million, with heavy demand on wood for construction and firewood. Timber was harvested from nearby Zhongnanshan Mountain, in Qishan and Longshan of the western area, and Lishi and Lan counties of southern Shanxi, resulting in extensive vegetation damage on the plateau. With over 300 years of destruction during the Sui and Tang dynasties, the plateau vegetation had greatly changed. The Mu Us sandy land in the north expanded southward, the vegetation boundary moved and the coverage of natural vegetation sharply declined. Natural forest vegetation was preserved only in the Taihangshan, Lüliangshan, Luyashan, and Yunzhongshan mountains (Sang 2005).

Agricultural area reached Tianshui and Longxi along the Weihe River towards the west, to the Huangshui Valley. During the Tianbao era (AD 742–755), the economy of the Tang Dynasty peaked, and the population of the Loess Plateau was 10.2 million. The pattern of agricultural production on the southern plateau was basically established during the Tang Dynasty, characterized by population increase, vegetation destruction, and development of towns. But overall destruction of the natural environment was not serious in the middle and northern parts. Animal husbandry still accounted for a large proportion in the loess hill area (Sang 2003). No natural forest vegetation could be found on the Guanzhong Plain and Fensu River Plain from the early part of this period.

8.2.5 Song and Jin Dynasties (AD 960–1234)

Although the capital city of the Song Dynasty was Kaifeng, downstream on the Yellow River outside the Loess Plateau region, destruction of vegetation on the plateau did not slow. There were massive construction projects in Kaifeng throughout the dynasty, which resulted in deforestation not only of nearby mountains, but as far as the southwestern plateau (Guo and An 2007). In addition, to defend the Liao and Xia states, the Song Dynasty built an approximately 1,000 km military fortification line on the northern plateau. Along this line, numerous towns and castles were built and a large number of troops were stationed on the frontier. This military deployment increased the population in the boundary area. To solve military supply problems, the ruler recruited the population to reclaim farmland along the border.

The significance of vegetation degradation during the Song Dynasty was manifested by extensive reclamation of sloping land on the northern and western Loess Plateau, owing to military demand. During the Jin Dynasty, the plateau was further reclaimed and forests extensively cleared to build palaces. It has been estimated that the course of the Yellow River shifted on average once every 60 years during the Song and Jin dynasties, and there were yearly flood disasters (Wang 2005).

8.2.6 Yuan Dynasty (AD 1271–1368)

The Yuan Dynasty unified China, halting military confrontation around the Loess Plateau, whose population had been greatly reduced. For instance, the population of Shaanxi decreased from 4.8 million in AD 1207–450 thousand in AD 1260 (Xue 2000). Many areas on the plateau became pastoral during the Yuan Dynasty. Watercourse diversion of the Yellow River did not occur during the 100 years of this dynasty.

8.2.7 Ming and Qing Dynasties (AD 1368–1911)

The Ming Dynasty built the Great Wall on the northern Loess Plateau to repel northern invaders. This wall became a boundary for agriculture and pasture. There were many border inhabitants and soldiers living near the wall. Both inhabitants and soldiers reclaimed farmland, generating heavy destruction of sloping land vegetation and grasslands near the wall.

During the Qing Dynasty, because of national unity and a relative stable society, the population grew rapidly. Total population of the Loess Plateau was estimated at only 15 million in the 1400s, during the Ming Dynasty, but it reached about 41 million in 1840 during the late Qing Dynasty (Liu et al. 1991). Because of conflict between needs for farmland and of an increasing population, immigrants on the plateau during the late Qing Dynasty settled in mountainous areas where the existing population was sparse. This led to severe deforestation in the period. Forest cover on the plateau greatly decreased during that dynasty (Ma 1990).

8.2.8 The Twentieth Century

From the late nineteenth century until establishment of the new government of the People's Republic of China in 1949, the country experienced continuous international and civil wars. During the Second Sino-Japanese War, deforestation for cultivation purposes was caused by numerous refugees fleeing onto the Loess Plateau. Chinese armies also reclaimed natural forests and shrub lands on the middle plateau.

Because of wars and natural disasters, population growth on the plateau was slow during the first half of the twentieth century. However, in the last half of the century, total population in the region increased from 40 million to 87 million. There was both deforestation and reforestation after 1949. However, under policies of the *Collectivization of Land* and *Great Leap Forward*, farmers were forced to either produce steel or create arable land throughout the country. Deforestation on the plateau was serious during the 1950s and 1960s. Natural forest area on Ziwuling Mountain had contracted about 40 % by the late 1970s. In many areas, natural vegetation was converted to farmland (Sang 2005).

Since the late 1970s, afforestation on the Loess Plateau has increased with implementation of national ecological projects. The plateau has been covered by several national major projects of vegetation rehabilitation, soil and water conservation, and desertification control. By the end of the century, more than ten million hectares of artificial forests, shrub lands and fruit trees had been planted, mainly for soil and water conservation and construction of agricultural shelterbelts. At that time, larger national ecological projects were implemented and deforestation was forbidden; sloping farmlands were gradually converted to forests or grasslands.

8.3 National Forest Management Projects and Achievements on the Loess Plateau

The Loess Plateau has been covered by a series of national ecological projects. The Three-North Shelterbelt forest program implemented in 1978 was a 73-year project covering 4 million km^2 (about 42 % of total national land area) in the northwest, north and northeast territories. It aimed to increase forest area by 35 million ha, or forest coverage from 5.05 % in 1977 to 14.95 % in 2050, for effectively controlling sandstorms and soil erosion, improving basic ecological conditions, and primarily improving living conditions of regional farmers. The National Key Projects for Soil and Water Conservation implemented in the 1980s also produced significant results in the upper and middle reaches of the Yellow River. This not only reduced sediment deposition in the river, but also improved agricultural conditions and ecological environments (Liu 2004). The Natural Forest Protection and Grain-for-Green projects implemented in the 1990s completely prohibited deforestation and have been converting sloping farmland back to forest or grassland (Chap. 10). In addition, the projects of Desertification Control, Sandstorm Source Control, Loess Plateau dam construction, the World Bank loan project for soil and water conservation of the Loess Plateau, and others, have greatly accelerated vegetation restoration in the plateau region. During 1990–2010, China had the largest afforestation area in the world (FAO 2010). The Grain-for-Green Project was considered the largest land use conversion plan in developing countries (Bennett 2008). In 2008, woodland (including forests and shrubs) and grassland reached land covers of about 16 and 43 % of the region, respectively (Lü et al 2012). Through decades of construction, especially with the start of forestry projects in the new century, about 2.3 million ha of steeply sloping land with serious soil erosion and cultivated land under serious desertification have been restored to forest or grassland in the region. Over 6.7 million ha of ditches and slopes on degraded land have been restored to forest vegetation, and about 8.8 million ha of land planted with grass (NDRC et al. 2010). These ecological restoration projects promote vegetation restoration and will have a profound influence on the environment and social economy on regional and national scales (Wang 2007).

8.4 Conclusions

Vegetation of the Loess Plateau remained in a natural state before the Zhou Dynasty. Natural vegetation still represented a large proportion during the Qin and Han dynasties. In the Tang and Song dynasties, natural forests disappeared from valley and plain areas, and vegetation in hill and mountain regions was also destroyed. The northern desert began to expand, suggesting a natural environment that was in a state of deterioration. Vegetation during the Ming and Qing dynasties was seriously damaged. The main causes of vegetation change during these historical periods on the plateau were land reclamation, deforestation and overgrazing. Such human activities intensified soil erosion in the region and increased sediment concentration in the Yellow River. A series of ecological projects implemented in recent decades has resulted in significant changes of vegetation cover and the environment on the plateau. These projects have eventually changed the trend of historical degradation to one of restoration.

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Part III

Countermeasures for Combating Desertification

Chapter 9
Comprehensive Chinese Government Policies to Combat Desertification

Zhan-Bin Li, Peng Li, Ping-Ping Huang, and Xiao-Jun Liu

Abstract Desertification in China is a serious and mounting environmental problem. Thus, combating it is of great importance to the ecological safety and socioeconomic development of the country. Many laws and regulations have been previously enacted by the Chinese central government. However, implementation of these laws and regulations still requires better management, and successful desertification prevention needs better cooperation between various stakeholders. Moreover, with its rapid growth over the past few decades, China must balance ecological, social and economic development and protection by instigating greater wisdom in decision making. Given the seriousness of the environmental issue, the country has accumulated great experience with prevention and mitigation of desertification. Currently, however, greater effort is required to effectively manage desertification control, including: (1) improving laws and regulations, and perfecting management and monitoring systems; (2) extending investment channels for desertification prevention; (3) strengthening both basic and applied research; (4) improving the ecological compensation mechanism; and (5) strengthening societal awareness of desertification issues and prevention.

Keywords Desertification • Legislation system • Scientific research • Ecological compensation • Societal awareness • Comprehensive management

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9.1 Introduction

According to the results of the third desertification monitoring program in 2004, desertification areas in China have increased to 2.636 million km^2, with resulting direct economic losses at some 54 billion Chinese Yuan (CNY, which was about 0.16 U.S. dollars as of May 2012) (Zhang and Ning 1996) and further indirect economic losses two to eight times the direct costs (Zhang et al. 1994).

To combat desertification, the Chinese government launched a series of policies, including the Three North Protection Forest Project, Natural Forest Protection Program, Sandstorm Source Control Project in and around Beijing and Tianjin, plus the Grain-for-Green Project and Returning Cropping Land to Forage Land Project. In addition, legislation has also seen great progress, with the Chinese government successfully enacting the Grassland Law of the People's Republic of China (P. R. China), Law of the P. R. China on Water and Soil Conservation, and the Law of the P. R. China on Prevention and Control of Desertification. Through these efforts, desertification prevention in China has seen some improvement. However, despite such initiatives and partial improvement in local environments, desertification remains a serious issue because of continuing policy and implementation difficulties (Guo and Zhou 2010).

Thus, it is essential that policy implementation be improved by clarifying the shortcomings of policy content and development. In this chapter, we analyze desertification prevention policies and management systems in China and discuss ways forward, including: (1) improving laws and regulations, and perfecting management and monitoring systems; (2) extending investment channels for desertification prevention; (3) strengthening both basic and applied research; (4) improving the ecological compensation mechanism; and (5) strengthening societal awareness of desertification prevention.

9.2 Revising Laws and Regulations and Improving Management and Regulation Systems

Combating desertification is an important part of the national economic and social development plans of the Chinese government. In the past 50 years, the country has held four national desertification control conferences and has launched the National Project for Prevention and Control of Desertification and the Three-North Shelterbelt System Construction Project. In the late 1990s, the government enacted important environmental schemes and policies such as China's Agenda 21, the National Program for Eco-environmental Construction Planning of China, the Forestry Action Plan (within Agenda 21), and the China National Action Plan to Implement the United Nations Convention to Combat Desertification. By implementing the Western Development Strategy, China has laid an ecological foundation for simultaneous planning, implementation, and development of the economy, as well as of the ecological environment. In 2010, the National Major Functional Zone Plan of

China presented the “Two Barriers and Three Belts” framework to combat desertification, which was also the focus of 25 important ecological functional zones in the country.

The Chinese government launched a series of policies and legislation to combat land desertification in the late 1990s, including the Forest Law of the P. R. China, the Grassland Law of the P. R. China, the Law of the P. R. China on Water and Soil Conservation, and the Environmental Protection Law of the P. R. China. Among these, the Law of the P. R. China on Water and Soil Conservation, implemented on June 29, 1991 and its revision implemented on March 1, 2011, discussed prevention, control, and legal supervision of soil and water loss in detail, and put forward new ideas for prevention, control, monitoring, and management of desertification. On August 31, 2001, the Law of the P. R. China on Prevention and Control of Desertification was adopted at the 23rd Session of the Standing Committee of the Ninth National People’s Congress, and was officially implemented on January 1, 2002 as part of the country’s commitment to desertification mitigation through relevant laws and regulations. The Law of the P. R. China on Prevention and Control of Desertification was the first national-level law specifically dedicated to tackling desertification in the world. It not only filled the legislation gap by improving technologies for and managerial experience in the control of desertified land in relation to legal principles and systems, but also achieved cross-departmental merging of legislation on resources at a larger scale (Du 2004). Following the principles of “Protection First, Positive Control, and Proper Utilization,” the Law of the P. R. China on Prevention and Control of Desertification specifically details national and local regulations and plans for prevention and control of desertification, prevention of land sandification, control of sandified land, and mandatory safeguard measures and legal responsibilities (Liu 2008).

The Chinese National Action Plan to Combat Desertification has implemented and organized large-scale development of cross-region, cross-basin, and cross-industry ecological projects, enhanced organization safeguard measures to combat desertification, accelerated desertification prevention work, and achieved evident ecological, social, and economic benefits. Such work has effectively controlled desertification in some regions. Moreover, the State Council has promulgated a series of administrative regulations such as the Regulations on Conversion of Farmland to Forests (January 20, 2003), Decision of the CPC Central Committee and State Council on Accelerating the Development of Forestry (June 25, 2003), and the Decision on Further Strengthening the Prevention and Control of Desertification (September 8, 2005). Additionally, local governments in desertified regions have enacted corresponding local regulations and rules to help combat desertification.

The Chinese government has also established a relatively robust organization and management system, which includes 18 ministries, commissions, and financial institutions, called the Chinese National Coordinating Group to Combat Desertification, to work towards desertification minimization across the country. In addition, the National Bureau to Combat Desertification was established in 1997 with the approval of the State Commission Office for Public Sector Reform, and is responsible for organizing, coordinating, managing, and instructing relative to the nationwide desertification issue. After 8 years of continuous effort, a monitoring organization system was established. Within this, the Chinese National Desertification Monitoring Center and Northwest Institute of Forest Inventory, Planning, and Design were designated as provincial centers for forest survey and design, and autonomous regions designated as sub-centers. The Chinese government actively participated in international cooperation under the United Nations Convention to Combat Desertification. The government hosted international conferences related to this convention, established regional networks to cooperate with international organizations and governments in relation to common environmental issues, and developed international partnerships under the convention framework.

The implemented laws and regulations as well as the robust organization structure and management systems provide a legal foundation and reliable safeguards to combat desertification in China. However, problems remain in relation to legal countermeasures. With economic development, the revision of relevant laws and policies in the country, and increasing desertification research, existing legislation is unable to solve many problems that occur in practice. Such problems are typified by unclear authorities and responsibilities of governments and undefined property rights for resources, creating conflict between stakeholders and impacting the prevention and control of desertification. For example, the period of forest ownership is undefined and, to date, China has undergone five major forest land use rights system reforms. These frequent reforms have led to unstable use and operation of farmland, such that many farmers have become apathetic toward the prevention and control of desertification. Regarding actual desertification mitigation in China, there are also issues related to law abidance and law enforcement. For example, many precious Chinese medicinal plants such as *Hippophae rhamnoides*, *Lycium chinense*, and *Glycyrrhiza uralensis* grow in arid desert regions; despite repeated orders that strictly ban unauthorized excavation and collection such plants, laxity in law enforcement and punishment has led to continued illegal harvesting, and consequent erosion and land desertification. Thus, lenient law enforcement in some regions has contributed to continued illegal activity that destroys forest resources. Such ineffective prevention of desertification demands strong laws and law enforcement to ensure implementation of all prevention systems and to improve relevant legislation.

Therefore, the following tasks require urgent attention to effectively monitor and prevent future desertification: (1) clearly define authorities for coordinated cooperation among various departments; (2) define property rights to increase interest by organizations and individuals engaged in desertification mitigation; (3) strengthen law enforcement to enhance management; and (4) improve the desertification monitoring, forecasting, and warning system.

9.3 Expanding Investment Channels for Combating Desertification

To ensure the sustainable development of desertification prevention and control, it is necessary to change existing production and operation modes, i.e., to transform the public welfare mode into an industrialized mode for expanding investment opportunities. Currently, desert exploitation requires great investment, but achieves little benefit and has a long return period (Bu 2008). Therefore, it is necessary to adopt a win–win, strategy-based investment plan in which all enterprises, investors, governments, and local populations can offer and obtain successful investment in the field of environmentally sound technologies. Bilateral and multilateral cooperation is also necessary for environmental protection, to expand investment avenues for controlling desertification.

9.3.1 Industrialized Desertification Control

A new era has begun in combating desertification. It combines desertification control with local economic and social development, and introduces public and private capital into desertification prevention for the social, economic, and ecological benefit of all participants. Relying on the Project of Conversion of Farmland to Forests, Yulin farmers have changed their traditional practices of extensive cultivation to the planting of grasses, mulberry, apricot, Chinese jujube and other fruit trees. In Ordos City, Inner Mongolia, a novel prevention strategy has been developed. It focuses on low-carbon economic development, new energy resources to combat desertification, and green industries to improve local wealth and wellbeing. Kubuqi Desert is the seventh largest desert in China. Through 20 years of relentless effort, the Inner Mongolia Elion Resources Group Company has invested more than 3 billion CNY to create oases in desertification-affected areas, developing a remarkable desert economy. The company has helped reverse desertification, increase local income, and enhance environmental protection and enterprise profits through industrialization methods.

9.3.2 International Cooperation

The Chinese government continues to cooperate internationally in bilateral, multilateral, and regional manners to tackle desertification. Bilateral cooperation is an important constituent of China's international cooperation. Since the country signed the first bilateral environment cooperation protocol with the USA, the State Environmental Protection Administration has, on behalf of the national government, signed bilateral environment cooperation documents with 33 countries, including Germany, Korea, Australia, Canada, France, and the Netherlands. Based on these documents, China has set up a bilateral cooperation framework covering the entire world, which primarily consists of non-reimbursable, assistance-based afforestation projects. Since the mid-1980s, the national government has actively expanded cooperation with international organizations to carry out assistance activities in arid regions of China. Such organizations include the United Nations World Food Programme (WFP), Food and Agriculture Organization (FAO), United Nations Development Programme (UNDP), Global Environment Facility (GEF), International Fund for Agriculture Development (IFAD), World Bank (WB), Asian Development Bank (ADB), and the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP).

To strengthen environmental cooperation and negotiations put forth at the first summit meeting in 1999, China, Japan, and Korea commenced the Tripartite Environment Ministers Meeting (TEMM) in the same year. The TEMM is held consecutively in the three countries to solve common environmental problems and promote sustainable regional development. A joint statement of the TEMM is signed by the ministers after every meeting. China hosted the second and fifth TEMMs in 2000 and 2003, respectively. As the main regional environmental cooperation mechanism in Northeast Asia, the TEMM has collaborated and made substantial achievements in sand-dust storm monitoring, the Acid Deposition Monitoring Network in East Asia (EANET), development plans for environmental education networks and human resources of the three countries, ecological conservation in Northwest China, protection of fresh water resources, and environment-friendly industry.

9.4 Strengthening Basic and Applied Research

Since the end of the last century, with rapid development and application of new theories and technologies, desertification prevention research has entered a new era. Adapting to the general trend of international desertification prevention research, desertification is considered a serious environmental and socioeconomic problem, and comprehensive research should be conducted from a natural, social, and economic viewpoint. Strengthening basic and applied research is key to comprehensive desertification prevention.

9.4.1 Strengthening International Cooperation and Exchange in Desertification Mitigation Research

With constantly developing international cooperation and exchange, strengthening research on fundamental applications to reduce or eliminate desertification is necessary for international prevention and control. The 2009 Kubuqi International Desert Forum, held in Ordos City, Inner Mongolia, adopted the 2009 Kubuqi International Desert Forum Declaration. Forum attendees stated that governments of various countries should enhance technological guidance and support to combat desertification, promote strong cooperation among academic organizations, scientific research institutions, relevant local governments and enterprises, increase support to government-owned scientific research institutions, and encourage various private organizations to devote themselves to scientific research and industrialized applications of desertification control. Significant effort must be made to popularize prevention and control measures that prove effective in mitigating desertification in China.

The forum attendees also stated that as environmental and desertification problems are common issues faced by humankind, international cooperation must be increased and communication between relevant academic organizations must be enhanced to augment sharing of global desertification prevention and restoration technologies. Relevant organizations of the United Nations and international desert forum organizations must assume more responsibility in this respect. Popularization and application of advanced desertification experience, scientific technologies, and new materials must be encouraged worldwide. Forum attendees called on governments of various countries to implement more flexible and positive policies for the turnover of funds, technologies, personnel, and materials related to prevention and control of desertification.

9.4.2 Theory of Sand Industry

Qian (1984) first proposed the concept of a sand industry as a knowledge-intensive, agriculture-based industry developed on “sterile land,” which utilizes all achievements from modern scientific technologies related to physics, chemistry, and biology. It also uses the photosynthesis of plants to fix and transform solar energy. Today, the sand industry provides output value up to 100 billion CNY on 1.50 million km^2 of desert (the Gobi) and desertified land in China, to exploit new food sources for human beings. Its continued emergence will lead to a new industrial revolution, and currently includes oasis agriculture, forestry (protection forest, forest and orchard, and desert shrub), animal husbandry, and development and use of economic plants (including unique Chinese medicinal and textile plants).

Development of the sand industry is progressive and follows the principle of development from lower to higher levels and from local to global scales. That is, the principle of “intensive operation and sustainable development in a scientific and reasonable manner, by taking measures adapted to local conditions” (Liu 2009). The essential purpose of the industry is to realize intensive, efficient, sustainable, and diverse resource exploitation in desert areas, for ensuring mutual promotion and harmonic development of economic, social, and ecological benefit (Liu 2009).

The knowledge-intensive sand industry has become a new growth point of economic development in Ordos City. For more than 20 years, combating desert encroachment near Ordos has changed from focusing on vegetation plantation to focusing on industrial development, and the city has gradually formed four green pillar industries (wool, meat, milk, and medicine). These have become novel leading industries in the “Conversion of Farmland to Forests and Pasture to Grassland” project.

The Gansu Sanxin Agriculture and Forestry Technology Company, located in the Hexi Corridor of Gansu, has introduced new fruit and vegetable species from the USA and cultivated up to 100 characteristic sand-industry products, including the famous “black tomato.” Compared with common tomatoes, the black tomato contains more lycopene, vitamin C and antioxidants. It has moderate acidity and sweetness and intense fruit flavor, as well as very high nutrient and medicinal values. Local farmers can now earn more than 8,000 CNY per year net income through black tomato planting.

9.4.3 Present Situation and Development Trends in Technologies Used for Desert Transformation

In the past 100 years, utilization of sand areas has mostly focused on exploitation of minerals, energy resources, and biological resources (light, heat, water and soil), with the development of industrial mineral exploitation being the fastest. The main objective in sand areas is to control highly destructive wind and associated sand disasters. Desertification control currently includes biological, technical engineering, and chemical sand-fixing measures. Beyond sand fixation and sand-dust storm control using novel sand-fixing agents and lignin-based sand-fixing materials, determining how to exert specific functions of biological technologies for effective transformation and control of the desert has attracted significant scientific attention. Since 1998, there have been six ideas for biological technology-based desertification control:

1. Searching for rare psammophytic plants and enhancing research on their breeding and ecological properties, to provide pioneer plants for transformation of desert areas
2. Introduction of psammophytic plants with strong adaptability to desert areas, and enhancement of research on their drought resistance and ecological properties
3. Use of specific microorganisms to transform the nature of the desert. For example, strengthening the study of silicate bacteria that may be used to change sand into soil
4. Development of biopolymers with high water absorption (which can be produced by some microorganisms) to transform the desert
5. Use of genetic engineering technologies to construct and cultivate drought-resistant plants for desert transformation
6. Combination of various organic wastes with effective aerobic and anaerobic microorganisms, to assist in desert transformation

With deepening and rapid development of biological technology research, scientists have proposed new ideas on how to effectively control desert expansion in recent years:

1. Introduction of plants with strong drought resistance and symbiotic nitrogen-fixing capability, e.g., *Hippophae rhamnoides* and *Glycyrrhiza uralensis*, which are closely linked with nitrogen-fixing microorganisms that not only increase nitrogen nutrition in plants, but also gradually increase organic matter and fertilize the desertified base. This is helpful for the transformation of desertified land, and for growing and breeding these plants and creating products with high added value. One action thereby serves multiple purposes.
2. Introduce the energy plant *Jatropha curcas*, which is barren-resistant and can build a symbiotic relationship with mycorrhizal fungi. It can grow in arid environments and its fruits provide quality biofuel, which is sulfur-free, pollution-free, nontoxic, completely natural, and biodegradable. The biofuel can be used as a substitute for diesel. If used as inoculants, symbiotic mycorrhizal fungi can improve the seed breeding ability and fuel yield of *Jatropha curcas*.

3. Develop microalgae, including blue algae and green algae for transformation of desertified land. In nature, color crusts are often distributed on the surface layer of arid rocks, which contain different organisms, including lichen (a symbiosis of blue algae and fungi). With the introduction of water, organisms in the crusts resume their life activities. Given this characteristic, transgenic plants with high drought resistance and extremely strong vitality can be cultivated from these crust organisms via transgenic technology, which can in turn boost effective desertification control.
4. The Biological Carpet Desertification Control Project is being initiated in China. The Chinese Academy of Sciences and related domestic institutions are exploring new ways to comprehensively use microorganisms and organism crusts of spore plants for desertification control. The principle is to take naturally formed organism crusts in arid, semiarid, and desert regions as "templates" and use modern biological technologies to duplicate them, so that activated desert surface layers are covered with "carpets" of organism crusts. Drifting sand is thereby controlled and desertification mitigated (Ke 2005).

9.4.4 Exploitation and Use of Water Resources in Sand Areas

Desert regions have arid climates, low vegetation coverage, strong wind and sand activity, scarce precipitation, intense evaporation, and water-deficient sand layers (He and Zhao 2002). Enhancing exploitation and use of water resources in desert regions is the main means for accelerating mitigation of desertification (Xue et al. 2005; Wang et al. 2003a, b). Currently, desert water resources are primarily provided by cross-basin water diversion, artificially induced water, changing the sand area microclimate, exploiting groundwater, transforming and using salty and sea water, dew and fog water resources, and developing various water saving technologies.

9.5 Improving Ecological Compensation Mechanisms

Ecological compensation is also called payment for ecosystem services. It means improving ecosystem status or establishing a new habitat with equivalent ecosystem functions or quality in a destroyed region, for compensating degradation of or damage to the functions or quality of the existing ecosystem caused by economic development or construction, to maintain ecosystem stability (Li 2005). In terms of the law, ecological compensation means that to resume, maintain, and enhance the ecological functions of an ecosystem, the country charges (or taxes) for exploitation or utilization of natural resources that degrade ecological functions. The country or beneficiaries of ecological protection offer economic or non-economic compensation to organizations or individuals who have relinquished their interests, for improving, maintaining, or enhancing ecological service functions.

Because of such considerations as great social benefit and difficult capital recovery, it is especially important to establish an ecological compensation mechanism in desertified regions (Lv and Gao 2009). The ecological compensation mechanism is, in fact, both an interest compensation and conflict coordination mechanism. The interest compensation mechanism means using normalized system construction to realize interest transfer between the central and local authorities and between different local authorities, to achieve reasonable inter-regional interest distribution (Xu et al. 2010). This mechanism is mainly embodied in the establishment of normalized financial transfer payment systems.

Problems faced in construction of an ecological compensation mechanism in the Western Regions presently include the following: (1) the "department-led" environmental protection system has undefined responsibilities and low-efficiency ecological protection, residents in ecologically protected areas receive little benefit, and ecologically protected areas have large populations in poverty; (2) the "project-specific" compensation mode affects long-term stability of ecological policies and sustainability of ecological protection; (3) the "blanket" compensation standard, low compensation standard, and coexistence of under-compensation and over-compensation influence the lives of residents in the ecologically protected areas; (4) ecological compensation financing channels are limited, mainly relying on transfer payments from central financial agencies, so the central government experiences high pressure; and (5) providers and receivers of ecological benefits are not clearly defined, and ecological compensation policies are neither scientific nor reasonable.

Relative to improving the ecological compensation mechanism in the Western Regions, the Department of Economics of the Chinese Academy of Governance (Wang and Dong 2007) forwarded the following countermeasures: (1) establish an ecological compensation mechanism based on long-term sustainable economic and social development, and raise the mechanism from policy level to law level, using the legal system to ensure the existence and development of the rights of Western Region residents; (2) enhance the stability of ecological protection policies, extending the period of ecological protection subsidization of the Conversion of Farmland to Forests Project by category, according to regional features; (3) set up financial transfer payment systems favorable to ecological protection and construction, and add an "ecological compensation" sub-item under "financial transfer payment"; (4) establish a "horizontal funds transfer" compensation scheme among local governments, so that the developed regions receiving benefits from ecological protection directly execute financial transfer payments to poor areas, providing ecological protection; (5) impose an "ecological tax" to provide long-term and stable sources of ecological compensation funds; (6) define the provider and receiver of ecological benefit and establish quantitative compensation standards scientifically and reasonably, on the basis of "Ecological Functional Zoning"; and (7) establish an eco-environment assessment index system and an assessment system for utilization efficiency of ecological compensation funds, to scientifically measure the eco-environment value and raise the utilization efficiency of ecological compensation funds.

In summary, ecological protection in the western desert regions is not just a simple ecological compensation problem, and a thorough solution to this problem is dependent on social and economic development in the Western Regions. Therefore, ecological protection can only be truly successful by using compensation to adjust economic and industrial structures and to improve the modes of production and lives of the population in those regions, especially desert areas, thereby mitigating eco-environmental pressure.

9.6 Strengthening Societal Awareness of Desertification Prevention

Although China continues to work toward its control, desertification continues to increase. Inadequate prevention awareness and understanding of desertification hazards have led to a public disconnect between desertification mitigation and the local living environment, economic development, and poverty alleviation. Many people do not associate interest-driven, short-term behavior with long-term interests of future generations, and do not follow the philosophy of "prevention first" (Jiang and Lu 2007). It is therefore essential to strengthen long-term awareness and education, so that individuals and organizations understand the importance and urgency of desertification control and that its prevention is an issue for all of society.

June 17 is the World Day to Combat Desertification and Drought. Every year in China, local governments organize and carry out multiple theme-based commemorative activities to mark this day. First, large-scale activities are held in public places to publicize the severe situation of desertification and sandification in the country. These activities also increase public knowledge about sandified land mitigation technologies and approaches, to enhance social responsibility and participation in tackling desertification and protecting the environment in desert areas. Second, the serious hazards of desertification and sandification are publicized to encourage government attention at all levels, and to increase support from various authorities for and active participation of the general public in combating desertification. Third, issues in combating desertification are reported via newspapers, television stations, and the Internet, to ensure comprehensive social publicity.

Through such publicity, some real changes have been achieved, and social awareness of desertification issues has improved. The following tasks should be introduced in the future:

1. Actively cultivate professional people and conduct technical training for combating desertification. Adopt preferential policies and actively encourage and attract talent to engage in scientific desertification research, and improve talent's benefits, production and living conditions. Moreover, encourage implementation of scientific research training systems, and adopt professional visitation and invitation programs for diverse training on managing personnel and technicians at multiple levels.
2. Broadly mobilize all levels of society to focus on and support desertification mitigation, and make full use of the People's Liberation Army, Chinese People's

Armed Police Force, People's Militia, labor unions, Women's Federation, Communist Youth League, and other social organizations. Recognize and reward organizations and individuals who have achieved significant performance in confronting desertification.
3. Actively explore new mechanisms and methods for mass prevention and control of desertification under new situations, and establish a public complaint reporting and supervising mechanism. Governments should create various conditions to facilitate public supervision of individuals and enterprises that destroy the environment. For example, a telephone number, mailbox, and website dedicated to complaint reporting can be established and publicized, with personal information kept confidential to protect the safety of those making complaints. Further, a mechanism providing grant honors and awards may be established.
4. Widely implement publicity and educational programs to improve ideological and social understanding of environmental issues. Organize campaigns to disseminate information and keep relevant information available to the public, and involve the public in education and publicity activities. Encourage the establishment of associations that focus on increasing public awareness of desertification. Compile and exchange education and public awareness materials on combating desertification, and implement relevant education and publicity schemes. Establish school courses according to educational standards in desertified regions, and cross-discipline participation schemes to incorporate desertification and drought awareness into the education curriculum so that environmental protection and desertification mitigation are tackled by the whole of society.

9.7 Conclusions

China is seriously threatened by desertification. For a long time, the central government has made a significant effort to combat desertification and has achieved remarkable outcomes. The main experience and progress of the Chinese government in combating desertification is as follows:

First, combating desertification is regarded as the main focus of state ecological safety by the central government, and effective laws and regulations have been enacted and rational management systems established.

Second, existing production and operation modes for combating desertification have been altered by transforming the public welfare mode into an industrialized mode for expanding investment opportunities. At the same time, there has been greater bilateral and multilateral environmental protection cooperation toward expanding investment avenues for combating desertification.

Third, by strengthening international cooperation and adopting new technologies, the knowledge-intensive sand industry has become an example of sustainable development and desertification control.

Fourth, it is important to establish rational ecological compensation mechanisms to adjust economic and industrial structures, and to improve both modes of production and the lives of the population in the Western Regions.

Finally, it is essential to strengthen long-term publicity and education, so that individuals and organizations in desertified regions understand the importance and urgency of desertification control, and that combating desertification is an issue important to all of society.

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Chapter 10
Grain-for-Green Policy and Its Achievements

Ji-Jun Wang, Zhi-De Jiang, and Zi-Lan Xia

Abstract The Chinese Grain-for-Green Policy began in April 1949. The policy was improved and perfected until implementation of the Grain-for-Green Project in 1999. Thus far, forest coverage has increased by an average of 3 % in the region covered by the policy. Trends toward ecological deterioration in some areas have been largely reversed and agricultural restructuring has been promoted. Wuqi County, a representative region of the policy coverage, has shown significant improvement in ecological restoration and agricultural production. Analysis has shown that the Grain-for-Green Policy was a compulsory regulation for required resources. The policy of financial compensation caused production operators to reduce their demand for resources, and the policy directly accelerated evolution of the ecological economic system in the region of implementation.

Keywords Achievement • Converting cropland to forest and grassland • Grain-for-Green Policy • Grain-for-Green Project

10.1 Retrospective of Grain-for-Green Policy

In April 1949, *The Provisional Regulations (Draft) on Forest Protection and Forestry Development*, which was issued by the administrative office of northwest Shaanxi Province, required that reclaimed and waste woodland be restored.

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This regulation directed that if reclaimed woodland near the forest could be easily afforested, it should be used for afforestation rather than farming; this also applied to small farmland areas in woodlands (Li 2002). Thus began the preliminary Grain-for-Green Policy in China.

In December 1952, the *Instructions of Arousing the Masses to Carry on the Movement of Prevention and Fighting Against Drought and Vigorously Carry Out Water and Soil Conservation,* which was signed and issued by Premier Zhou Enlai, pointed out: "…in mountain hills and plateau areas, closing off mountain areas to nurture forests, grassland-planting, and prohibition of steep slope cultivation should first be conducted in a planned way…". In May 1957, the *Interim Soil and Water Conservation Program of the People's Republic*, passed at the 24th plenary State Council meeting, directed: "Originally steep cultivated land above regulated slopes, with low population density, should be converted to forest and grassland gradually, on the basis of increasing yield per unit area on gently sloping land."

In March 1984, the *Instruction to Begin the Movement of Afforesting the Motherland Thoroughly and Solidly Put Forward by the Central Committee of the Communist Party* stated: "In areas suitable for forest, the marketing policy of government purchase and crop supply should be adjusted reasonably, contradictions between agriculture and forestry should be handled well, and the Grain-for-Green Policy should be promoted in a planned way, step by step."

In January 1985, *10 Policies on Further Activating the Rural Economy Put Forward by the Central Committee of the Communist Party* decreed: "To make full use of topographic advantages, sloping cultivated land above 25 degrees in mountain areas should be converted to forest and pasture in a planned way, step by step. The state sells food to those areas that produce insufficient food."

In June 1991, Article 14 of the *Soil and Water Conservation Law of the People's Republic* directed: "Reclamation of hillsides with a slope over 25 degrees for cultivation of crops shall be prohibited."

In August 1998, *the Notification Concerning Stopping Deforestation for Reclamation and Abusing Forestland to Protect Forest Resources by the State Council* pointed out: "Every region should convert all reclaimed farmland to forestland within a definite time on the basis of checks, according to the principle that everyone should be responsible for what has been approved by them and recovering what they have destroyed."

In August 1998, Article 39 of the revised *Land Administration Law of China* provided that: "It is forbidden to destroy forests and grassland in the process of land reclamation. Likewise, reclaiming parts of lakes for farmland and occupying sandbanks of rivers are also prohibited. According to the general plans for utilization of land, reclaimed land that has damaged the ecological environment should be converted to forestland step by step, in a planned way."

On October 14, 1998, the *Decision of Several Major Issues Concerning Agricultural and Rural Work by the Communist Party of China Central Committee*, passed in the third plenary session of the 15th Central Committee of the Communist Party of China indicated: "It is forbidden to destroy forestland, grassland or lakes to reclaim farmland. Overly reclaimed land should be converted to forestland, grassland or lakes step by step, in a planned way."

On October 20, 1998, *Suggestions about Post-disaster Reconstruction, Rivers and Lakes Regulation and Water Conservancy Building*, put forth by the Party Central Committee and State Council, stated: “Closing hillsides to actively facilitate afforestation, converting excessive reclaimed cropland to forestland step by step in a planned way, and speeding up vegetation recovery are major measures to improve the ecological environment and prevent and control river floods” (Li 2003).

The above regulations effectively promoted the Grain-for-Green Policy and improved the ecological environment. But ecological governance and economic development advanced erratically because of the influence and restriction of various factors. Systemic and planned practices of the Grain-for-Green Policy, which caused farmers to act consciously, began in 1999. On August 5, 1997, Chairman Jiang Zemin put forth the important instructions “to rebuild a beautiful landscape in the northwest.” Furthermore, in June, 1999, he pointed out that “Because of many wars, natural disasters, and all kinds of human factors over thousands of years, the western region’s natural environment has worsened into an unremittingly deteriorating situation, especially regarding shortages of water resources, serious water loss and soil erosion, an problematic ecological environment and desertification, which has pushed eastward continuously year after year. This adversely impacts the economy and social development not only in the western region, but in other areas. Improving the ecological environment is by no means a trivial problem, and must first be studied and solved for the western region's development and construction. The strategy to realize sustainable development in this region will fail without significant improvement of the ecological environment from now on.”

In the second half of 1999, Premier Zhu Rongji proposed comprehensive measures of ecological construction, including “converting cropland to forest and grassland, closing hillsides to facilitate afforestation, a grain relief system, and individual contracts,” after he inspected the five western provinces. Pilot demonstration projects of the Grain-for-Green Project were then immediately carried out in Sichuan, Shaanxi and Gansu provinces, which marked the beginning of that project (Li 2003).

10.2 Implementation Effects of Grain-for-Green Project

Grain-for-Green was launched as a pilot project for the first time in Sichuan, Shaanxi and Gansu provinces in 1999. Through 2000, it was gradually extended to 188 counties of Yunnan, Guizhou, Chongqing, and Hubei provinces in the upper reaches of the Yangtze River, plus the regions of Shanxi, Henan, Ningxia, Qinghai, Xinjiang in the upper and middle reaches of the Yellow River, and the administrative area of the Xinjiang Construction Corps. From 1999 to 2001, total area afforested was 1.162 million hectares, and afforestation in waste mountain areas and lands was 1.001 million hectares. During that period, the program involved 20 provinces or municipalities, 400 cities or counties (districts), 5,700 townships or towns, 27,000 villages, 4.1 million farmer households, and about 16 million farmers (Wu et al. 2009).

From 1999 to 2008, the state coordinated conversion of 26.87 million hectares of cropland to forestland and grassland, and 15.8 million hectares of waste hills and unreclaimed lands to forest area, and closed 1.8 million hectares of hillsides to facilitate afforestation (Wu et al. 2009). Overall, the Grain-for-Green Project achieved a high planted tree survival rate and good quality reforestation. This changed the previous status at certain locations of “no forest despite afforestation year after year, and no trees despite planting year after year.” To actively facilitate afforestation, all locations within the program of closing hillsides also increased construction of rural methane tanks, carried out ecological emigration, and sped up ecological construction. As a result, forest coverage area increased by 2 %, which led to a net decline of land desertification and a continuous reduction of soil and water loss and sand hazards. Further, ecological deterioration in some areas has been fully controlled. The food production decline caused by cropland decrease was addressed by increasing basic farmland and popularizing good crop strains and agricultural technologies. As a result, consciousness of ecological protection among the population distinctly improved. The method of animal husbandry changed, from open grazing to a ban on pasturing, with hillside closures and drylot feeding with captive breeding. Moreover, an advanced ecological attitude of “loving, protecting, and promoting green” was preliminarily formed. At the same time, the program was important in promoting agricultural structure adjustment, advancing agricultural-industrial operation, and broadening channels for increasing income to farmers. These contributed to sustainable economic and social development (Wu et al. 2009).

In 1999, Wuqi County took the lead in launching the Grain-for-Green Project over a large area (103,700 ha). It comprehensively implemented the policies of forbidding pasturing by closing hillsides, and began drylot feeding sheep in captive breeding programs. Wuqi County is a model for the Grain-for-Green Project in the country, so it is taken here as an example for analyzing the effect of implementation. Wuqi County is northwest of Yan’an City in Shaanxi Province, bounded by longitudes 107°38′–108°32′E and latitudes 36°33′–37°24′N. It stretches 93.4 km from north to south and 79.89 km from east to west, covering an area of 3,791 km^2. The county governs 12 villages and towns, 164 administrative areas and 1,110 villager groups. The population is 127,000, including an agricultural worker population of 109,000. The county physiognomy is a beam-shaped, hilly-gully area of the Loess Plateau, with altitude between 1,233 and 1,809 m. It is one of the areas with the highest soil and water loss on the plateau. Wuqi County has a semiarid, temperate continental monsoon climate. Annual average temperature is 7.8 °C. Average annual rainfall is 483.4 mm, and total surface water and groundwater resources are estimated at 117.521 million cubic meters and 43.918 million cubic meters, respectively (Li 2002).

After the Grain-for-Green Project, the social and economic makeup of Wuqi County changed dramatically, and agriculture and animal husbandry development made remarkable achievements. In addition, project implementation and a combination of ecological construction and economic development led directly to a successful merging of economic, social and ecological benefits. By the end of 2006, Wuqi County had converted 158,100 ha of cropland to forestland. It was the county with the earliest and largest area Grain-for-Green Project benefiting the general public, among the 150 counties (cities, districts) implementing the policy.

Therefore, it became the national flag-bearer of the project. Overall, the project advanced local ecological construction and economic development, and promoted benign interaction within the ecological economic system. Some challenges and positive changes during its implementation are discussed below.

10.2.1 Clear Improvement of the Ecological Environment

After nearly 10 years of the Grain-for-Green Project and ecological construction, forest (grass) coverage in the county increased from 19.2 % in 1997 to 62.9 % in 2006, and formerly barren hills turned green. An increase in vegetation limited soil and water loss. Runoff observations showed that annual soil erosion in Wuqi County declined from 15,300 tons/km^2 in 1998 to 5,900 tons/km^2 in 2004 (Yang et al. 2005). This indicates basic achievement of the goal "mud never descending the mountain and water never exiting the ditch." The increase of vegetation significantly improved local weather conditions. Jiang et al. (2009) gave the following changes relative to 10 years ago: Average annual rainfall in Wuqi County increased from 478.3 to 582 mm; annual average frost-free days increased from 151 to 161 days; average annual days with blowing dust decreased from 31.6 to 6.5; drought, hail and frost disasters dropped about 70 % (Jiang et al. 2009). In addition, the vegetation increase enriched biological diversity. Animals and birds such as wolves, foxes, weasels and owls, which disappeared for many years, have reappeared and increased.

10.2.2 Great Improvements in Comprehensive Agricultural Production Capacity

Wuqi County organically combined the Grain-for-Green Project with improving comprehensive agricultural production capacity, and vigorously carried out basic farmland construction. Since 2003, total investment capital to basic farmland construction in the county has been more than 6,000 CNY (one Chinese Yuan is about 0.16 U.S. dollars), and there are 15,200 ha of new basic farmland. County-wide basic farmland increased from 800 ha before the program to 21,200 ha currently. Wuqi realized the goal of 0.13 ha productive farmland for every farmer. Through promoting dry farming technology, increasing farmland investment and implementing intensive management, food crop yields increased from 870 kg per hectare in 1998 to the current 2,820 kg. Total output production rose or remained stable. Consequently, problems were effectively solved. Facts show that food security and supply ability in Wuqi County were not weakened by the huge area implementing the Grain-for-Green Project. Instead, with construction of high quality basic farmland and increased input to the planting industry, food output from present cropland is still increasing.

Table 10.1 Changes in land use of households before (1998) and after (2004 and 2006) Grain-for-Green Project (He et al. 2008)

	Cropland area per household (ha)					
Year	Slope land	Terrace land	Flat land	Cropland area per capita (ha)	Grassland area per household (ha)	Forestry area per household (ha)
1998	3.33	0.04	0.03	0.77	0.15	0.51
2004	0.44	0.06	0.27	0.17	0.16	2.53
2006	0.12	0.29	0.28	0.15	0.35	2.4

Note: 1,600 households were surveyed in 1998 and 2004, and 200 households in 2006. The same sample sizes apply to Tables 10.2 and 10.3

10.2.3 Significant Change to Agricultural Production Structure

According to He et al. (2008), Grain-for-Green implementation in Wuqi County has created significant production in land use, planted area and crop yield, input and structural change, animal husbandry, and rural employment. Each of these is discussed in the following sections.

10.2.3.1 Land Use Change

With advance of the Grain-for-Green Project, the amount of arable land for farmers sharply declined, and land use also changed.

Table 10.1 shows that through project implementation, cropland area per household in 2004 decreased by 86.86 % over 1998. Because of the project, forestry area increased substantially by 1,378.60 %, and grassland area slightly increased by 20.30 %. Cropland area per household declined from 2004 to 2006 by 9.76 %. Sloping land without irrigation is among the reduced areas. In contrast, terraced and flat land increased. Owing to the measures of building new farmland, terraced land increased 79.08 %, from 0.06 ha per household in 2004 to 0.29 ha per household in 2006. The gross area of grassland and forestland did not change substantially. There was a small increase in grassland area and minor reduction of forestland, which provided basic conditions for development of the animal husbandry industry.

10.2.3.2 Change in Planting Scale, Structure and Production of Crops

We see from Table 10.2 that before project implementation, the corn cultivation area accounted for less than 10 % of cropland area per household, potato planting area more than 20 %, grains 70.48 %, and wheat cultivation zero. This indicates that, compared with potatoes, planting wheat or corn on the Loess Plateau had no natural or economic advantage. After project implementation, the absolute area of minor

Table 10.2 Changes in planted area and crop yield, before (1998) and after (2004 and 2006) Grain-for-Green Project

		Corn		Potato		Minor cereals		Vegetables
Year	Farmland area per household	Planted area per household	Yield per ha	Planted area per household	Yield per ha	Planted area per household	Yield per ha	Planted area per household
1998	3.34	0.17	3,350.55	0.83	8,076.15	2.40	1,160.40	0
2004	0.76	0.09	4,421.55	0.33	9,974.25	0.34	1,390.20	0
2006	0.69	0.11	2,421.75	0.42	8,604.00	0.13	1,385.55	0.03

Note: Coarse cereals include buckwheat, corn millet, millet, adzuki bean, millet, beans, black beans and others. Crops in table were planted by every household

cereal planting decreased sharply. In Wuqi, it dropped from 2.4 ha one year before the project to 0.34 ha in 2004, and 0.13 ha in 2006. Accordingly, there was a significant decrease in the proportion of minor cereals to cropland per household. This decrease was from 70.48 % the year before the project to 44.97 % in 2004, and 19.23 % in 2006. Among planted crops, the share of potatoes had a rising rather than declining trend after project implementation. In Wuqi, it increased from 24.38 % in 1998 to 43.59 % in 2004, and 60.97 % in 2006. Northern Shaanxi is known for its high potato production. All cities and counties there produce potatoes, with maximum yield, strong disease resistance, bright and clean skin, brilliant color and luster, large size, thick meat, granular texture and rich nutrients. As a result, potatoes from that region have higher market prices. Rapid progress in agricultural science and technology has also contributed to the increase of potato production in the region.

The corn yield of farmers in Wuqi rose from 3,350.55 kg/ha in 1998 to 4,421.55 kg/ha in 2004, but dropped to 2,421.75 kg/ha in 2006 because of drought. Minor cereal yield climbed from 1,160.40 kg/ha 1998 to 1,390.20 kg/ha in 2004, and then decreased slightly to 1,385.55 kg/ha in 2006. An increase of yield per area, reduction of agricultural population, cheap and efficient food crop production, and development of the energy industry combined to change farming behavior and reduce land utilization in Wuqi. To improve agricultural benefits, the evolution of farming household planting structures was increasingly oriented toward "curtailing production of other food and increasing potato production." The proportion of potato cultivation in Wuqi increased from 24.38 % 1 year before the project to 43.59 % in 2004, and 60.97 % in 2006. Per-unit potato yield increased from 8,076.14 kg/ha 1 year before the project to 9,974.25 kg/ha in 2004, decreasing to 8,604.00 kg/ha in 2006 because of the drought. The latter figure is an increase of 527.85 kg/ha over the year prior to conversion, however. This implies that the structural change of cultivating potatoes can help reverse continued low agricultural yields.

As shown in Table 10.3, farmers planted corn before and after Grain-for-Green implementation in Wuqi. Yields were far below the national average (which was 5,267.85 kg/ha in 1998, 4,698.45 kg/ha in 2001, and 5,120.10 kg/ha in 2004). Nonetheless, because of planting habits and demands on feed grain, corn cultivation

Table 10.3 Changes in sheep breeding [head/household], before (1998) and after (2004 and 2006) Grain-for-Green Project

Year	Minimum breeding number	Maximum breeding number	Mean breeding number	Standard deviation of breeding number
1998	1	5,000	49.97	216.45
2004	1	11,550	27.79	450.08
2006	1	380	25.11	69.64

was never interrupted, and per-hectare yields of minor cereals after the project were higher than those before. It is clear that intensive crop planting in Wuqi was improving.

10.2.3.3 Scale Change in Animal Husbandry Breeding by Farmers

The data in Table 10.3 indicates that the number of sheep bred by large-scale households (maximum breeding number) after the project (in 2004) exceeded those before the policy. The main reason for this is that significant pastureland after the project played a role in economies of scope. However, both average level and breeding scale of large-scale breeding households in 2006 were lower than those of 2004. The reasons for these reductions are as follows: First, income channels of farmers increased with the exploitation of energy resources in Wuqi. Moreover, breeding costs increased because of the lack of pasture.

10.3 Problems Faced During Implementation of Grain-for-Green Project

Despite the positive changes observed with program introduction, there were some challenges during its implementation. These are discussed in the following sections.

10.3.1 Uneven Spatial Distribution of Converted Plots

Because of haste and improper planning toward the goal of balancing the conversion index allocation among farmers in various townships, villages and towns, there were uneven and unreasonable conversion phenomena. In our survey, we found that gently sloping croplands, flatlands and even terraced lands were converted in some places, whereas some steeply sloping croplands remained cultivated. In some villages, there was conversion of relatively high-yield flat farmland in easily-checked nearby places while cropping remained in some low-yield sloping land in far places.

Converted lands were too scattered in certain places, which led to a flower-like distribution of converted land and farmland. If this is not corrected, the consequences will affect optimization of the entire landscape pattern and ecological function. Moreover, it would hinder realization of the goal of reasonable allocation and efficient use of land resources. The survey also showed that, although the Ecological Migration project was implemented in some towns, some farmers living on distant mountains and in deep gullies were migrated to flatlands near highways. However, since their original croplands were not involved in the conversion plan, the long distance from their home made the cropland management difficult. Besides, the distribution of residence made the construction of basic farmland difficult.

10.3.2 Unreasonable Forest Structure of Converted Land

To ensure high survival rate and program passing rate early in policy implementation, some forest tree species were emphasized more than others. This resulted in the current situation of simplex tree species and unreasonable forest structure. Given the limitations of climate conditions and lack of effective technical guidance, economically important orchards of mainly apple and apricot trees have had slow growth, very low hang rates and unclear economic benefits. Consequently, adjustment of the forest structure is now a major task. Based on respect for the laws of ecology, this requires increasing species diversity, making the forest ecological system more rational and its function more efficient, and enhancing stability. If these are not achieved, the forest will degenerate after a few years, and the phenomenon of "no forest despite afforestation year after year" would recur, impairing the achievement of the Grain-for-Green Project. Without doubt, the forest structure reflects the development orientation of the forestry and fruit industries. The problem of forest types and tree species suitable for long-term construction and development of post-project ecological public welfare forests in Wuqi County have not been completely solved. Further, there has been no cultivation of major fruit industry products suitable to the local climate.

10.3.3 Insufficient Animal Breeding Industry Development and Low Forage Resource Utilization Rate

Because of widespread measures forbidding pasturing after hillside closure, the sheep breeding industry was curtailed after the conversion. Drylot feeding sheep under captive breeding was attempted to solve this problem in Wuqi. After an initially prosperous period, the practice seems to have gone dormant again. The sheep population has fluctuated in recent years, and the enthusiasm of farmers toward sheep breeding has declined for a number of reasons. First, the risks of drylot feeding sheep under captive breeding are high, because of unsolved problems of lack of feed variety and technology. Second, because of limited amount of land in household farming operations, single households lack sufficient pasture area to develop large-scale breeding and reduce costs. Further, since local oil industry development has greatly increased cost of hiring farm labor, profit to farmers has decreased. This in turn has resulted in waste of forage resources on converted land. Without effective use in the long term, grassland degradation is unavoidable and the agricultural structure will tend toward disorder in the absence of support from animal husbandry.

10.3.4 Lack of Flexibility in Grain-for-Green Project and Compensation Standard

Given limits of the rural economic and social background when the policy was established, fairness in policy implementation was considered more, and the main function of ecological compensation considered less. In addition, to ensure compensation funds reached farmers directly and associated capital loss was reduced, simple implementation measures were established. This required that policies be mandatory, and implementation methods and standards were unavoidably "one size fits all." Local governments, grassroots-level organizations and farmers were left with few choices in the processes of distributing the index and using compensation funds. Standards of money, food and seedling allowances had not been carefully checked with respect to the costs of forestry and ecological construction. As a result, the standards could not match farmers' compensation requests. Without improvement, two negative tendencies inevitably ensued: First, the Grain-for-Green Project allowances could not accomplish resource allocation as an "invisible hand." In other words, the rigid compensation standard facing millions of farmers appeared too high or low, and could not effectively link with the behavioral incentives and results of ecological construction. Secondly, the Grain-for-Green standards were not conducive to muster the enthusiasm of local governments and rural grassroots organizations for project management. They tended to passively implement state policies, or even take the opportunity to cheat.

10.4 Future Research Prospects

In the last decade, the ecological system has been restored or effectively rebuilt, and the economic system function continually strengthened, because of Grain-for-Green Project implementation. However, inconsistencies have remained within the ecological and economic systems. Therefore, we should strengthen research on a coupled agricultural, ecological, and economic system.

Coupling was primarily a physical concept, and was later referenced in biology, economics, and earth science. The theoretical significance of "system coupling" was that it brought extension properties (accumulation of free energy) from inherent openness of the ecological system into play. Coupling has led to liberation of evolution and production potential through coupling research on desert, oasis and grassland systems (Ren 1999). It was concluded that production could improve 6 to 60 fold after this type of system coupling. In China, coupling model studies have mainly focused on the Heihe River basin. For example, a coordinated development coupling model of water–ecology–economy in that basin was established, based on a coordinated development coupling relationship formed by interactions among ecological, economic and life systems (Fang 2002).

Research and the practice of system coupling are significant to setting up a sustainable and efficient agricultural, ecological and economic system. From the perspective of current study dynamics and needs for development of agriculture and ecological economy, the system coupling model will be one of the most important directions of future research. Quantification of coupled systems will be a difficult task, which must be addressed within this research (Lin and Hou 2004).

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Chapter 11
Poverty Alleviation Projects Through Integrated Ecological Management Supported by the World Bank: Case Study of the Yanhe River Basin

Puling Liu, Yi Zhang, and Yongqing Ma

Abstract The Chinese government launched poverty alleviation projects in the 1980s and 1990s, which were supported by loans from the World Bank. One of the projects was organized by the Ministry of Water Resources to control, in an integrated manner, soil and water in the provinces of Shaanxi, Gansu, Shanxi and Inner Mongolia. These provinces include nine tributaries of the Yellow River. One of these tributaries, the Yanhe River in the city of Yan'an, was chosen as a project area. Yan'an City applied for a loan of 28 million USD and provided matching funds of 161 million CNY, amounting to a total project investment of 392 million CNY as of the 1990s. After 8 years of project implementation from 1994 to 2001, living conditions for local residents have greatly improved. Economic, social and ecological benefits were evaluated at the end of project implementation. The World Bank summarized lessons learned from the project, which can be referenced by similar projects.

Keywords Lending policy • Loess Plateau Watershed Rehabilitation Project • Poverty alleviation • World Bank • Yanhe River Project

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11.1 Introduction

To effectively control soil erosion and improve both the ecosystem and livelihood of local farmers on the Loess Plateau, the central government of China launched poverty alleviation projects in the 1980s and 1990s, which were supported by loans from the World Bank. One of these projects was organized by the Ministry of Water Resources to control soil and water, in an integrated manner, in the provinces of Shaanxi, Gansu, Shanxi and Inner Mongolia, which include nine tributaries of the Yellow River (World Bank 2003). The Yanhe River is one of these tributaries, and flows through a serious erosion area of the Loess Plateau. According to social and ecological demands as well as the capacity of local government to provide matching funds and repay the loans, the Yanhe River Basin in Yan'an City (Prefecture) was chosen as one of the project areas, following a series of comprehensive investigations and analyses. The city government of Yan'an applied for a loan of 28 million USD and provided matching funds of 161 million CNY (one Chinese Yuan is about 0.12 USD as of 2002, when the project was evaluated). This amounted to total investment in the project of 392 million CNY, as of the 1990s. Similar to projects in other provinces, the Yanhe River Project was managed as a sub-project of the national project of Soil and Water Conservation of the Loess Plateau. In this chapter, we take the Yanhe River Project (Stage I) as an example of the implementation and achievements of this investment approach. The main content is based on the project report (Yan'an City World Bank Project Administration Office 2002).

11.2 Natural and Socioeconomic Conditions of the Project Area

11.2.1 *Natural Conditions*

The project area is in the middle reach of the Yellow River, in the northern part of Yan'an, Shaanxi Province, between 36°23′–37°18′N and 108°50′–110°21′E. Three counties (Ansai, Baota and Yanchang) were included in the project, embracing 30 towns with a total of 485 administrative villages. Total area is 3,034 km^2, accounting for 41.4 % of the Yanhe River drainage area at Yan'an.

The Yanhe River Basin is on the ancient landforms of Mesozoic bedrock and Cenozoic red soil layer, which is covered by thick aeolian loess. This area of the Loess Plateau belongs to the seriously eroded hill-gully region. Long-term annual precipitation and annual average temperature are about 520 mm and 9.4 °C, respectively. The annually accumulated temperature for ≥10 °C is 3,355 °C. Annual sunshine is 2,350–2,550 h, and the frostless season is 155–200 days. Annual runoff in the area is about 35 mm, producing a total basin runoff about 106 million m^3. The precipitation and runoff are not evenly distributed through the year, and concentrate in July and August (over 40 %). The highest sediment concentration reaches 1,560 kg m^{-3}. Over 95 % of

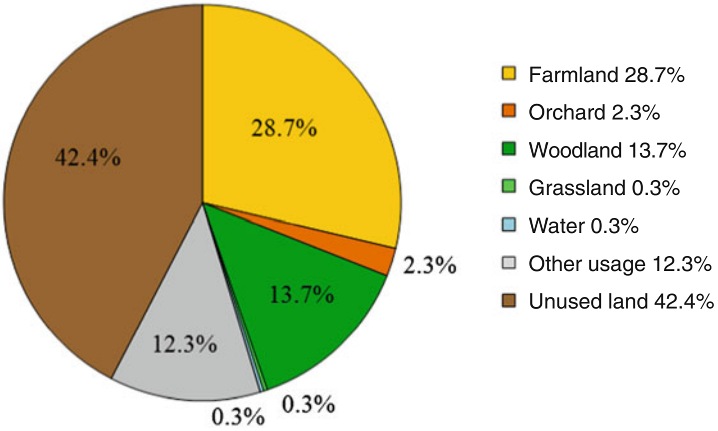

Fig. 11.1 Proportions of land use types in project area

annual sediment discharge is from June through September. The area is characterized by recurrent drought and windy weather in spring, hot weather with both dry and showery days in summer, cool and rainy weather with rapidly decreasing temperature and early frost in autumn, and cold and dry weather with little snow during long winters.

The Yanhe River Basin is one of the areas in the middle reaches of the Yellow River most seriously affected by soil erosion. Three counties of the project area are included on the list of counties in the basin with serious soil erosion problems. The total affected area by soil erosion is 2,900 km^2, which represents 10.08 % of the total area of the city. The average annual soil erosion modulus is 10,400 ton km^{-2}, and annual total sediment discharge is 30.16 million tons. Before implementation of the project, there were soil and water conservation measures in about 560 km^2, or 19.3 %, of the area under erosion. However, owing to a lack of project planning, investment mechanisms and management systems, the management measures were simple and not quality controlled. This resulted in low rates of conservation after several years.

11.2.2 Socioeconomic Situation

The project area has a population of 214,500 people, with an agricultural population of 193,400 and agricultural labor force of 58,900. Population density is about 71 km^{-2}, corresponding to an average land area per capita of 1.41 ha. However, average farmland per capita is only 0.45 ha.

The proportions of various land use types in the project area are shown in Fig. 11.1. Although there is 28.7 % agricultural land in the area, slope farmland comprises 77 % of the total farmland, and about 25 % of this land has slopes ≥25°.

Serious erosion has caused soil and water loss, and soil fertility and productivity are low. Grain yields are low and unstable. Total grain yield of the area is about 73.7 million kg, with average productivity less than 1,000 kg ha^{-1}. The total agricultural production value was 260.6 million CNY prior to project implementation.

11.3 Project Objectives

The overall aim of the project was poverty alleviation. One of its specific goals was to reduce sediment entering the Yellow River, through comprehensive watershed management in the area. In addition, the project aimed to improve agricultural production, and to increase grain yield and income for farmers. The planned implementation area of soil and water conservation measures reached 57.84 %. Through strengthening of management, overall soil and water loss could be controlled. The per capita share of grain increased from 381 to 543 kg. Farmers' average income per capita rose from 348 to 756 CNY (an increment of 120 %).

After several years of preparation and field investigation, the World Bank and Chinese Central Government Project Office established a Board of Executive Directors in 1994, officially approving implementation of the poverty alleviation projects. In 1997, based on the early implementation phase and investment situation, a mid-term adjustment was made to the plan. Planned objectives, after adjustment and achievements, are shown in Table 11.1.

11.4 Project Implementation and Achievements

After 8 years of implementation, a majority of the planned objectives were fully achieved (Table 11.1). Some components such as forest plantation area and number of orchards exceeded the targets, at 142 and 133 %, respectively. In addition, four

Table 11.1 Objectives and achievements of the 8-year project

Project contents	Planned	Fulfilled by 2001
Total area (ha)	111,723	111,856
Terrace (ha)	18,213	16,982
Amount of check dams	475	366
Check dam land (ha)	570	439
Amount of irrigation works	30	25
Irrigated field (ha)	360	305
Forest plantation (ha)	17,830	25,320
Shrub plantation (ha)	34,160	31,582
Orchard (ha)	8,390	11,124
Grass (ha)	32,200	26,104
Amount of key engineering facilities	58	38
Amount of fruit granaries	2	1

nurseries of 40 ha each were constructed for breeding and culturing of forest and horticulture seedlings. The project office of each administrative class (e.g., city and county) conducted various types and levels of training, according to project content and goals. The province project office organized 20 training sessions, including investigations carried out domestically and abroad, for 75 persons/times of high-level project managers and technicians. The city and county project offices organized 120 sessions of various training for 6,369 persons/times of local technicians and skilled farmers. Project offices took charge of these management initiatives and services. Monitoring stations were also established under the leadership of city and county project offices, for monitoring project progress and evaluating benefits to society, the economy, ecology, and with respect to soil and water conservation.

11.5 Benefit Analyses

11.5.1 Economic Benefits with Respect to Investment

Economic benefits were calculated according to Chinese national standards and project norm documentation. These include *Economic Evaluation Norms for Water Conservation Construction*, *Calculation Method of Comprehensive Management of Soil and Water Conservation Benefit*, *Feasibility Report of the Project*, and *Project Monitoring and Evaluation Technical Specification*. Based on these standards, typical samples within the project area were set up and monitored. A total of 60 typical households and 96 typical land plots were monitored to assess changes in production and standard of living.

Two prices were used, for input and output, depending on the study period. These are the average price of project implementation over an 8-year period, and predicted future price based on the current price. Economic benefits include direct and indirect benefits. Direct benefits comprise outputs from crops, trees and grasses on terraces, water, dam land, orchards, and others. Indirect benefits include those from sediment as estimated by quantitative analysis.

Here, investment implies actual investment, and includes that for construction of various soil and water conservation measures and for project support and management. The output is based on incomes of typical farmers and land plots.

The soil conservation benefit index per unit area is calculated from observed runoff data in the project area. The dam sediment retaining index is based on monitoring data of typical reservoir dam siltation and general survey data in the region. According to related standards of the Yellow River Administration Committee for sediment dredging costs and other costs of electricity and equipment, the benefit for retaining 1 ton of sediment is calculated at 1 CNY. Finally, the overall benefits were quantified in terms of internal rate of return and net present value.

The estimated indexes of economic evaluation are shown in Table 11.2. The overall project highlights two aspects of poverty alleviation and ecological environment.

Table 11.2 Results of economic benefit analysis

	Economic benefit		Financial benefit	
	Including sediment reduction		Excluding sediment reduction	
Component	Internal rate of return (%)	Net present value	Internal rate of return (%)	Net present value
Umbrella project	9	9,525.2	7	−77.9
Terrace	13	4,781.5	11	3,317.8
Dam land	57	1,225.4	12	320.5
Irrigated land	24	915.2	24	887
Trees	5	−449	2	−1,186
Shrub	3	−750.6	–	−1,460.3
Orchard	12	10,368.4	11	9,850.7
Grassland	3	−195.8	1	−296.9

The total internal economic and financial internal rates of return are 9 and 7 %, respectively; the required index rate was 7 %. Sediment reduction benefit accounted for 2 %. The project is believed to have attained its desired economic effects.

11.5.2 Socioeconomic Benefits

11.5.2.1 Economic Growth

With project implementation, the economy of the project area has continued to grow. GDP of the area increased from 349 million CNY in 1993 to 874 million CNY in 2001, with GDP per capita reaching 4,230 CNY. All types of agricultural production increased, including increments of grain production at 32,100 ton, fruit production at 107,800 ton, timber volume at 255,000 m^3, and firewood at 129,800 ton. The total socioeconomic value in the project area increased from 260.59 million CNY in 1993 to 536.97 million CNY in 2001.

The rural industry structure changed significantly, with production weights of farming, forestry, fruit production, animal husbandry, and sideline and fishing industries changing from 46.2, 6.2, 15.5, 28.3, 3.6 and 0.2 % in 1993 to 28.3, 3.3, 16.5, 16.9, 33.2 and 1.8 % in 2001, respectively.

In Ansai County, project implementation resulted in large increases of basic farmland area and greenhouse planting (Table 11.3). Solar greenhouse vegetable cultivation became the leading local industry. The project area covered only one-third of the county land area, whereas contributions to vegetable yield and value were considerable (around 60 %).

Fruit production increased rapidly in the project area. During the 8 years of implementation, 1,800 ha of high-quality pear orchards were planted in Yanchang County, approximating 15,000 ton or 20 million CNY. A farmer named Yan Xinping in the village of Heijiabao planted 1.2 ha of pear orchards in 1994. His family of four had a pear yield of 9.5 ton, with output value 35,100 CNY. Baota County is one

Table 11.3 Farmland and vegetable industry inside and outside project area of Ansai County in 2001

Classification	Total land area (km^2)	Basic farmland area (km^2)	Amount of greenhouses	Greenhouse vegetable yield (ton)	Vegetable output value (million CNY)
Project area	1,021	118.1	2,880	14,400	14.40
Non-project area	1,929	81.8	2,040	9,800	9.18

Table 11.4 Temporal changes of fruit industry production and value in project area of Baota County

Year	1998	1999	2000	2001
Area of fruit bearing (ha)	1,408	2,352	2,905	3,417
Yield (kg ha^{-1})	3,360	4,032	4,704	5,376
Unit output value (CNY ha^{-1})	5,040	6,048	7,056	8,064
Yield value (million CNY)	7.096	14.225	20.498	27.555

of the most suitable areas for apple production. During the 8 years, there were 5,062 ha of apple orchards planted in the county, which began to bear fruit in 1998. Since then, there has been considerable fruit production (Table 11.4).

The project has completely resolved problems of food and clothing demand in the area. In the initial stages of project implementation, there were 34,000 households at the poverty level, representing an impoverished population of 155,000. At the end of implementation, this population dropped to 4,800, and the Engel coefficient changed from 0.81 to 0.29. The per capita net income of farmers increased from 348 CNY in 1993 to 1,643 CNY in 2001, and the per capita share of grain increased from 381 to 512 kg.

11.5.2.2 Socioeconomic Improvements

Conditions for agricultural production were improved. First, basic farmland per capita increased by 0.08 ha. Second, the return of cultivated land on steep slopes reached 31,642 ha over the 8 years, with the proportion of sloping to total farmland declining from 77 to 32.8 %. Third, an environmental conservation system combining biological, tillage and engineering measures was gradually created, resulting in effective control of soil erosion and soil water loss. Finally, road construction was facilitated; tillage, production and transportation became more convenient, and labor demands on farmers were greatly relieved.

Land use structure was reasonably adjusted. The proportions of land use in farming, forestry, fruit production, animal husbandry and other fields (including unused land) changed over the project duration from 28.7, 13.7, 2.3, 0.3 and 55 % to 18.5, 32.4, 6, 8.9 and 34.2 %, respectively. The land use ratio increased from 57.6 % to the present 79.5 %; land productivity increased from 858.9 CNY ha^{-1} to 1,769.8 CNY ha^{-1}; labor productivity increased from 17.02 to 29.59 CNY per working day.

Road transport infrastructures were ameliorated. Within the project area, county roads above Level III (tertiary highways of width 8.5 m that allow traffic speed 40 km h^{-1}) increased by 138 km, simply-constructed roads increased by 360 km and connect all villages, and other simple roads by increased by 3,664 km across the countryside.

Various aspects of technology were introduced. The combined efforts at city and country levels, related colleges, universities and scientific research departments resulted in more than 50 advanced and applicable science and technology initiatives in the project area. These included agricultural farming, fruit growing, grass planting, poultry farming, solar greenhouses, and water resource development. Nearly 10,000 peasant technicians were recruited. Most farmers were able to accept new knowledge, information and technologies.

11.5.2.3 Improvement of Farmers' General Living Standard

The living conditions of farmers, as expressed by the numbers of telephones, televisions, satellite TV receivers, motorcycles and new houses, were greatly improved. Hospitals at or above the county level increased from 8 to 9; township level hospitals increased from 30 to 34. Every village in the project area constructed a health center. Rural doctors per 1,000 people increased from 2 to 2.6, and medical facilities in health centers at all levels were greatly enhanced. In addition, problems of drinking water supply for humans and livestock were resolved.

The enrollment rate of rural school-age children in the project area reached 98.6 %. Various technology training classes were organized in the project area; more than 70 % of households participated in this training. Employment also improved. Aside from agricultural labor, some were employed in the processing, transportation, and services industries, and other non-agricultural industries. Many women were involved in project works.

11.5.3 Ecological Benefits

It was estimated that the project area reduced eroded sand by 9.13 million ton annually, and trapping efficiency reached 43.69 %. Annual water storage reached 21.4 million m^3, and accumulated water capacity attained 31.84 %. Compared with the early stages of the project, those two measures increased by 30.28 and 20.16 %, respectively.

Soil properties and fertility improved in terraced fields. According to fertility level analyses, organic matter, nitrogen, phosphorus and potassium contents all increased to some degree. Soil bulk density declined by 11.8 %, and porosity increased by 10.2 % on the terraces, relative to that of sloping farmland.

Vegetation coverage largely recovered, increasing from 16.3 % in 1933 to 47.3 % in 2001. Species diversity substantially increased. Ecosystems have developed in a positive manner, and extensive floods have not occurred along the Yanhe River since 1996.

11.6 Evaluation of Project Implementation

11.6.1 Achievement of Benefit Indexes and Their Influences

As shown in the analyses of Tables 11.1 and 11.2, the project attained expected goals on the whole. While the total internal economic and financial rates of return exceeded the general required index rate of 7 %, achievement was slightly lower for several items. Some external and internal factors may be responsible for this result.

The external factors include dry climate, mouse problems in the fields, and price increases. During the 8-year project duration, there were 5 years of severe drought, with annual rainfall less than 380 mm and continuous dry days up to 6 months. Agricultural production was therefore affected. The Chinese zokor rat caused serious economic damage to the roots of orchard trees in the region. Oil prices, mechanical costs and wages for labor all increased by 30 % during the period. Some engineering facilities were unable to be completed as a result.

The internal factors include acceptance by farmers and administration policies. For example, farmers were unwilling to accept plants with low economic returns, in spite of great ecological benefits. A major policy problem in some towns and villages was a lack of long-term land contracts. This curbed farmers' enthusiasm for contributing to stable management.

11.6.2 Assessment of Sustainable Development

11.6.2.1 Sustainability of Economic Development

Project implementation greatly improved basic conditions of agricultural production. High and stable yields per capita satisfied basic demands for food. Cash forests and fruit orchards continued to increase, and rural roads extended in all directions. The project changed long-lasting traditional farming practices of extensive cultivation, yielding meager harvests. Large ridges and furrows, horizontal ditches, plastic film mulching and other advanced farming techniques have been widely applied across the project area. Outdated and inefficient crop species have been gradually replaced by higher quality species. Project construction provided local farmers with a high standard basic farmland of 0.08 ha per capita. Per capita grain production stabilized at more than 500 kg, and the rural per capita net income exceeded 1,600 CNY.

11.6.2.2 Sustainability of Social Development

The continuous growth of the rural and agricultural economy has contributed to cultural education and enhanced medical and healthcare facilities. Communication media like radio and television covered the entire project area. Nine years of compulsory education became common, giving educational access to all school-age children in the countryside. Rural medical stations have been constructed in each county, which solved problems of epidemic prevention and control for local farmers and greatly improved their health conditions. Advanced applied agricultural science and technology became widespread in the project area. Land use and output efficiencies grew significantly. Various types of technical training for farmers were conducted. The quality of life of local people continued to improve, and their ability to accept new technology steadily increased. These factors enabled them to learn, grasp and explore technological knowledge that can be adapted to modern rural and agricultural economic development.

Large-scale intensive operation was gradually established, and large labor forces were transferred from pure grain production to forestry, animal husbandry, and non-agricultural industries. Women, who represent half of the population, played a tremendous role in project construction. They comprise the main labor force in the fields of livestock and poultry breeding, greenhouse planting, nursery stock breeding, and others.

11.6.2.3 Sustainability of Ecological Environment

With respect to comprehensive management of soil and water conservation in the Yanhe River watershed, engineering, biological and agronomic measures went hand in hand. As a result, the soil erosion has been effectively controlled. The ecological environment has been greatly altered; droughts, floods, sandstorms and other natural disasters have decreased, and the ecological system has gradually entered a favorable cycle.

The vegetation coverage rate greatly improved, a joint configuration mode combining arbors, shrubs and grasses was formed, plant communities with dual ecological and economic functions were restored, and the regional climate pattern changed clearly in time and space.

11.7 Social Effects of Project Achievements

The 8 years of the Yanhe River World Bank Project injected new thinking and advanced management experiences into the project area. This induced government leaders at all levels, officials, and individuals to have greater understanding of the importance and necessity of ecological environment construction. It also accumulated rich experiences in comprehensive control of soil and water conservation in the Loess Plateau region.

The World Bank loans for managing and developing the plateau were not only a strategic means for local government to open up to the outside world and speed development, but these were also beneficial attempts to integrate international and domestic economic management systems and reform the investment system.

The successful implementation of the Yanhe River project achieved high praise the World Bank, and was credited as one of three outstanding World Bank projects on the plateau. The project has served as a guide for construction of the ecological environment in China. It also greatly enlarged the country's investment scale for management and development of the Loess Plateau region, which has created a good precondition for executing the strategy of development in western China.

11.8 Lessons Learned from Project Implementation

The World Bank summarized the following project lessons, which may be referenced by similar projects (World Bank 2003):

1. Watershed management projects require well-designed technical packages that generate income for local communities. The comprehensive technical packages supported by these projects included afforestation, halting cropping on steep slopes, establishment of large-scale terracing and sediment control structures, and reduction of overgrazing. These technically sound project interventions combined sustainable soil and water conservation practices with gains in agricultural production and farm incomes, and were the foundation and prerequisite for project success.
2. Strong ownership at different levels makes a project truly participatory. Project interventions were adapted to the requirements of each watershed. Local communities were in charge of developing their own plans. Equally important was support from different levels of government, who saw clear benefits in downstream flood control, reduced soil and water erosion and reduced sandstorms. As a result, high-quality technical and management staff were assigned to the project, and issues such as counterpart funding were speedily resolved.
3. Effective project management with rigorous monitoring and evaluation contributes to successful project implementation.
4. Successful pilot activities can be scaled up with good project planning and management.
5. Consistency in the composition of a competent core task team greatly enhances Bank–client cooperation.
6. The "public good" nature of the project should be fully recognized, with the financial obligations accepted by the various stakeholders. Much of the environmental impact from increased vegetation cover and reduced sediment and sandstorms created benefits outside the project area. The costs of major project inventions, which generate such benefits, should be jointly borne by project farmers, and by local and central governments. If this government responsibility had been fully accepted, the project achievements in sediment dam construction could have been higher.

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Chapter 12
Policies and Measures of Chinese Local Government on Grain-for-Green Policy and Desertification Control

Yin-Li Liang, An-Rong Luo, and Lan Mu

Abstract To reduce soil erosion and ecological degradation and improve land quality, in 1998 China initiated the state-funded project “Grain-for-Green” in the north, northwest and southwest of the country. This project of converting steep cultivated land to forestland and grassland is one of the most important initiatives for developing western inland regions. To make the project more effective, local governments have established certain policies and measures. These include improvement of existing policies and measures in different regions, establishment of assessment and incentive systems, registration and certification for land use, and development of guidelines for assistance funds and maintenance of past achievements. It was found that the project based on these measures had positive ecological effects (amount of land converted and afforested, ecosystem productivity, water and soil conservation, and pollution reduction) and socioeconomic effects (alleviation of poverty, aid to farmers in changing their income structure by shifting from farming to other activities). These are helpful to both farmers and local governments.

Keywords Grain-for-Green • Local government • Policy

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12.1 Introduction

To reduce soil erosion, desertification and sandstorms to a minimum, the return of farmland to forestland and desertification control projects have been initiated since 1998 by the Chinese government. These efforts have been in the north, northwest and southwest parts of the country, where problems were severe. To execute the projects, local governments have established certain policies and measures, including: (1) improving policies and measures in regional contexts; (2) establishment of assessment and incentive systems; (3) registration and issuance of certificates for using land and wood in forests; (4) guidelines on use and management of assistance funds; (5) maintenance of past achievements. This chapter addresses best experiences of the various policies and measures implemented under the "Grain-for-Green" project framework by local governments, particularly in the Loess Plateau region of China.

12.2 Improving Policies and Measures in Regional Contexts

Policies and measures established by the Chinese government are based on the same problems in all regions. However, certain problems are present in only one or several regions. Consequently, local governments have approached them based on their particular situations. We take Jilin and Inner Mongolia Provinces as two examples.

The Jilin Province is one of six forested areas, with a total forest area 9,722,600 ha, accounting for 51.37 % of total land area of the province. Nonetheless, it is one of the main regions that have targeted desertification control (Government of Jilin Province 2008). There are 730,000 ha of desertified cropland and 666,000 ha of desertified, salinized and degenerated grassland, which seriously impact economic and social development and human life in this province.

Therefore, because of the local impact of desertification, the Jilin Government took measures to reduce it, as follows:

(a) Investigation of the desertified area and principal land types. Desertified land is distributed across 15 counties, cities and districts—the counties of Tongyu, Zhenlai, Qianguo, Changling, Qian'an, Fuyu, Lishu and Nong'an; the cities of Shuangliao, Taonan, Da'an, Gongzhuling and Huichun; and the districts of Taobei and Ningjiang. Management focuses on: the desertified land; sandy land in drought; sandy cropland; desertified, salinized and degenerated grassland; bare hills and shoal; dry ponds; low quality, low-yield and protective function forest; and others.

(b) Ensuring the plan is effective and efficient. The desertification control plan for counties is examined and approved by the municipal (state) Ministry of Forestry department, with the involvement of other departments such as animal husbandry, water conservation, land resources, environmental protection, development and reform. The plan for cities (states) is examined and approved by the provincial Ministry of Forestry.

(c) Strengthening vegetation protection in sandy areas. The government formulates laws and rules, and provides funds to protect the vegetation in these regions.
(d) Forbidding grazing on sandy areas of hills and grassland. The government helps farmers build huts, and introduce and improve livestock varieties.
(e) Strengthening construction and management of conservation areas. In the latter zones, cutting down trees is forbidden. However, aged and weak trees must be cut, after approval by the provincial forestry administration department.
(f) Accelerating construction of nature reserves. In these reserves, overgrazing, and excessive digging are not allowed, and farming is restricted. Farmland and pasture must be converted to forestland and grassland as soon as possible.
(g) Strengthening management of water resources in sandy areas. This fortifies paddy management and averts abandoning of paddies, to prevent salinization. Water-saving irrigation technologies must be used to improve water use efficiency. Water resource assessment and water use rights systems are implemented. High water-consuming companies are forbidden in sandy areas.

Inner Mongolia is one of the provinces most severely affected by desertification, which involves 60 % of total land in the province. Since 1949, the environment has been improved in some small regions; however, overall deterioration has not decreased much. Various natural disasters (especially drought) have been frequent, and socioeconomic development has been slow. Therefore, the government of Inner Mongolia began converting farmland to forest area, thus affecting the environment. As a result, the environment has shown signs of regeneration (Government of Inner Mongolia Autonomous Region 2005)

Environmental measures implemented by the government include:

(a) Implementation of the Grain-for-Green policy, combined with farmland planning. To make up for farmland decrease stemming from that policy, the government builds water-saving irrigation facilities to increase irrigated land and crop yield. The government also helps farmers gain access to farm technologies that can increase yield and quality. As a result, the income of farmers improves.
(b) Implementation of the Grain-for-Green policy, combined with energy development in rural areas. Farmers in biogas-available regions use biogas instead of other energy sources. The province also has high potential for solar and wind energy, so these can be used for power generation. In addition, a type of cook stove that can save wood has been distributed, thereby enabling an increase of forest that would otherwise be harvested for firewood.
(c) Implementation of the Grain-for-Green policy, combined with migration and poverty alleviation strategies. Poor farmers without adequate food supply in intervention areas move to better villages, so as to attain a better quality of life; at the same time, this makes land available for rehabilitation. Moreover, the government helps farmers who no longer need to work in the field to acquire skills that enable them to work in cities or run their own businesses.

(d) Returning farmland to forestland, combined with subsequent industrial development. The government supports large and powerful enterprises to participate in subsequent construction of industry. The government supports and encourages industrial and commercial enterprises to develop animal husbandry, Chinese herbal medicine, special agriculture and ecological tourism. Furthermore, the government supports bank loans to big enterprises and encourages technological innovation in these enterprises.

(e) Combination of converting farmland to forestland and captive livestock feeding. Local people share their knowledge of captive breeding and spread this experience to other areas, resulting in cessation of grazing. People build livestock housing, and plant grasses to provide food for the livestock. This transforms livestock management from extensive to intensive management, and increases farmers' income.

12.3 Establishment of Assessment and Incentive Systems for Desertification Control

12.3.1 Jilin Province

The western part of the Jilin Province has been affected by environmental, resource, social and economic problems. Hence, the local government established the following assessment and incentive systems to foster enthusiasm for desertification control policies among its residents (Government of Jilin Province 2008):

(a) Establishment of financial, tax and credit systems. Personal taxes are reduced or exempted if people invest in desertification control. For desertification control projects meeting bank loan requirements, the bank should provide more support and services. The bank furnishes small loans to farmers who need funding to develop businesses that are beneficial to desertification control.

(b) Encouraging the populace to participate in desertification control. The government encourages and supports people to control desertification as much as possible. The government collects funds from individuals and enterprises in China, or in other countries. Industrial development and ecological construction complement each other. Anyone who controls desertification on state-owned land can use that land for 70 years. Such controlled-desertification land contracts and management rights may be inherited or bequeathed. The government provides techniques and equipment service to people who plant trees on severe saline-alkali land, mobile and semi-mobile dunes, and other areas that are difficult to use.

12.3.2 Qinghai Province

Like Jilin, Qinghai is one of the provinces with extensive desert land. Total desert land comprises 20,454,000 ha, accounting for 28.4 % of total land in the province.

Therefore, the government developed measures to ensure implementation of the Grain-for-Green project (Government of Qinghai Province 2009a, b).

(a) The local government is responsible for using and managing special funds, and manages these funds strictly according to the laws and rules.
(b) Finance and related departments collaborate to supervise and inspect the management of special funds, identify problems and solve them in a timely fashion. Any person causing loss, interception or misappropriation of special funds are penalized in accord with the "Financial penalties ordinance for sanctions violations" (State Council Decree No. 427) and other laws and regulations.
(c) Departments carry out the project according to the plan. If project location, content, construction scale and construction standards need to be modified, changes must be authorized by the original approving department.
(d) Relevant provincial departments make checking rules, and manage, inspect, review and assess special funds and projects according to these rules. For certain non-compliance and unauthorized changes, the funds, project approval and implementation are suspended. Persons who are responsible will receive administrative sanctions.

12.3.3 Yan'an City in Shaanxi Province

In 1999, the Grain-for-Green Project began in the city of Yan'an in Shaanxi Province. It has been implemented in three provinces of western China. The environment in these areas has improved substantially, which is beneficial to economic and socially sustainable development and mitigation of ecological crises. Income and the capacity for food self-sufficiency of farmers have increased, and the poor population has declined markedly. Economic and social development has accelerated in Grain-for-Green project areas.

The main task now and in the future is to compile results from the course of desertification control, so they can be made available for users in China and elsewhere. Therefore, in Yan'an City, the government amassed comprehensive daily evaluation results (Government of Yan'an City 2008). The comprehensive examination process was carried out as follows. First sample counties were selected. These were randomly selected to confirm 3–20 % of total return (farmland to forestland) area. The second step was information material collection in the following areas, for which the county provided annual field survey and internal results: Information on the use of special funds and returned land, forbidden grazing on hills and grassland, captive livestock feeding, property rights, protection and management responsibility, policy implementation, fund distribution, township organization, file management, and disposition of petition cases. The third step was to investigate aspects related to the following tasks. Internal responsibilities were mainly to investigate the system setup, documents, accounts, tables, cards, books and other raw materials; other tasks were to conduct field survey checks or measure parameters according to the plan and map. All field survey results required an authorized signature. If results were in question, they were reviewed by the appropriate governmental authority. Results were managed by a team leader and stored daily after investigation. The fourth step was providing aggregate scores. The investigating group provided a closed aggregate score. The group calculated verification and passing rates, tree survival rates, summarized household surveys and other items, calculated county scores, and ranked these according to the scores. The final step was evaluation and supervision. The return of farmland to forestland project was supervised throughout its duration. A supervision group randomly checked assessment results and determined if anyone had violated any rules. Anyone observing irregularities in implementation could inform the supervision group or local government.

12.4 Registration and Issuance of Certificate for Forest Land and Wood Use—The Case of Henan Province

We cite the example of Henan Province, which designed and implemented registration and certificate issuance schemes for the use of forest land and wood (Government of Henan Province 2003).

First, people who received a certificate improved their understanding of the Grain-for-Green project and clarity of ownership, protecting personal legal rights.

Second, important points of the project were highlighted. People who converted farmland to forestland can obtain certificates if the farmland (including land interplanted by forest and grass, economic forestland, and reforested wasteland) met the requirement of forest rights.

Third, officials who issued certificates based on the policy, and who were responsible for checking procedural details, had to adhere to the following principles: (a) open to the public, just and fair; (b) timely issuance of certificates—people obtain the certificate soon after the farmland conversion; (c) only one certificate is issued for each piece of land. The cropland certificate is replaced by the new forest certificate once the conversion is made to forestland. Old forestland certificates are replaced with a new certificate. Some pieces of land without certificates are first registered, then a certificate for the land is issued later. If the forest right has changed, the certificate is issued according to the new right. If the forest right is disputed, the dispute is first resolved, then the certificate is issued. It is illegal for anyone who issues certificates to infringe upon lawful rights, or to appropriate state forest for their own use.

Fourth, farmers are charged according to the laws and regulations, and certificate cost is only five Chinese Yuan. Any other fee charged to farmers is illegal.

Fifth, responsibility is clarified. Forest rights certificate issuance is the responsibility of county government or higher bodies. The government issues the certificate according to the project aim, duties, funds, as well as food and responsibility requirements in each county.

The forestry department of the province makes rules for issuing and exchanging the certificate and supervises the issuance process. Forestry, planning, finance, agriculture, land resources, taxation, and food departments should cooperate in certificate issuance. The provincial forestry department does an acceptance check after the certificate is issued. If they find illegal cases, those responsible are penalized according to regulations.

12.5 Guidelines on Use and Management of Assistance Funds—The Cases of Henan and Qinghai Provinces

Assistance funds represent an important part of the Grain-for-Green Project. Therefore, some local governments make rules and regulations on usage of these subsidies. Henan and Qinghai Provinces are taken as examples (Government of Henan Province 2004; Government of Qinghai Province 2007).

12.5.1 Henan Province

(a) The government subsidizes farmers 140 Chinese Yuan per 667 m^2 in the Yellow River and Huaihe River basins, and 210 Chinese Yuan per 667 m^2 in the Yangtze River and Huaihe River areas. (b) The subsidy range is approved based on farmland size. (c) Fund allocation from province to city and from city to county is calculated according to the provincial Grain-for-Green plan and subsidy standard. (d) Information about subsidies to farmers, areas of their returned land, and the subsidy standard are open to the public. The public notification period is not less than 7 days. (e) Subsidy funds are deposited in a special bank account for the farmer.

12.5.2 Qinghai Province

(a) Special funds are used in the following order: (1) farmers developing basic cropland; (2) farmers developing methane, biomass energy stoves, and solar ovens; (3) development of characteristic local industries; (4) residence in Alpine minority areas.
(b) Special funds accounts cannot be used for other purposes. Counties (cities, districts), the financial sector, and agriculture, forestry, and water conservancy departments establish a file for using and managing special funds.
(c) Some special funds are to be used for maintenance and reforesting achievements, and for solving long-term livelihood problems of farmers.
(d) Some equipment, materials, and germ chit are required for bidding, in order to achieve fairness, openness and equity. Some of these are purchased by the government and allocated to farmers. Subsidies for farmers are deposited to a card, and the government manages them via the card system.

(e) Subsidy allocation is related to the benefit for the land. Farmers can obtain the subsidy when they pass an acceptance standard. If the land is not adequate, the farmer must do more work (planting of more trees, for example) to meet the requirement.
(f) County finance departments check final accounts in detail. Special fund management results are submitted to the provincial finance department before 31 March every year.

12.6 Maintenance of Past Achievements

About 66 million ha of farmland was converted to forestland in Henan Province from 2000 to 2004. Within this amount, there was conversion to 0.22 million ha forestland from farmland, and 44 million ha to forestland from barren hills (Government of Henan Province 2005). This was accomplished by maintaining past reforesting achievements, such as by the following procedure.

First, the local government frequently reviews the forest, forest right certificates, young forest management and protection, technology service and policy implementation after the land return. This is very important, because Grain-for-Green is a long-term project and achievements must be maintained. This entails the following activities: (a) Timely replanting of trees to ensure enough plants, in accord with the national requirement. (b) Timely issuance of forest rights certificates. Local county government works with national resource and forestry departments, to ensure efficient registration and certificate issuance. (c) Strengthening of forest management. Responsible officials protect the forest from people and animals, look after young forest stands and interplant suitable plants, and provide protection from forest fires, insect and rat damage. (d) Providing technical service. The forestry department furnishes technical service to a commercial forest that is converted from farmland, to make it productive as soon as possible.

Second, all local governments cooperate with various departments, combining Grain-for-Green with other projects (Guo 2010). This includes: (a) Combining with irrigation projects. Government should ensure adequate cropland for farmers and improve low-yield land. It is not permitted to ask farmers to convert all their farmland. (b) Combining with rural energy construction. According to different situations in various areas, development of methane, firewood-saving kitchens, and firewood-producing forest are encouraged. (c) Combining with ecological migration. National and local governments help farmers move to better locations for a better life quality, thereby protecting the environment. (d) Combining industry development with developing the rural economy. Governments try to find solutions to increase funding for future industries. (e) Combining with development of animal husbandry. Governments forbid grazing on hills and support captive breeding instead.

Jilin Province maintains its Grain-for-Green project achievements through sand conversation and control in the following ways (Government of Jilin Province 2008): (a) Sandy estrepement farmland is planted with trees by the contracted management. Anyone can manage the land, but owners of farmland are given priority.

(b) Governments manage desertified, degenerated and salinized grassland. They must plant and replant grass, mix grasses with shrubs, and continue the prohibition of grazing on hills. Governments should strictly penalize those who conduct illegal grazing or destroy grass. (c) The government combines the Grain-for-Green project in desertification areas with wind resistance and sand prevention belts at the border of Inner Mongolia and Liaoning Province. (d) Improving protection of the forest system. Forest density is increased in serious sandstorm areas, and dead and overly mature trees are replaced to improve wind protection.

The government of Qinghai Province came up with a feasible plan for the period 2008–2015 to maintain achievements according to Grain-for-Green project management, for the short-term and long-term benefit of farmers. Key points of the plan include basic food cropland, rural energy, ecological migration, replanting and subsequent industry for farmers who convert farmland to forestland (Government of Qinghai Province 2009a, b). The local county government develops its plans, and submits them to provincial departments. Those departments have the following duties and responsibilities.

1. Provincial water conservation departments make and check provincial plans for basic food cropland.
2. Provincial agriculture and animal husbandry departments make and check provincial plans for rural energy.
3. Provincial forestry bureaus make and check plans for ecological migration.
4. Provincial forestry bureaus make and check plans for replanting.
5. Provincial forestry bureaus make and check plans for subsequent industry for farmers who convert farmland.

The Government of Shaanxi Province summarized the experience of maintaining its achievements in the Grain-for-Green project (Government of Shaanxi Province 2005).

First, the government distributes basic food cropland to farmers (667 m^2 per person in southern Shaanxi Province, 1,000 m^2 in the central province, and 1,300–2,000 m^2 in the northern province), constructs irrigation facilities, and provides supplementary food and grants as soon as possible.

Second, rural energy is developed, with methane as the key focus, and others as complementary. This includes building of kitchens that save firewood energy-saving firewood kitchens, developing firewood-producing forests, as well as small-scale hydro, wind and solar power.

Third, ecology migration is promoted in the Qinba Mountain, Baiyu Mountain and Tushishan areas. Cropland is thereby converted to forestland.

Fourth, subsequent industry development is accelerated. This includes development of the fruit industry, animal husbandry and characteristic agriculture, bamboo industry, Chinese medicine industry, breeding industry, ecotourism, labor movements and others. These increase the income of farmers in various ways.

Fifth, prohibition of grazing on hills is continued and captive breeding is promoted. This includes production of lamb in northern Shaanxi Province, milk and beef in the central province, and pork in the south. Further, support the animal husbandry community, breeding enterprises, and epidemic disease prevention and control.

The Grain-for-Green and grassland restoration projects in the Ningxia Autonomous Region began in 2000 and 2003, respectively (Government of Ningxia Hui Autonomous Region 2007). By the end of 2006, forest area was 759,000 ha. Of that area, 314,000 ha came from cropland conversion, 412,000 ha from afforestation of barren hills, and 33,000 ha was developed from damaged forest. This project cost more than 33 billion Chinese Yuan.

About 1,306,000 ha of grassland was rehabilitated after grazing was prohibited, while about 210,000 ha of grassland was improved by reseeding the original grassland. This project cost more than 4.8 billion Chinese Yuan.

In 2006, the Third National Monitoring of Desertification results showed that controlled desertification land comprised 46.7 million ha in Ningxia Autonomous Region, and desertification land declined by 25.84 million ha relative to the year 1999. The greatest desertification control was achieved in this province. Forest cover grew from 8.4 % in 2000 to 9.84 % in 2006. Commitment of the populace to environmental protection became much stronger. As a result, millions of people benefitted from the Grain-for-Green and grassland restoration projects. Therefore, all departments should maintain these achievements and promote regional economic integration to develop rapidly, based on the following guidelines. (a) Manage and protect forest and grasslands carefully. (b) Improve the contract responsibility system to ensure sustainable use of grasslands. (c) Use forage from the grassland restoration project and accelerate development of livestock husbandry. (d) Improve the examination and approval system, and strictly prohibit illegal invasion, occupation, and destruction of grasslands. (e) Commit to enabling farmers to survive in the long term.

To improve farmers' quality of life in the long term, first give sufficient cropland to farmers left with less than 1,300–2,000 m^2 of cropland per person. Second, it is important to provide funds and food according to the minimum living standard security system.

The Tibet Autonomous Region government took measures to maintain achievements in the Grain-for-Green project (Government of Tibet Autonomous Region 2008). The measures include the following:

(a) Increasing subsidies to farmers with cropland less than 333 m^2 per person to 600 Chinese Yuan per 667 m^2. (b) Encouraging farmers to interplant vegetables and short plant-height crops in the forest, as long as interplanting does not lead to soil erosion. (c) Planting trees on bare hills and closing off some hills, according to the plans. Local governments supervise and examine the work. (d) Carrying out disease, pest mouse and rabbit prevention and control. (e) Managing and culturing young forest stands, including loosening of earth, weeding, trimming, watering, and fertilizing young forest in a timely manner.

12.7 Conclusions

Despite the relatively short period since the beginning of the Grain-for-Green project, government policy and measures have already demonstrated substantial ecological and socioeconomic impacts. In light of our analysis, we draw the following conclusions:

1. Improving policies and measures within a regional context. This measure benefited Jilin and Inner Mongolia Provinces, which led their governments to make their own policies with consideration for their unique conditions, greatly enhancing economic and social development and human lives. With their continuance, impacts of these policies will increase in the future, as ecosystems recover.
2. Establishment of assessment and incentive systems for desertification control. The main purpose of these systems is to increase the enthusiasm of the local population for desertification control programs. In Qinghai, Jilin and Shaanxi Provinces, these measures increased income and the capacity of food self-sufficiency for farmers; the proportion of low-income people declined markedly, and economic and social development accelerated. However, the project created financial burdens for many local governments. This is because no taxes have been collected on the converted cropland since program inception, and the agricultural tax on cultivated land is now exempted. However, this short-term negative effect and structural changes in forestry and agriculture may ultimately benefit both farmers and governments.
3. Registration and issuance of certificates for use of forest land and wood, and guidelines on use and management of assistance funds. About 66 million ha of farmland were converted to forestland in Henan Province from 2000 to 2004. The province thereby benefited from these measures, and proper certificate issuances greatly increased enthusiasm and a sense of duty in the residents and producers. Therefore, this is an indispensable measure in the Grain-for-Green project.
4. Maintenance of past achievements. Experience suggests that the key to successful policies will be development of appropriate measures in the early stages of policy planning and implementation. Therefore, the most important project stage is maintenance of project achievements, because this not only retains accomplishments but also produces further gains.

Thus far, the policies and measures of Chinese local governments in the Grain-for-Green project have been implemented well. Soil erosion and desertified areas have shown yearly declines, and the environment and agricultural production have improved significantly. Agricultural restructuring and subsequent industries such as forage, potato, and fruit production, as well as the service economy are growing gradually. The Grain-for-Green program provides important insights into opportunities and challenges during development and implementation in north, northwest and southwest China.

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Part IV
Development of Technology to Combat Desertification

Chapter 13
Monitoring Regional Desertification

Reiji Kimura

Abstract The monitoring of desertification requires important biological and physical methods. In this chapter, diagnostic methods for regional desertification of the Loess Plateau will be introduced using water balance and water-use efficiency obtained by actual field observation and remote sensing techniques. A wetness index using a numerical simulation soil model (see Chap. 2) and meteorological data from 43 observatories was developed for diagnostic methods at the macro scale (across the Loess Plateau). Potential distribution of vegetation cover in the plateau was explored by comparing the distribution as determined by the wetness index with the present-day vegetation cover from satellite imagery.

The index, using a numerical simulation model and remote sensing technology, was developed to estimate the surface wetness of each land surface type at a local scale. The index corresponded with actual seasonal variation of moisture availability over an area of varied land-cover types. This method could be used as aridity and/or drought indices.

Keywords Desertification • Land-use • Vegetation index • Water balance • Wetness index

13.1 Scale Affects Desertification Monitoring

The process of monitoring desertification involves numerous biological and physical methods such as the wetness index. When assessing surface wetness the applicable methods are determined by the temporal and spatial scale (Kimura et al. 2008) (Fig. 13.1). For example, when the temporal scale is years and the spatial scale is

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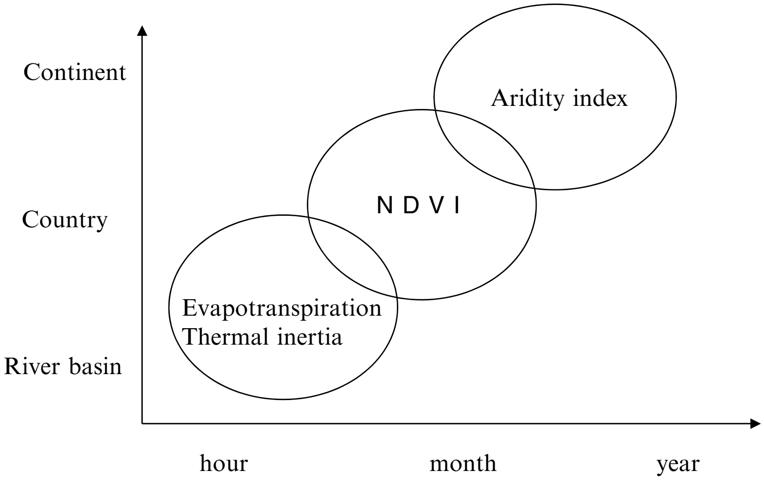

Fig. 13.1 Monitoring methods used in accordance with temporal and spatial scales

continental, the aridity index (the value obtained by dividing annual precipitation by the potential evapotranspiration) is commonly used (UNEP 1997; MA 2005). Furthermore, the normalized difference vegetation index (NDVI) is often used to estimate evapotranspiration and monitor desertification at the country level over a time-scale of months. However at the macro- and micro-scale, evapotranspiration can be directly calculate to investigate surface thermal inertia related to soil water content.

When choosing a monitoring method, one must ascertain the scale of what is being examined, paying attention to the sampling interval including the resolution of the meteorological and satellite data used.

13.2 Monitoring Desertification in the Loess Plateau

The aridity index used by UNEP (1997) and MA (2005) is based on the concept of water balance using meteorological data like temperature and rainfall. To assess the surface wetness, the most reliable method is to monitor soil water content (Shinoda 2002). However, the lack of data is often a major impediment to the analysis. The advantage on the Loess Plateau is the availability of numerous meteorological stations has resulted in sufficient data to allow a monitoring method focusing on current vegetation types, their extent and their relationship to the soil water content.

The wetness index θ_e, was defined by soil water content using previous calculations (Chap. 2). This included meteorological data from 43 observatories and the

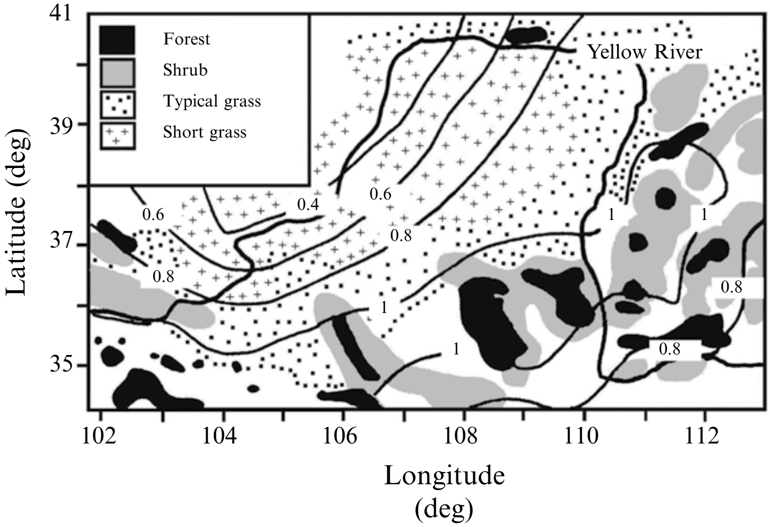

Fig. 13.2 Wetness index compared with the distribution of existing vegetation across the Loess plateau. The land-use type in white areas is mainly cultivated soils and desert. The contours represent wetness index (Kimura et al. 2005)

spatial distribution of existing vegetation cover from satellite data (Kimura et al. 2005). The wetness index, $\theta_{e,}$ is defined by the following equation:

$$\theta_e = \frac{\theta - \theta_w}{\theta_f - \theta_w} \tag{13.1}$$

where, θ is the mean volumetric soil water content at soil depths of 2–70 cm, θ_f and θ_w are the field capacity and wilting point where the pF ($pF = \log_{10}|\Psi \times 100|$(cm), Ψ is soil water potential) value is 2 and 4.2.

In the case of forest for example, the area where θ_e is between from 0.6 and 0.8, accounts for only 3 % of the total existing forest (Fig. 13.2). Similarly, forest area covers 22 %, where θ_e is between 0.8 and 1.0 and 75 % where $\theta_e > 1.0$. Seventy-five percent of existing forest occurred where $\theta_e > 1.0$ and 97 % occurred where $\theta_e \geq 0.8$. Ninety-five percent of shrubland cover occurs where $\theta_e \geq 0.8$. In grassland, 83 % occurred where $\theta_e \geq 0.8$. Grassland was the dominant vegetation type, even where $\theta_e \geq 0.8$, the model predicated that the environment was suitable for forest or shrubland. The landscape in the grassland areas is characterized by terraced fields, sloping pastures-land and eroded gullies erosion that are characteristic of the Loess plateau. Where short grasslands occur, 80 % are found in places where $\theta_e < 0.8$. The resultant vegetation growth is unstable because of the dependence of θ_e on rainfall intensity where $\theta_e < 0.8$. Miyazaki et al. (2004) conducted detailed monitoring of the heat balance and surface conditions in central Mongolia (annual precipitation ca. 200 mm)

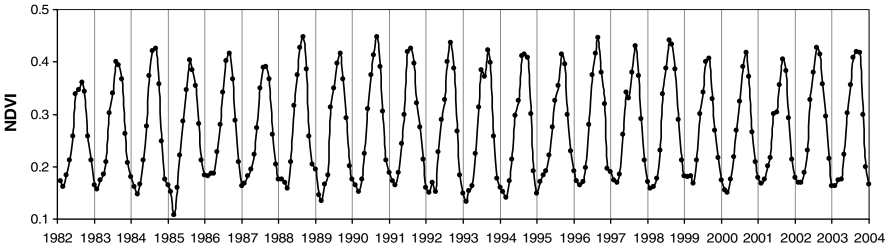

Fig. 13.3 Inter-annual change in NDVI across the Loess Plateau (1982–2003) (after Wang and Kimura, 2006)

and found that intensive rainfall in early summer (June/July) significantly influenced vegetation growth. Similarly, Kimura (2011) demonstrated the association between heavy rainfall and vegetation growth on the Loess plateau.

The remaining 20 % of short grassland is found where θ_e is between 0.8 and 1.0, occurring in the Mu Us Desert. However, shrub and grassland landscapes would have originally been more widespread because the potential areas of distribution fall within the models parameters of θ_e between 0.8 and 1.0. Historically, the Mongolian herders have grazed their livestock in this area, but since the 1950s desertification has accelerated because of anthropogenic influences, including improper land-use and over-grazing (Xue 1996; Bo and Long 2002). Wang and Takahashi (1999) analyzed the impacts of desertification, suggesting that this region should be conserved or protected. Numerical experiments indicate that desertification in the Inner Mongolian grassland influences the regional climate, leading to reduced evaporation, reduced rainfall, and increased surface temperatures (Xue, 1996).

In the southeast part of the plateau (Fig. 13.2) an area occurs where θ_e is below 1.0 even though it has a high rainfall. This is attributed to the presence of heavy loam, where the capillary phenomenon readily occurs (i.e., high evaporation). This results in high levels of salinization causing serious problems in this area.

Based on these results, the aridity was classified in the Loess Plateau (Kimura et al. 2005) as:

$\theta_e \geq 1.0$, Forest area
$0.8 \leq \theta_e < 1.0$, Shrub and typical grass area,
$\theta_e < 0.8$, Short grass area.

In view of these results, the Loess Plateau has a suitable environment to grow forests, shrubs, and natural grass species. Changes in NDVI over the entire Loess plateau from 1982 to 2003 reveal the following (Fig. 13.3; Wang and Kimura 2006).

1. Vegetation cover is increasing in many areas of the plateau. This is especially evident in the central and northern areas where there was little vegetation cover (Mu Us Desert zone, Yulin, Shenmu, and Fugu in Shaanxi Province, and several areas in the Inner Mongolia Autonomous Region). In these areas the NDVI has increased 20 % in the last 20 years. Currently, it is unclear if this increase is a result of the Chinese government's efforts to reduce farmland and promote greening projects.

2. Vegetation cover is declining in the Ziwuling forest and in areas with rain-fed agriculture (central and southern Shanxi Province).
3. In arid regions such as the Kubuchi Desert, vegetation cover is similar to the levels observed first half of the 1980s.

13.3 Land Surface Wetness Monitoring at Local Scale

We show an example of a method that estimates surface wetness and water balance at the river basin scale by combining satellite imagery and meteorological data. The amount of evapotranspiration across three different land use/land cover types in a small river basin (7 km^2) of the Loess Plateau (Liudaogou River basin, Shenmu County, Shaanxi Province: 38°47′N, 110°21′E; 1,224 m) showed relatively large differences (Table 13.1). The amount of evapotranspiration was calculated using an estimation algorithm, combining Landsat 5 TM data and heat balance calculations (Kimura et al. 2007). On average, evapotranspiration showed a decrease in the following order: irrigated fields (corn crops), shrub (dominant by *Caragana korshinskii*), grassland (dominant by *Stipa bungeana*), and rain-fed crop fields (e.g., foxtail millet, Japanese barnyard millet, and potatoes).

Table 13.2 shows the evapotranspiration estimation results for each land use type in the period between June 5 and August 31, 2004. When considering the coverage of each land-use type in the Liudaogou River basin, the amount of evapotranspiration over the basin was 132 mm during the growing period from June to September (Kimura et al. 2006, 2007). Runoff and infiltration accounted for the remaining 206 mm (Pr-ET). The observed runoff during the same period accounted for 88 mm

Table 13.1 Evapotranspiration values (mm) for the different land-use and land-cover types estimated for June 16, July 2, and August 3, 2004 (Liudaogou River basin, Shenmu County, Shaanxi Province)

	16 June (DOY = 168)	2 July (DOY = 184)	3 August (DOY = 216)	Average
Farmland (Irrigation)	2.3	2.9	4.0	3.1
Farmland (Rainfed)	1.2	1.3	3.0	1.8
Shrub	1.2	2.9	4.0	2.7
Grassland	1.2	1.9	3.0	2.0

Units are mm. DOY = Day of Year (Kimura et al. 2007)

Table 13.2 Evapotranspiration (mm) for the different land-use and land-cover types in the period between June 5 and August 31, 2004 (Liudaogou River basin, Shenmu County, Shaanxi Province)

Total Pr	ET$_0$	ET (Grassland)	ET (Shrub)	ET (Farmland with irrigation)	ET (Rain-fed farmland)
338	346	127	171	197	114

Pr precipitation, ET$_0$ is the reference evapotranspiration defined by Allen (2000), and *ET* evapotranspiration. Units are mm (Kimura et al. 2007)

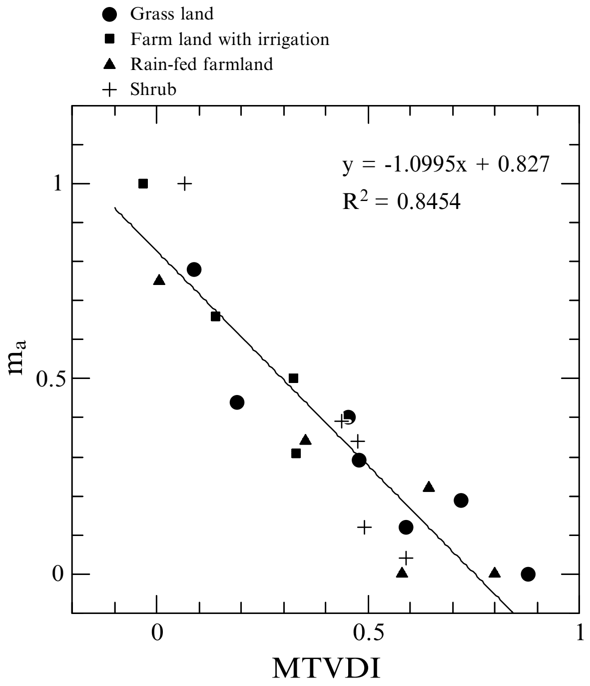

Fig. 13.4 The relationship between MTVDI and m_a for various types of ground cover (Kimura 2007)

(26 % of rainfall) (Hinokidani et al. 2006), meaning that the remaining 118 mm (35 % of rainfall) infiltrated into the soil.

The evapotranspiration estimation algorithm uses complex calculations, such as radiation balance and heat balance calculation including a correction for air stability, to quantitatively estimate evapotranspiration. The land surface temperature changes with evapotranspiration. Therefore, it is possible to qualitatively estimate surface wetness with the following equation (Kimura 2007):

$$MTVDI = \frac{T_s - T_{s\min}}{T_{s\max} - T_{s\min}} \tag{13.2}$$

where MTVDI is the modified temperature-vegetation dryness index, T_s is surface temperature (radiant temperature observed by satellite).

Surface temperature (T_s) changes with physiological activities like evapotranspiration and meteorological conditions. Equation (13.2) has been devised so that the effects of various physiological activities on T_s can be separated from the effects of various meteorological factors by normalization. T_{smax} is the aerodynamic surface temperature where no evapotranspiration occurs and T_{smin} is the aerodynamic surface temperature where sufficient evapotranspiration occurs. These estimates can be derived from the heat balance calculations.

In various landscape types in the Liudaogou River basin the relationship between MTVDI and m_a (the ratio of actual evapotranspiration to potential evapotranspiration) was significant (Fig. 13.4). The correlation between them was high, suggesting that MTVDI could be used as a surface wetness or drought indicator. However, MTVDI is significantly affected by meteorological conditions when estimating the aerodynamic surface temperature, limiting this method to the small-scale such as individual plants. When applying to the larger-scale, a detailed grid of meteorological data would be required. Detailed grids of meteorological data could be applied in the future, allowing MTVDI to be a useful tool for water management and water stress detection in vegetation at the river-basin scale. Additional work in other river basins is required to validate the MTVDI method, including comparing it with another proven monitoring method.

13.4 Land Use/Land Cover in the Liudaogou River Watershed

The Liudaogou River basin has the potential to host natural grass species (Fig. 13.2). In the past, humans grazed large herds of livestock in this area, but desertification (mainly soil erosion) has occurred because of overgrazing hill cultivation. However, the NDVI analysis shows that recently the vegetation cover has gradually increased in the river basin.

Water use efficiency (WUE) of the natural grasslands is relatively high, effectively preventing soil erosion and recharging groundwater (Kimura et al. 2006). The evapotranspiration and m_a from the grasslands were small compared with those from irrigated farmland and shrublands (Table 13.2; Fig. 13.4). The WUE of the grasslands was comparatively high because of the physiological function that grasses restrain transpiration under harsh environmental conditions (Kimura et al. 2006). Here, WUE was defined as protection from erosion achieved per unit of water used (Kimura et al. 2006). According to results from field experiments in the Liudaogou river basin, erosion resulted in the loss of: 6,750 kg/ha of soil from bare soil surfaces, 3,750 kg/ha of soil from farmland and 93 kg/ha of soil from natural grassland (Smil 1996). Therefore, the assumption could be made that converting the entire basin into natural grassland would effectively reduce soil erosion. However, the interests and wellbeing of local residents must be considered; converting the landscape into natural grassland would most likely interfere with the residents' lifestyle. Further thought is required to understand the land use, balance agriculture requirement, livestock husbandry, other uses and ultimately soil conservation.

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Chapter 14
Countermeasures to Prevent Water Erosion in the Loess Plateau of China

Juying Jiao

Abstract The Loess Plateau suffers the most severe soil erosion rates in the world. Great efforts have been made since the 1950s to combat soil erosion and environmental degradation. In this study, the runoff and sediment benefits of major countermeasures including bench terrace, vegetation and check dams are analyzed under different conditions. The development and benefits of integrated management in small watersheds are discussed. We also analyze the variation of sediment yields in the Hekouzhen-Longmen region in the middle reaches of the Yellow River basin. Important considerations that must be addressed for future soil erosion and flood control are discussed. Future management objectives need to be investigated that focus on different soil erosion areas. Future key control areas of the Loess Plateau are mainly regions where there is inadequate management efficiency and high erosion rates (≥5,000 ton km^{-2} yr^{-1}). Further studies should focus on preventing soil erosion at the source, rather than intercepting sediment yield downstream, and on rational utilization and sustainable development of recovered vegetation.

Keywords Bench terracing • Vegetation • Check dam • Integrated management of small watersheds • Soil erosion • Sediment yield

14.1 Introduction

Soil erosion is an increasing global environmental problem, and China is one of the most seriously affected regions in the world (Yang et al. 2003). The Loess Plateau suffers the most severe soil erosion rates in the world (Shi and Shao 2000).

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Great efforts have been made since the 1950s to combat soil erosion and environmental degradation. Before 1969, which is regarded as the pre-control period, soil and water conservation were in an initial and scattered control phase (Xu 2003). Since the 1970s, a series of soil and water conservation measures including land terracing, tree and grass planting, and conservation tillage practices have been implemented, and many check dams have been built for sediment interception (Xu and Cheng 2002). During the 1970s, land terracing was the main soil and water conservation measure, aimed at solving a food shortage (Wang et al. 2009). In the 1980s, integrated management of small watersheds (Cai 2001) was implemented, based on previous soil erosion control experiences. Soil and water conservation in the 1990s, guided by the Law of the People's Republic of China on Water and Soil Conservation, was intended to prevent and control soil and water loss and to protect and rationally utilize soil and water resources (Wang et al. 2009). Through the twenty-first century, with implementation of the "Grain for Green" project, soil erosion control was focused on large-scale vegetation construction (Zhou et al. 2009). As a result, sediment entering the Yellow River has declined about 77 % since the early 1970s (Xu and Cheng 2002). Based on sediment yield at Shaanxian (1919–1959) and Tongguan (1960–2009) stations, annual sediment yield decreased from 16.0×10^8 ton (1950–1969) to 13.2×10^8 ton in the 1970s, 7.8×10^8 ton in the 1980s, 7.9×10^8 ton in the 1990s, and 3.1×10^8 ton between 2000 and 2009. The benefits of different soil-water conservation measures, comprehensive management of small watersheds and sediment reduction in the middle reaches of the Yellow River are important foundations for further study of soil erosion and flood control.

14.2 The Benefits of Main Individual Countermeasures

The benefits of individual countermeasures are important for water and soil conservation design and construction. The major countermeasures include bench terracing, vegetation and check dams (Fig. 14.1).

14.2.1 Bench Terracing

Bench terracing, a basic soil erosion control measure on Loess Plateau farmland, has the greatest soil and water conservation benefits. This is because of its effect on ground slope and runoff coefficient. In practice, however, the benefit of bench terraces is subject to design standards and construction quality, such as field smoothness and height of the dike and ridge.

We used rainfall and erosion information for bench terraces and sloping farmland plots at Wangjiagou in Lishi County of Shanxi Province (1957–1966), Dabiangou in Yan'an County of Shaanxi Province (1959–1967), and Wangmaogou (1961–1964), Xindiangou and Jiuyuangou (1960–1966) in Suide County of Shaanxi

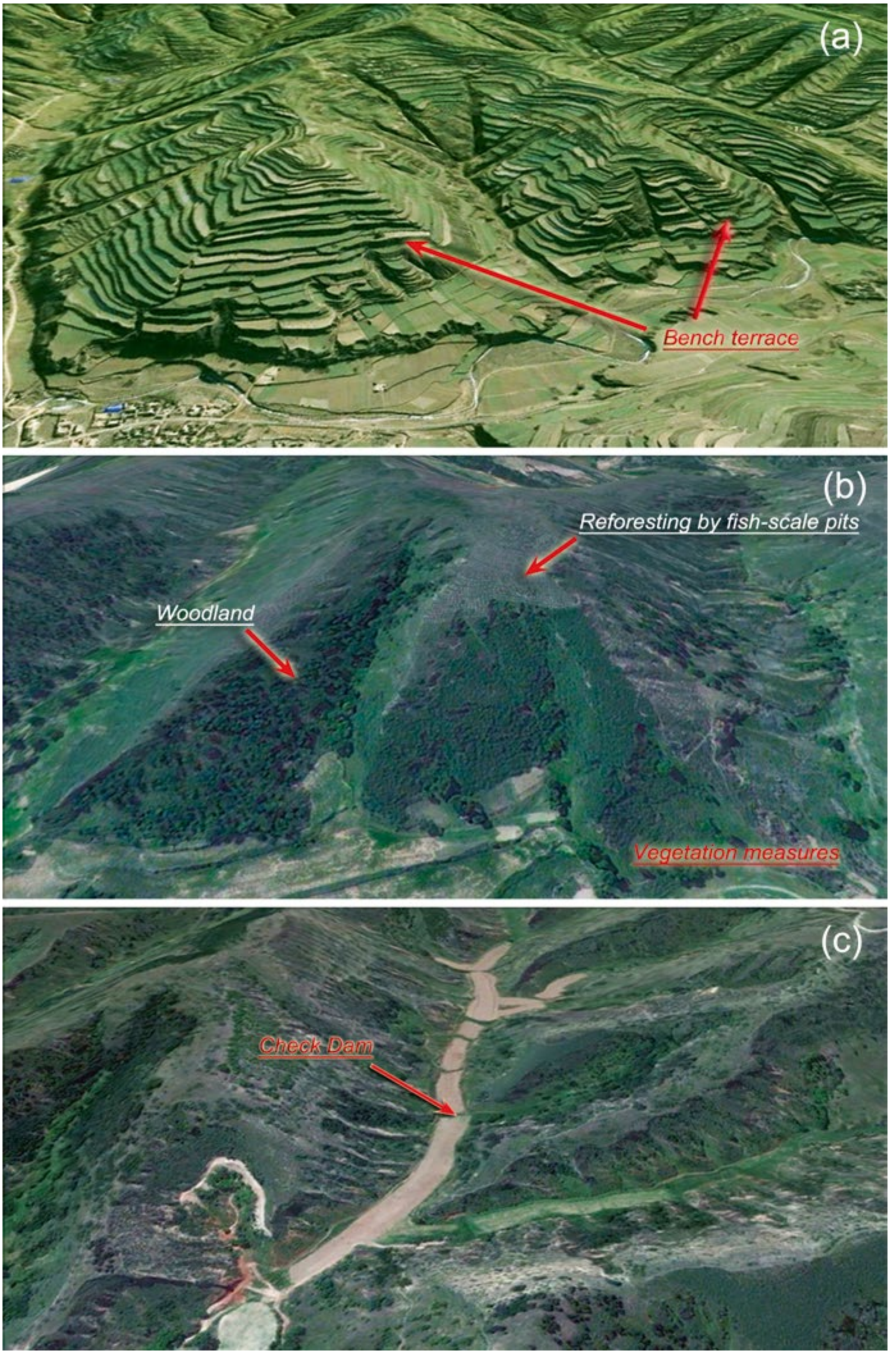

Fig. 14.1 Bench terrace, vegetation measures and check dam on Loess Plateau, from Google Earth. (**a**) Bench terrace in Yangjiagou watershed, Zhuanglang County, Gansu Province, China; (**b**) vegetation in Wangzui watershed, Yan'an, Shaanxi Province; (**c**) check dam in the Beishijiagou watershed, Yan'an, Shaanxi Province

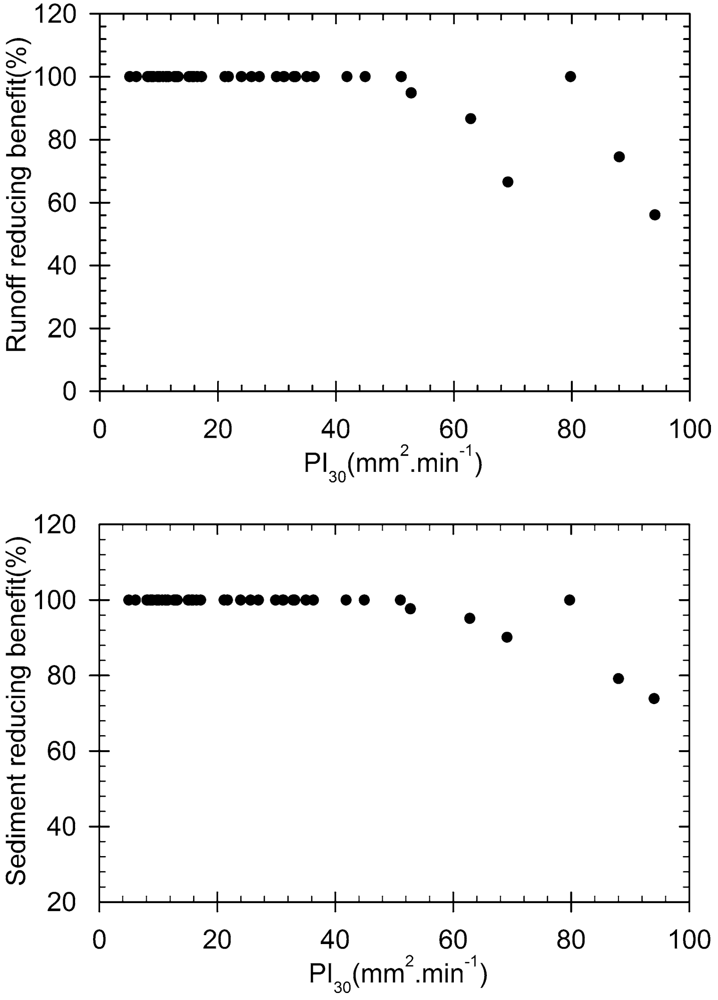

Fig. 14.2 Runoff (*top*) and sediment (*bottom*) reduction benefits of bench terrace under various rainfall conditions in the hill-gully Loess Plateau region (Jiao 2000)

Province. Based on this information, runoff and sediment reduction benefits of bench terracing in different rainfall conditions were analyzed, choosing sloping farmland of 10–25° as a reference. In the analyses, the bench terrace at Wangjiagou (1960–1966) was taken as a terrace without a ridge, and the others with a ridge. The rainfall indexes used were greater than the erosive rainfall standards of sloping farmland. The product (PI_{30}) of rainfall amount (P, mm) and maximum 30 min intensity (I_{30}, mm min^{-1}) was selected as the erosive rainfall standard. These factors were $PI_{30} > 4.4$ mm^2 min^{-1} and $I_{30} > 0.28$ mm min^{-1}, based on information of 245 sloping farmland runoff plots of slope 5–25° in the Hekouzhen-Longmen area. Based on 48 erosive rainfall events with $PI_{30} > 4.4$ mm^2 min^{-1} and $I_{30} > 0.28$ mm min^{-1}, a scatter plot of runoff and sediment reduction benefits versus PI_{30} (Fig. 14.2) shows these benefits in bench terracing. When $PI_{30} < 50$ mm^2 min^{-1}, and rainfall frequency

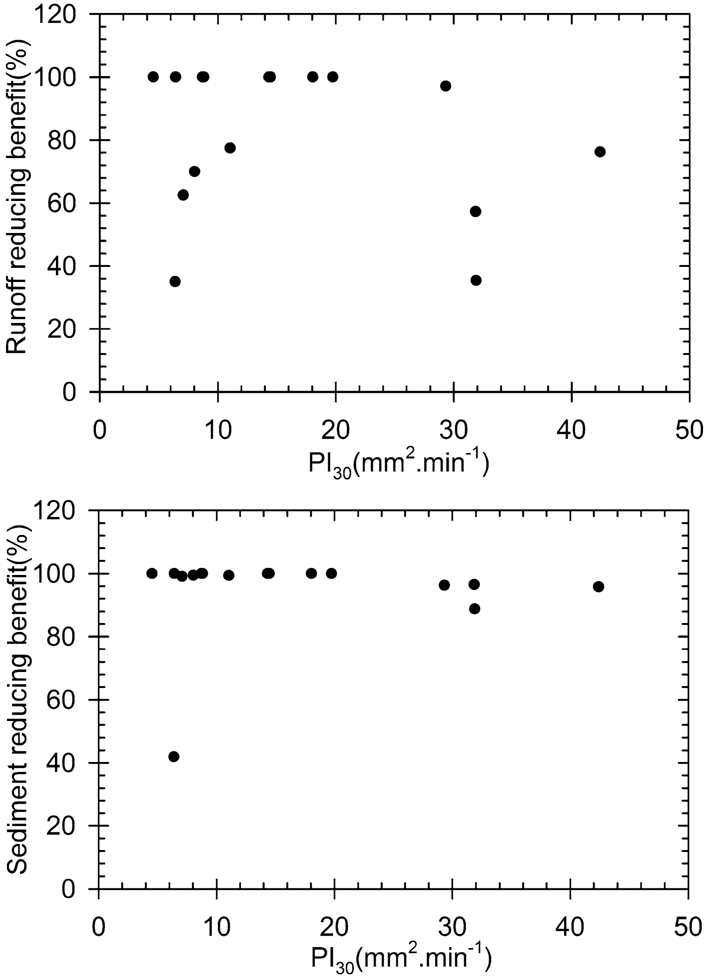

Fig. 14.3 Runoff (*top*) and sediment (*bottom*) reduction benefits of no-ridge bench terrace under different rainfall conditions in hill-gully Loess Plateau region (Jiao 2000)

was 85.4 %, runoff and sediment reduction benefits were 100 %. When $PI_{30} > 50$ mm^2 min^{-1}, rainfall frequency was only 14.6 %. Those benefits decreased with increasing PI_{30} (Jiao 2000; data from observations of soil and water conservation of Shanxi and Shaanxi provinces).

For a bench terrace without a ridge in the Wangjiegou watershed, the runoff and sediment reduction benefits were generally less. Specifically, the runoff reduction benefit was much lower (Fig. 14.3). Average runoff and sediment reduction benefits of the no-ridge bench terrace were as follows: 82.0 and 94.8 % when PI_{30} was 4.4–45 mm^2 min^{-1}, 87.1 and 95.0 % for PI_{30} of 4.4–20 mm^2 min^{-1}, and 66.5 and 94.3 % for 20–45 mm^2 min^{-1}, respectively. As already discussed, terrace quality is very important, and the engineering quality in particular has an important influence on the benefits of soil and water conservation.

14.2.2 Vegetation Measures

We analyzed runoff, sediment and rainfall data from the runoff plots of sloping farmland, woodland and grassland at the following sites: Xindiangou and Jiuyuangou (1959–1963) and Wangmaogou (1961–1964) in Suide County; Dabiangou (1959–1967) in the city of Yan'an; Wangjiagou in Lishi County (1957–1966); and An'sai County (1980–1989). Data were from the observations of soil and water conservation of Shanxi and Shaanxi provinces. Crops on sloping farmland plots were foxtail millet, proso millet, beans, sorghum vulgare, potato and others. Areal coverage was from 0 to 60 %, but most was below 35 %. The trees of woodland plots in the analysis were *Robinia pseudoacaia, Ailanthus altissima, Ulmus pumila, Amorpha fruticosa* and *Caragana intermedia*, at coverages between 10 and 90 %. The grasses studied included *Medicago sativa, Melilotus suaveolens* and *Astragalus adsurgens*, with areal coverage between 10 and 100 %. Woodland and grassland were distributed on the slope, which was between 20°–35°. On the basis of 424 erosive rainfall events at the farmland plots on the slope, we estimated the standard erosive rainfall of this farmland, corresponding to woodland and grassland, at $PI_{30} = 3.20$ mm^2 min^{-1} and $I_{30} = 0.24$ mm min^{-1}. According to rainfall events with $PI_{30} > 3.20$ mm^2 min^{-1} and $I_{30} > 0.24$ mm min^{-1} for woodland and grassland without land preparation measures, the relationship between runoff (R, %) and sediment (S, %) reduction benefits and erosive rainfall index (PI_{30}, mm^2 min^{-1}) and vegetation coverage (v, from 0 to 100) were obtained as follows (Jiao 2000):

$$\text{Woodland:}\quad \begin{aligned} &R = 235.306 - 2890.644\,(1/v) - 37.442 log(PI_{30} \cdot v)\\ &r = 0.835^{**}\\ &n = 88 \end{aligned} \tag{14.1}$$

$$\begin{aligned} &S = 223.923 - 3103.189(1/v) - 30.985 log(PI_{30} \cdot v)\\ &r = 0.682^{**} \end{aligned} \tag{14.2}$$

$$\text{Grassland:}\quad \begin{aligned} &R = -81.799 + 39.695 log(v/PI_{30}) + 61.934 log(v)\\ &r = 0.715^{**}\\ &n = 110 \end{aligned} \tag{14.3}$$

$$\begin{aligned} &S = -108.520 + 46.194 log(v/PI_{30}) + 84.813 log(v)\\ &r = 0.787^{**} \end{aligned} \tag{14.4}$$

We found that the runoff and sediment reduction benefits of woodland and grassland decreased with increasing PI_{30}. Woodland showed runoff and sediment reduction benefits with coverage >30 %. When coverage exceeded 60 %, however, these benefits tended to stabilize. Similarly, grassland had evident effects of water and soil conservation with coverage >40 %. When that coverage exceeded 60 %, the potential increase in benefits was greater than for woodland, for a similar coverage trend.

Although the planting of trees and grasses may control soil erosion and improve the environment in the short- to medium-term, they consume large quantities of soil water, desiccating the upper soil layer (Cao et al. 2009; Wang et al. 2008). Afforested areas also threaten long-term ecological sustainability because they increase evapotranspiration and decrease gravitational infiltration of water, effectively preventing replenishment of groundwater supplies and further desiccating the soil layer (Shangguan 2007; Wang et al. 2008). Thus, natural succession with enclosure should receive more attention for vegetation construction in the Loess Plateau region.

14.2.3 Check Dam

The check dam is the main engineering measure for soil and water conservation on the Loess Plateau. Based on data from 4877 check dams on the Dali, Jialu, Tuwei, Kuye and Huangfuchuan rivers, the runoff and sediment reduction benefits and a sediment interception index of check dams were analyzed (Jiao 2000). Those benefits increased with dam height, and the sediment reduction benefit far outweighed that of runoff reduction. Average runoff and sediment reduction benefits of the five rivers were 5.74 and 34.4 %, respectively. Sediment reduction benefits of check dams with heights 5–10, 10–15, 15–20, 20–25, 25–30 m were estimated at 13.5, 27.9, 38.3, 42.0 and 48.4 %, respectively, whereas the runoff reduction benefit was 1.97, 4.63, 7.26, 6.37 and 7.73 %, respectively. However, the runoff and sediment reduction benefits of some check dams of height >30 m were relatively small; this was related to larger erosion and runoff contributing areas. The benefits of dams within the same height range for certain tributaries varied greatly, owing to differences in the distribution proportion of control area and dam height (Table 14.1).

Table 14.1 Average runoff and sediment reduction benefits of check dams of different heights (Jiao 2000)

	Dam height (m)						
River	5–10	10–15	15–20	20–25	25–30	≥30	Average
Runoff reduction benefit (%)							
Huangfuchuan	3.93	3.67	5.26	3.98	5.53		4.4
Kuye River	1.62	3.00	9.52	7.66	8.93	4.56	4.85
Tuwei River	0.66	7.60	9.37	4.19	6.12	7.58	6.83
Jialu River	1.05	2.06	2.84	5.24	5.43	4.2	3.46
Dali River	2.61	6.84	9.32	10.76	12.66	14.32	9.14
Average	1.97	4.63	7.26	6.37	7.73	7.67	5.74
Sediment reduction benefit (%)							
Huangfuchuan	26.91	25.61	36.22	27.71	38.02		30.50
Kuye River	17.19	25.99	39.32	44.22	37.32	47.56	29.88
Tuwei River	7.18	38.65	50.99	41.59	65.34	70.62	47.76
Jialu River	6.68	13.52	18.86	32.14	33.79	28.28	22.00
Dali River	15.13	36.12	49.21	55.46	59.61	78.45	47.57
Average	14.62	27.98	38.92	40.22	46.82	56.23	35.54

Table 14.2 Sediment storage index for different dam heights on five rivers (Jiao 2000)

River	Sediment storage index (ton km^{-2}) <5 m	5–10 m	10–15 m	15–20 m	20–25 m	25–30 m	≥30 m	Average
Huangfuchuan		222.9	384.0	529.4	631.1	849.0	1,338.6	453.4
Kuye River	94.5	243.6	415.0	625.5	748.0	907.0	1,180.8	499.9
Tuwei River	153.6	288.9	467.5	618.8	755.0	829.7	1,060.8	551.6
Jialu River		201.3	333.1	439.2	604.6	660.5	889.5	470.6
Dali River	181.6	320.9	483.7	636.8	816.7	975.5	1,231.9	556.4
Average	143.2	255.5	416.7	569.9	711.0	844.4	1,140.3	506.4

Table 14.3 Amount of retained sediment in Yellow River watershed (Zeng et al. 1999)

Period	Sediment retained by check dams (10^6 m^3)	Total retained sediment by soil and water conservation measures (10^6 m^3)	Percentage of sediment retained by check dams
1952–1962	600.72	647.42	92.8
1963–1969	1,004.42	1,135.26	88.5
1970–1979	2,151.37	2,694.69	79.8
1980–1989	1,823.77	3,144.77	58.0
1990–1995	1,547.04	3,032.65	51.0
Total	7,127.32	10,654.79	66.9

The average sediment storage index (i.e., storage amount of sediment per dam land) of Huangpuchuan, Kuye, Tuwei, Jialu and Dali rivers was 453.2×10^4 ton km^{-2}, 499.9×10^4 ton km^{-2}, 551.5×10^4 ton km^{-2}, 470.6×10^4 ton km^{-2}, and 556.4×10^4 ton km^{-2}, respectively, with an average of 506.4×10^4 ton km^{-2} for all five. The average index for dams of heights <5, 5–10, 10–15, 15–20, 20–25, 25–30 and ≥30 m was 143.2×10^4, 255.5×10^4, 416.7×10^4, 569.9×10^4, 711.1×10^4, 844.4×10^4, and $1{,}140.3 \times 10^4$ ton km^{-2}, respectively (Table 14.2).

Over 100,000 check dams were built on the Loess Plateau in the last 50 years, and agriculture associated with the check dam systems has created a marvelous landscape on the vast plateau (Xu et al. 2004). Check dams are particularly effective for preventing coarser sediment from entering the Yellow River (as shown in Table 14.3), and thus reduce sedimentation downstream and prevent overtopping on the lower river. Ran et al. (2008) reported the dominant role of dams in sediment control within sub-basins of the plateau.

14.2.4 Other Measures to Prevent Water Erosion

After engineering and vegetation measures, tillage is the third main measure for soil and water conservation. It is classified into three types. First are measures altering the microtopography, such as counter farming, ridge tillage and field pitting, level trench tillage, and others. The second type are measures that can increase field coverage, for example, interplanting, crop rotation, mixed seeding, counter and broadband rotation, and cover farming (including crop residues, stalk, sand, plastic mulching, and others). The third are measures that improve the soil, like subsoiling, organic fertilizer, green manure, no tillage, zero tillage, and others. With the development of agricultural farming technologies, to achieve greater soil and water conservation benefits, tillage measures are not implemented independently, examples include level ditch mulching, level ditch intercropping, ridge mulching and furrow seeding, deep loosening with mulch, no-tillage with mulch, and others. In general, tillage measures involve low investment and less labor. They are simple, practicable and produce quick results, but they are only effective over a short term.

14.3 Integrated Management of Small Watersheds

Integrated management of small watersheds refers to a comprehensive prevention and control system. This system adjusts measures to local conditions, comprehensively incorporating a combination of engineering, vegetation and agricultural technology measures, and control of mountains, water, forestry and roads. The main objectives are to utilize water and soil resources rationall, and to optimize the structure of agriculture, forestry and animal husbandry. This is done by taking the watershed as a unit, taking into account the long-standing experience and lessons of soil and water control, plus the characteristics and laws of soil erosion.

Integrated management of water and soil conservation, taking the small watershed as a unit, dates to the 1950s. The Chinese Academy of Sciences, Ministry of Water Resources and other relevant ministries, along with provinces (regions), established 11 typical experimental demonstration areas of small watershed management in five provinces (regions). They established different models for comprehensive management of soil and water loss and agricultural development. Eleven typical watersheds were thoroughly investigated in a hilly region in the Yellow River gorge, a gully region in that gorge, a hill and gully region in northern Shaanxi, and a gully region on the arid plateau of the northern Wei River. In this investigation, typical watersheds were classified into five management models for controlling soil and water loss. The benefits of watershed management and of the five models and 11 typical watersheds are shown in Table 14.4 (Wang et al. 2003).

The Loess Plateau of Shaanxi adopted agro-forestry, economic forestry (crop) and ecological agriculture models to control soil and water loss, reduce management cost, and improve management benefits. The current situation of typical experimental demonstration areas has shown significant changes. Soil loss has markedly decreased and productivity has improved significantly (Tables 14.5 and 14.6). Soil loss on the 11 typical watersheds has decreased by 50–90 % after 10 years of control (Liu et al. 2004).

Through 20 years of development, small watershed management on the Loess Plateau developed from single and sporadic control measures to a comprehensive and

Table 14.4 Benefits for watershed management of five models and 11 typical watersheds (Wang et al. 2003)

Study area	Pilot watershed	Management model	Characteristics of management model	Ecological benefit (%)	Economic benefit (%)	Social benefit (%)	Total score (%)	Ranking
Hill region in the Yellow River gorge	Quanjiagou	Eco-agriculture model	Taking science and technology as the principal factor, integrated planning and reasonable land use, combined engineering and biological measures, ensures economic and social benefits through ecological benefit	90	71	52	79	8
	Zhifanggou	Eco-agriculture model		81	95	83	86	4
Hill and gully region in northern Shaanxi	Hanjiagou	Eco-agriculture model		91	40	47	69	10
	Qiutangou	Wood and grass model	Constructing mixed forests and shrubs, artificial planting of grass, fundamentally improving eco-environment	96	60	77	82	7
	Liuhuayu	Traditional agriculture model	Adopting traditional agricultural farming methods, comprehensive and unified management not developed	60	22	50	46	11
	Rentai	Traditional agriculture model		92	50	67	75	9
	Luogou	Economic forest model	Combined engineering and biological measures, planted commercial crops like apple and tobacco according to local conditions, developed economy with soil and water conservation promotion	98	82	77	90	3
Gully region on arid plateau of northern Wei River	Dongchenchao	Economic forest model		91	77	77	85	5
	Baijiahe	Economic forest model		93	62	96	83	6
Gully region in Yellow River gorge	Hangshui	Agro-forestry model	Combined engineering and biological measures, developing intercropping with pepper, fruit and grain according to the superior local resources	88	98	99	93	1
	Nihegou	Agro-forestry model		94	85	91	91	2

Table 14.5 Results of small watershed comprehensive management on Loess Plateau (Liu et al. 2004)

Region	Watershed	Area (km^2)	Degree of management (%)		Grain yield (kg hm^{-2})		Net income (CNY[a] p^{-1} yr^{-1})		Soil erosion rate (ton km^{-2} yr^{-1})	
			a	b	a	b	a	b	a	b
Loess hill and gully region	Mizhi	5.6	—	69.2	2,761.5	2,667	532	811	—	3,024
	Ansai	8.3	37.2	54.2	976.5	1,446	484	1,078	7,197	5,276
	Zhunqi	7.7	57.2	84.2	2,022	3,207	611	1,300	5,464	3,022
	Guyuan	15.1	55.6	74.6	1,296	1,633.5	484	961	3,859	1,660
	Xiji	5.7	83.6	96.4	1,366.5	1,989	529	878	708	256
	Dingxi	9.2	56.8	84.8	1,788	1,956	424	750	2,482	714
	Lishi	9.1	60.8	68.7	2,164.5	2,017.5	617	880	1,708	314
	Longxian	10.7	7.2	54.6	1,918.5	3,880.5	268	700		4,836
Loess Plateau and gully region	Changwu	8.3	68.2	82.4	3,999	3,612	380	926	1,000	618
	Chunhua	9.2	66.5	78.9	2,821	3,108	769	1591	1,034	
	Qianxian	8.5	56.1	73.6	3,012	3,072	325	747	1,793	1,086

a = average from 1985–1990; b = average from 1990–1995

[a] One Chinese yuan (CNY) is equivalent to about 0.16 United States dollars as of May 2012

Table 14.6 Benefits of small watershed comprehensive management in Zhifanggou, Ansai County (Liu et al. 2004)

Year	Population (p.)	Agriculture: forestry, pasture	Erosion modulus (ton km^{-2} yr^{-1})	Grain yield (kg hm^{-2})	Farmland per capita(hm^2)		Net income (CNY[a])
					Total area	Terrace	
1975	383	1:0.1:0.1	1,400	444	0.92	0.05	
1985	417	1:0.5:0.7		503	0.73	0.12	222
1990	476	1:0.9:1.2	7,140	1,350	0.48	0.13	667
1994	552	1:1.6:1.9	4,160	1,835	0.29	0.16	1,631
1997	546	1:1.6:2.1	1,630	2,101	0.27	0.17	1,461
2000	546	1:2.0:2.2		2,730	0.17	0.17	2,033

[a] CNY: see Table 14.5

systematic control model. Regional-scale management by means of the combination of engineering and biological measures was initiated. Watershed development and management was realized through a variety of management responsibility systems and multi-level management, depending on "family bag watershed" (watershed is managed by a family with contract agreement on behalf of improving ecological, social and economic benefits), "united bag watershed" (watershed is managed by families in a corporate partnership with contract agreement on behalf of improving ecological, social and economic benefits), "usable barren auction" (barren hills, hillsides, abandoned lakes and desolated beaches are managed by stakeholders through auction), and others. In the meantime, investment modes of multiple forms and channels arose, and a stimulation mechanism was established for encouraging and protecting small watershed management. All these measures caused small watershed management on the Loess Plateau to follow the mode of "manage mountains and water, cast off poverty and ignorance" (Si and Peng 2002). Furthermore, implementation of integrated management in small watersheds satisfies various needs of socio-economic development, facilitates large-scale management and innovative development mechanisms, integrates artificial restoration with natural self-rehabilitation, and promotes soil conservation in China (Liu et al. 2004).

14.4 Reduction Benefits of Sediment Yield in Middle Reaches of Yellow River

The Hekouzhen-Longmen region is in the middle reaches of the Yellow River basin (Fig. 14.4) and has a total watershed area of 129,654 km^2. This represents 14.8 % of the total area of that basin, but the sediment yield is 55.7 % that of the entire basin. Coarse sediment (>0.05 mm), which contributes to channel silting in the lower reaches,

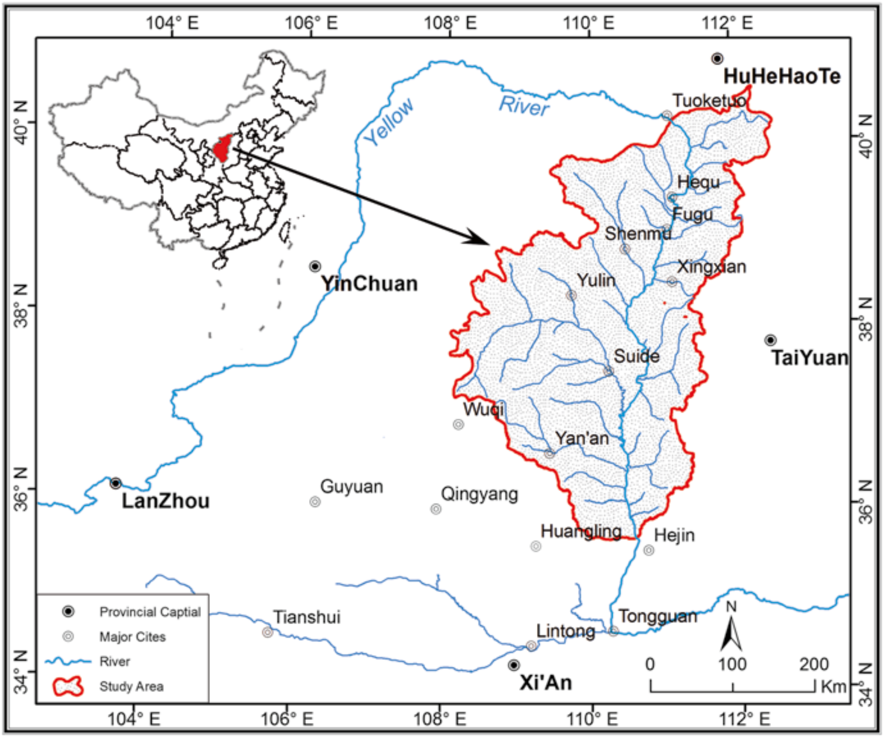

Fig. 14.4 Location of Hekouzhen-Longmen region in middle reaches of Yellow River, based on MWR-YRWCC (1989)

Table 14.7 Sediment yield in different time periods in Hekouzhen-Longmen region

Period	Sediment yield (ton km^{-2} yr^{-1})	Total sediment mass (10^8 ton)
1950–1959	7,982.94	10.35
1960–1969	7,318.25	9.49
1970–1979	5,806.07	7.53
1980–1989	2,870.79	3.72
1990–1999	3,635.96	4.71
2000–2009	1,064.24	1.38
1950–1969	7,650.59	9.92
1970–1909	3,344.27	4.34
1970–1989	4,338.43	5.62
1990–2009	2,350.10	3.05
Average	4,779.71	6.20
Maximum	16,482.33	21.37
Minimum	83.30	0.11

takes up 75.0 % that of the entire basin. Thus, the Hekouzhen-Longmen region is often a focus area for soil and water conservation and ecological construction.

Annual variation of sediment yield in the region from 1950 to 2009 was analyzed based on sediment data from Toudaoguai and Longmen stations, provided by the Yellow River Water Conservancy Commission. The sediment yield had a general decreasing trend after 1970, especially after 1980. The average was 6.20×10^8 ton, the maximum 21.37×10^8 ton in 1967, and the minimum 0.11×10^8 ton in 2008. Compared with 1950–1969 (before soil erosion control), sediment decreased by 24.1, 62.5, 52.5 and 86.1 % in the 1970s, 1980s, 1990s and 2000s, respectively. The average decline between 1970 and 2009 was 56.3 %. The sediment yield was obtained from annual sediment yield divided by catchment area of the Hekouzhen-Longmen region. It decreased from 7,650.59 ton km^{-2} yr^{-1} during 1950–1969 to 1,064.24 ton km^{-2} yr^{-1} during 2000–2009 (Table 14.7).

In summary, the sediment yield in the Hekouzhen-Longmen region has clearly decreased since 1970. The reduction of sediment in rivers was strongly influenced by human activities and climate change (Walling and Fang 2003; Chakrapani 2005; Peng et al. 2010). It has been shown that human activities account for nearly 80 % of the sediment load decrease, while the remaining 20 % is attributed to precipitation decrease above Huayuankou station (at the end of the middle reaches of the Yellow River basin) (Peng et al. 2010). The proportions of sediment reduction caused by human activity in the Wuding River (the largest tributary in the Hekouzhen-Longmen region) were 79.8, 80.4, 71.8 and 88.9 % in 1972–1979, 1980–1989, 1990–1999 and 2000–2006, respectively (Gao et al. 2009). Sediment load in the middle reaches has been more affected by water and soil conservation practices and the commissioning of reservoirs (Mu et al. 2007; Gao et al. 2010; Peng et al. 2010). However, appropriate and rational control measures and management methods in the section need further investigation.

14.5 Key Problems to Address in the Future

Soil and water conservation on the Loess Plateau can be divided into four control stages. From 1949 to 1969 was the no-control or sporadic control stage. From 1970 to 1989 was the preliminary control stage for solving the food supply problem, which included the gradual transition from single measures with terrace construction to small watershed comprehensive management. From 1990 to 2009 was the middle control stage, which included changes from solving the food problem to improving the eco-environment. This was also the transition from multiple small-watershed control to concentrated and large-scale construction of vegetation, especially with the "Grain-for-Green" project. From 2010 to 2029 is believed to be the last stage, for constructing ecological civilization. It will be a transition stage, from concentrated and large-scale construction of vegetation to harmonious ecological, economic, and social development (Wang et al. 2012).

Hence, the following scientific problems must be considered for future control.

1. A diversity of geographic and geomorphic conditions creates vast differences of soil erosion magnitude in the various areas. Therefore, the management objective for the Loess Plateau cannot use a single standard. For example, the standard promulgated by the Ministry of Water Resources, i.e., a soil loss tolerance on the plateau of 1,000 ton/km^2 yr^{-1}, is difficult to achieve in some erosion type regions, like the loess "Mao" hill and gully, Loess Plateau residual hill and gully regions. However, the tolerance was already below this standard in some earth rocky mountain areas with good vegetation cover. A future management objective must be studied, and aimed at the various soil erosion areas.
2. Management of the Loess Plateau should not only focus on environmental problems there, but should also consider problems of sediment in the Yellow River. For this reason, soil loss tolerance on the plateau should be ascertained under the guiding principle of "maintaining the healthy life of the Yellow River," and with consideration of water health and river sediment deposition in the downstream part of the river. The soil loss tolerance for different soil erosion types and land uses should be examined according to soil erosion and sediment characteristics, soil and water conservation benefits, and requirements of regional ecological and social functions in different areas. This would provide significant guidance for setting management objectives and maintaining the healthy life of the Yellow River.
3. Two aspects should be considered for future key control areas on the Loess Plateau. One is the regions where management efficiency is inadequate, such as the Loess tableland hill and gully, Loess Plateau residual hill and gully, and loess terrace regions. The other is the prioritization of regions with high erosion rates ($\geq$5,000 ton km^{-2} yr^{-1}), such as the loess "Mao" hill and gully (2.2×10^4 km^2), arid loess hill and gully (1.5×10^4 km^2), Loess Plateau and gully (0.86×10^4 km^2), and loess "Liang" hill and gully (0.46×10^4 km^2) regions (Wang et al. 2012).
4. Based on soil erosion control experiences in regions where soil erosion was successfully reduced, appropriate and rational control measures and management

methods in the various regions should be further investigated. These investigations should focus on preventing soil erosion at the source, rather than intercepting sediment yield downstream.

5. Problems requiring additional study include whether recovered vegetation can be used, to what extent vegetation recovery may be done, and the utilization patterns and extents of recovered vegetation. To maintain the sustainability of soil and water conservation benefits of vegetation, a natural and artificial vegetation recovery stability mechanism and technology system must be advanced. Also, the multi-functional management technology of vegetation construction and sustainable development mode of water and soil conservation requires establishment.

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Chapter 15
Secondary Salinization and Its Countermeasures

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Abstract We selected for study the eastern block of the Luohui Irrigation District, which is called the Luodong block. The research area is in the southeast part of the Loess Plateau, which is in a semiarid climate zone. Furrow and border irrigation in the block have been practiced over about 32,000 ha of irrigated area, where crops such as cotton, wheat and fruit are predominant. Based on onsite experiments in the research area, we classify salinization processes, reveal causes of farmland salinization, and propose countermeasures to prevent these phenomena. Lowering groundwater level by improving drainage systems, controlling dumped saline soil, and managing the use of saline irrigation water are recommended.

Keywords Secondary salinization • Irrigation water quality • Drainage improvement • Leaching • Warp soil dressing

15.1 Introduction

Salinity development is a lesser problem in parts of the Loess Plateau that are characterized by hilly topography, good drainage, and a deep water table. However, in lowland areas along rivers and level tablelands in downstream areas, there are drylands where secondary salinization (referred to in this chapter as salinization) readily occurs and therefore demands caution. As stated in Chap. 7 of this book, there is

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considerable upland crop farmland on the Guanzhong Plain that is waterlogged and saline or sodic. This chapter describes research results for the Luodong block (32,000 ha) of the Luohui irrigation district in Dali County, Shaanxi Province. It sheds light on the mechanisms by which problems occur and addresses preventive measures from the perspective of water management. First, we describe the situation in this area, including the current state of irrigated farmland salinization and effects of irrigation management on groundwater behavior and salinization. We then propose appropriate irrigation management methods. See Chap. 7 for detailed information on the Luohui Irrigation District.

15.2 State of Salinization in Luodong Block

In Chap. 7, Fig. 7.10 shows the change in area of Luodong block farmland affected by salinization, starting in the 1950s. Saline farmland rapidly increased in the 1950s when full-scale irrigation began in the block, and tended to increase until about 1974. The main cause of salinization was water table rise because of irrigation, which proceeded at a yearly rate about 0.6 m. Construction of drainage channels then lowered the water table and the amount of saline farmland tended to decrease until about 1980, after which it again tended to increase until the mid 1980s. This happened because of problems with drainage channel management. Since that time, saline farmland has tended to decrease, but the future trend is unpredictable.

The Luodong block roughly comprises three terraces—at lower, medium, and upper levels. Salinization is severe on the high terrace, and less on the medium and low terraces. However, there is serious salinization near a salt lake, making it hard to grow crops other than cotton. The growth of even highly salt-tolerant cotton is inhibited here. Figures 15.1, 15.2, 15.3, 15.4, 15.5, and 15.6 show the state of salinization in the upper and lower terraces of Luodong block.

Figures 15.1 and 15.2 show salinization on the upper terrace, which occurs because the water table is always high, within 2 m of the surface; this is in turn controlled by low water permeability of the subsoil. The overall cause is groundwater capillary rise. Electric conductivity of the soil pore water (ECp) is at least 10 dS m^{-1}. In the area shown in Fig. 15.1, salt concentration is especially high and crop production has been abandoned. In the area shown in Fig. 15.2, there was a little cultivation of highly salt-tolerant cotton but, owing to poor yields, the land has recently been used to raise ostriches.

Figure 15.3 shows salinization on the lower terrace. At first glance, it appears that this farmland has severe salt damage, but ECp is at most about 3 dS m^{-1}. The ground becomes whitish in early spring, when there is little rain. At other times, it looks the same as ordinary farmland, and there is not much salinization effect on fruit trees.

Figure 15.4 is the oblong salt lake in the southeast part of Luodong block, which stretches from west-southwest to east-northeast (Figs. 7.2 and 15.8).

Fig. 15.1 Salinization on upper terrace (northern part), attributable to high water table caused by low water permeability of subsoil (June 2002)

Fig. 15.2 Salinization on upper terrace (northern part), attributable to high water table caused by low water permeability of subsoil (June 2002)

This lake is a depression into which water drained from the surrounding area flows. Its salt concentration is 40 dS m^{-1} or higher, and it therefore heavily impacts nearby farmland. Figures 15.4, 15.5, and 15.6 show saline farmland in vicinity of the salt lake. Much of the farmland has ECp of 10 dS m^{-1} or more, where almost no crops other than high salt-tolerant cotton can grow.

Fig. 15.3 Temporary salinization on lower terrace (southern part), which appeared only in early spring because of little rainfall (March 2004)

Fig. 15.4 Southern end of salt lake, which is lowest point in Luodong block (ECw: 41.5 dS m^{-1}; June 2002)

Fig. 15.5 Salinization in saline farmland near salt lake (western part), attributable to high water table (ECp: 8.5–11 dS m^{-1}; June 2002)

Fig. 15.6 Cotton in saline farmland near salt lake (western part), which is only feasible crop under severe saline conditions (ECp: more than 10 dS m^{-1}; August 2002)

15.3 Water Table and Water Quality Trends and Salinization

Figure 15.7 shows the impact of water table change in the area of salt-damaged farmland, based on records from Luodong block and from yearly change of water table observed in an observation well in Dali (Kitamura et al. 2003). It is evident

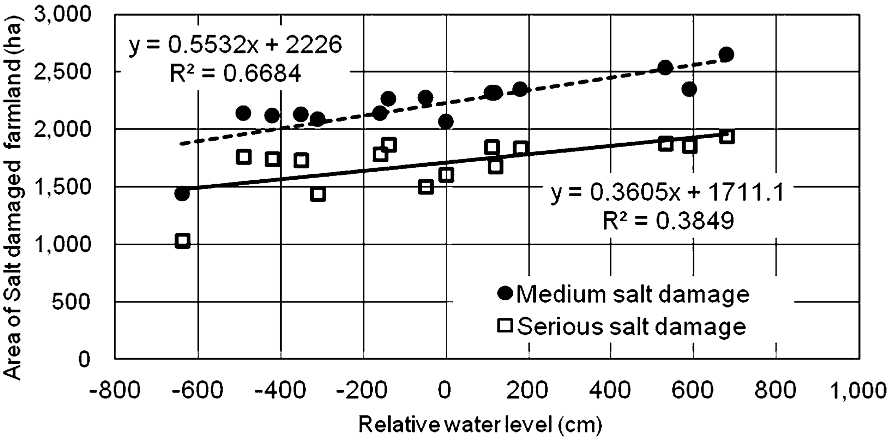

Fig. 15.7 Effect of change in water table depth at Dali, in area of salt-damaged farmland in Luodong block

Fig. 15.8 Location of Luodong block in Luohui irrigation district, and distribution of 73 observation wells used in this study

from this figure that water table rise increases the amount of salt-damaged farmland.

Figure 15.8 shows the distribution of observation wells in Luodong block (Solomon et al. 2005). The depth of groundwater and its quality, including EC, pH and Na^+, Mg^{2+} and Ca^{2+}, were measured at each observation well. According to the figure, 60 wells (75 %) were for irrigation, six (7.5 %) for drinking water, five (6.3 %) for insecticide mixing, three (3.7 %) for industrial or other use, and six (7.5 %) were unused.

Table 15.1 shows results from 73 observation wells in late August 2002 (Kitamura et al. 2003). Water table depth ranged from 2.05 to 37 m, with average 12.9 m. Groundwater electrical conductivity (ECw) had a wide range from 0.53 to 21.0 dS m^{-1},

Table 15.1 Water table depth and groundwater ECw observed at 73 wells in Luodong block of Loess Plateau (figures are percentage of number of wells within the ranges of water table depth and groundwater ECw to total number of wells)

Water table depth ranges (m)	ECw value ranges ($dS \cdot m^{-1}$)				
	$ECw < 1.5$	$1.5 \leq ECw < 3$	$3 \leq ECw < 6$	$ECw \geq 6$	Totals
0–5	0.0	4.1	6.8	6.8	17.7
5–10	1.4	12.3	8.2	5.5	27.4
10–15	12.3	5.5	1.4	1.4	20.6
15–20	9.6	1.4	0.0	0.0	11.0
20–25	12.3	1.4	1.4	0.0	15.1
25–	6.8	1.4	0.0	0.0	8.2
Total (%)	42.4	26.1	17.8	13.7	100.0

averaging 3.0 dS m^{-1}. The table clearly confirms that the higher the ECw value of a well, the shallower the water table depth. Wells with ECw values 3.0 dS m^{-1} or greater were those where the water table was shallow, especially where it was less than 10 m from the surface.

Based on Table 15.1, this tendency is attributed to acceleration of soluble salt dissolution in the subsoil by a rising water level. Large amounts of soluble salts are found in subsoil. The reason is that salts accumulated in topsoil during dry seasons or long spells of dry weather leach out, when irrigation begins and after subsequent rainfall and irrigation. The salts thereby move downward into the subsoil. Because of this, water table depth greatly influences groundwater ECw, which suggests that appropriate control of water table depth is important for preserving water quality.

In Luodong block, especially its upper terrace, the electrical conductivity of soil saturation extract (ECe) was high at depths of 80 cm and greater. If the water table rises to within 2–3 m of the surface, soluble salts dissolve into the groundwater and rapid capillary rise occurs, resulting in severe salinization. Field soil moisture near observation wells in the northern part of the Luodong block rapidly increased with soil depth, confirming a large upward flux and indicating the vigorous capillary rise of moisture from the water table level. The salinization of fields shown in Figs. 15.1 and 15.2 is indeed the result of this process.

It was also confirmed that groundwater ion concentration tended to increase with the water table rise. This is attributed to the rising water table accelerating the dissolution of soluble salts in the subsoil, as with ECw. Accordingly, keeping the water table below a certain level will help control salt concentration. In particular, Na^+ accounted for 75 % of cations, higher than Mg^{2+} and Ca^{2+}. As such, there are concerns about the risk that continued use of this groundwater for irrigation will make the soil sodic. Sodification is a process in which exchangeable sodium content of the soil increases.

The sodium adsorption ratio (SAR) is an indicator of the risk that soil will become sodic, which would, for example, decrease plant nutrient absorption or soil water permeability. SAR is calculated as follows.

$$\mathrm{SAR} = \mathrm{Na}^{+} \Big/ \left\{ \left(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} \right) \Big/ 2 \right\}^{1/2}, \tag{15.1}$$

where:

Na^+ is groundwater sodium concentration ($\mathrm{mEq \cdot L^{-1}}$),
Ca^{2+} is groundwater calcium concentration ($\mathrm{mEq \cdot L^{-1}}$), and
Mg^{2+} is groundwater magnesium concentration ($\mathrm{mEq \cdot L^{-1}}$).

If soil contains a large amount of Na^+, it creates an environment unfavorable to plant growth in terms of soil chemical and physical properties, in addition to being a physiological disturbance to plants. When Na^+ persists by being adsorbed onto soil colloids, those colloids disperse throughout the soil, forming a finely structured and hard stratum and greatly reducing soil water permeability. However, if there is enough Ca^{2+} and Mg^{2+}, they neutralize the effect of Na^+. In Luodong block, the groundwater SAR (SARw) is high overall, and especially high in central and western sections. Even if the water table is low, SARw remains at more or less the same value. This is attributed to the fact that even if Na^+ concentration declines as the water table falls, Ca^{2+} and Mg^{2+} concentrations likewise decline. Therefore, even if Na^+ concentration is comparatively low, the SARw value will remain high. FAO water quality standards include a warning that if SARw is 9 or higher, crops may not get enough micronutrients because of soil alkalinity (Ayers and Westcot 1989). Such damage has been confirmed in the Luohui irrigation district. Figure 15.9 integrates a US Salinity Laboratory (1954) graph showing the risk of salt injury versus that of sodium damage (sodification) with groundwater ECw and SARw data for Luodong block. The figure clearly shows that the water of nearly all observation wells is at risk of salinity and sodicity. In August 2002, groundwater data showing low- or medium-level sodium damage accounted for at least half of all data. SARw values then gradually increased, and in August 2004 groundwater in the high- and very high-level ranges for risk of sodium injury, which did not exist in August 2002, accounted for about 40 % of the total. This increasing trend is attributed to the strong effect on Na^+ dissolution by farmland flooding caused by extremely heavy rain from August through October 2003. This event had an exceedance probability of 1/30 for rain during this period, that is, a heavy rain occurring with a frequency of once in 30 years.

15.4 Water Management to Prevent Salinization

The causes, processes and countermeasures of salinization in Luodong block are presented in the following, as outlined in the work of Solomon et al. (2005).

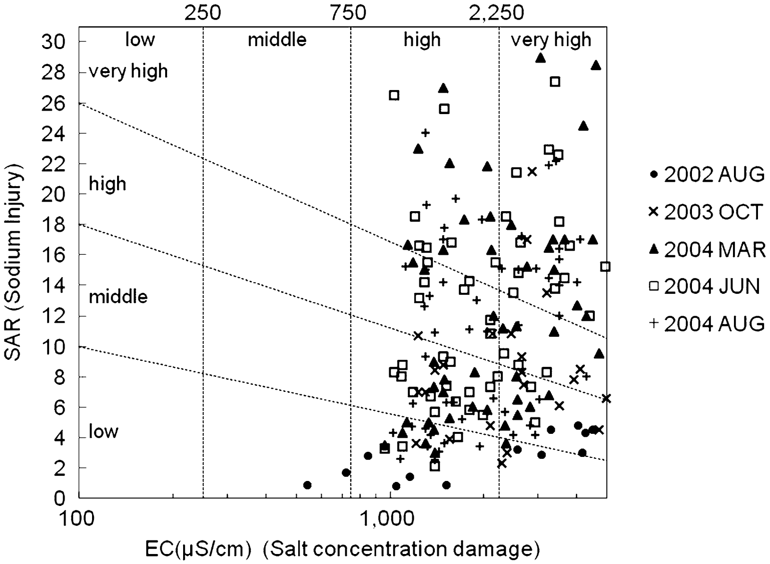

Fig. 15.9 Quality of irrigated water based on standard of U.S. Department of Agriculture (modified from US Salinity Laboratory 1954)

15.4.1 Classification of Salinization Processes

Salinization processes in the irrigation district can be classified into four categories. These include: (1) salinization caused by capillary rise of groundwater; (2) salinization and sodification caused by continued irrigation using groundwater with high salt concentration; (3) salinization caused by cultivation on waste (high salt concentration) soil, from well digging and spread in the field near wells; and (4) salinization of poorly drained areas, caused by topographic and drainage characteristics.

15.4.2 Causes of Salinization

The causes of the above salinization processes include: (1) high water table—a major cause, especially when the water table is within 2–3 m of the surface (northern and central areas); (2) groundwater with high salt concentration (northern and central areas), (3) soluble salts accumulated in the subsoil; (4) lower layer having soil with low water permeability (especially upper terrace); (5) large conveyance loss of water channels (especially unlined channels or those with damaged linings) and large seepage loss in fields (caused by irrigation between ridges and border irrigation with long ridges); (6) inadequate management of drainage channels and groundwater (in particular, failing underground drainage); and (7) drainage systems with management-related problems (irrigation and drainage systems managed by different entities).

15.4.3 Measures to Prevent Salinization of Irrigated Farmland

Measures to prevent salinization of irrigated farmland include: (1) Improving drainage system efficiency, and system management such that the water table is maintained at an appropriate level. This requires consideration of both surface and underground drainage. (2) Restricting the use of groundwater with high salt concentration, and creating usage standards corresponding to salt concentration. (3) Hauling away waste soil with high salt concentrations, where it will not affect farmland when digging wells. (4) Prohibiting actions that impede surface drainage, and carrying out repairs and construction in places that may impede drainage; raising awareness among local people is also important. (5) Actively applying and promoting warping (deliberate flooding with silty water), which makes advantageous use of soil runoff from the Loess Plateau (see "Improvement of saline soil with warping" below). (6) Prevent waterlogging, and promote planting of trees along water channels or around fields (actively use bio-drainage). (7) Promoting improvement of irrigation efficiency (doing everything possible to reduce conveyance and field water application losses).

To realize the intent of point (7), the following actions should considered:

(a) Promote channel lining, repair all damaged places, and avoid high-grade application of lining.
(b) Make field ridge (long-side) length as short as possible, and improve the accuracy of field leveling work to increase the flow speed of water.

(8) Integrate irrigation system management (currently performed by the irrigation district) and drainage system management (currently performed by the Dali County People's Government), and establish a system for this purpose.

We have briefly reviewed drainage channel construction, leaching, and warp soil dressing options for the Luodong block, including the eight points above.

15.4.4 Drainage Channel Construction

One must consider a variety of factors when designing a drainage system. The most important are the intervals and depths of drainage channels. Spacing channels far apart reduces drainage effectiveness, whereas spacing them too closely decreases cropland, makes tilling difficult, and increases the drainage cost. Making the channels too deep also raises the cost and impairs channel stability, whereas making them too shallow diminishes drainage effectiveness. Therefore, it is important to design drainage systems with consideration of these factors as a whole.

Table 15.2 Appropriate values for drainage channel spacing and depths in Luohui irrigation district (Luohui Records Editorial Committee 1995)

Soil texture	Spacing (m)	Depth (m)
Light clay soil	250	2.0
	300	2.4
	350	2.7
Heavy loam	360	2.3
Medium loam	400	2.5
Light loam	350	1.8
	400	2.1

Appropriate intervals and depths of drainage channels in the Luohui drainage district were standardized as in Table 15.2, after having comprehensively considered factors including soil water permeability, groundwater quality, change in soil salt concentration, and sizes of farmland plots (Luohui Records Editorial Committee 1995).

15.4.5 *Leaching*

Leaching is a method that prevents salinization by using water to wash out excess soluble salts that have accumulated on the soil surface and other places, thereby removing them from the soil. Following is a summary of items based on long-term experiments in the Luohui district, which should be considered for enhancing leaching effectiveness (Luohui Records Editorial Committee 1995).

First, the leaching period is chosen dependent on salt composition. This is because ground temperature varies seasonally, and salt solubility changes. It is better to leach sulfates in autumn (August and September), and chlorides in winter and spring. There are different leaching methods. To improve efficiency, it is better to use intermittent flooding, which provides leaching water via several releases, than to use continuous flooding. Wang et al. (1998a, b) and Yano and Honna (1998) obtained the same results in Kazakhstan. Intermittent flooding requires time for salts to fully dissolve and for groundwater to recover, which makes the leaching interval important. Heavy loam generally takes about 72 h, and light loam about 48 h. One must also consider that soil properties make for differences in the amount of leaching water needed for intermittent flooding. With heavy loam, one should begin with a large amount of water, and then reduce it. With light and medium loam, one should use little water at the beginning and end of leaching, but increase the amount used in the middle period. The number of leachings is related to amount of soil salts. Three leachings are favorable if soil salt content is between 0.3 and 0.5 %, and three or four leachings for soil salt content 0.5–0.7 % (Luohui Records Editorial Committee 1995).

The closer the drainage channels, the more effective the leaching. In locations not influenced by drainage channels, leaching actually accelerates salinization. Achieving efficient leaching requires farmland preparation such as deep tillage and leveling prior to leaching. It is reported that deep tillage makes it possible to improve desalination efficiency by about 27 % (Luohui Records Editorial Committee 1995).

Fig. 15.10 Saline farmland before warping (June 2002)

Bordered plot size appropriate for leaching is 3 m × 30–50 m, and it is desirable that elevation difference within the plot be 5–7 cm (1/600–1/700). When irrigating, water is supplied such that it flows from high to low elevations and does not leak outside ridges. When leaching, it is optimum to begin at locations near drainage channels, and leach the farthest locations last (Luohui Records Editorial Committee 1995). After leaching, plowing the soil surface to suppress capillary rise and evaporation from that surface prevents soil surface salinization.

15.4.6 *Warp Soil Dressing*

Luo River water has a comparatively low salt concentration (total dissolved solids or TDS < 1.056 g L^{-1}; pH $= 7.9$) and high sediment content, with sediment particle size between 0.0399–0.0431 mm. Especially during the flood season, its water is muddy because it contains much runoff from the Loess Plateau (maximum sediment content is about 70 % by weight, and it also contains nutrients from upstream). This water is drawn onto saline land to flood it. Time is allowed to let the water seep into the ground and to let suspended soil precipitate. In other words, leaching and warping are done simultaneously. This is a way to improve saline soil by ingeniously taking advantage of the watershed's material cycle, and it is also effective in reducing the amount of sediment runoff into the Yellow River. Figures 15.10, 15.11, 15.12, and 15.13 illustrate the process of improving saline farmland by warping. Figure 15.10 shows saline farmland before warping. Only halophytes grew there, and the EC value of soil pore water (ECp) was about 7 dS m^{-1}. Soil banks in the

Fig. 15.11 Warping on saline farmland (Luohui Records Editorial Committee 1995)

Fig. 15.12 Saline farmland in the process of soil improvement after warping (October 2003)

background are dikes to contain flooding by muddy water rich in silt, in preparation for soil improvement by warping the following year.

Figures 15.11 and 15.12 show saline farmland being improved by warping. Muddy water containing soil runoff from the Loess Plateau is drawn onto the farmland to flood it. The area is then left until it dries.

Fig. 15.13 Farmland improved by warp soil dressing in 1999 (June 2002)

Figure 15.13 shows saline farmland revived by warping, so it can be planted with crops.

Soil productivity of farmland improved by warping is much greater, because of improvements in soil structure, moisture characteristics, fertility, water permeability, and soil air content. According to a study of Luohui irrigation district, average organic matter in the top 20 cm of improved farmland increased by 37–44 %, while total nitrogen increased by 35–48 % (Luohui Records Editorial Committee 1995). Also, because the soil surface is raised, relative depth to the water table increases. During the 12 years from 1969 to 1981, 3,722 ha of saline farmland were improved by warping (Luohui Records Editorial Committee 1995), which means that on average about 310 ha of land were improved by this method each year. It is desirable to do warping in summer, when temperatures are high. This is because the effectiveness of leaching increases with temperature (Luohui Records Editorial Committee 1995). Investigation of the sustained effect after warping showed that in areas with good drainage, seasonal change in soil and groundwater salt concentrations was not great, and yearly change also gradually declined, ultimately stabilizing within a certain range. But in areas with poor drainage, salt concentrations of soil and groundwater increased at a very high rate. There were reports that crop production again became impossible after just one or two crops, because of salinization (Luohui Records Editorial Committee 1995). Therefore, sustaining the effect of saline soil improvement by warping after implementation requires that drainage facilities be provided.

15.5 Conclusions

We selected for study the eastern block of the Luohui irrigation district, which is also called the Luodong block. This area is on the southeast Loess Plateau. Based upon onsite experiments in the research area, we classified salinization processes, illustrated causes of farmland salinization, and proposed countermeasures to prevent and rehabilitate salinized farmland by drainage channel construction, leaching, and warp soil dressing. In all cases, adequate functioning of drainage systems is important. Lowering groundwater level by improving the drainage system, controlling the dumping of saline soil, and managing the use of saline irrigation water are recommended.

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Chapter 16
Enhancing Drought Resistance of Plants Using Wheat as a Test Crop

Xi-Ping Deng

Abstract Achieving greater crop yield per unit of rainfall is one of the most important challenges for wheat production in dryland environments. Efficient use of limited water resources may be one means of achieving this goal. This chapter reviews the physiological adaptation to water deficit under variable environmental conditions in wheat. In addition, it reveals the compensatory effect of limited irrigation and fertilizer supplementation on wheat water-use efficiency (WUE) and highlights the breeding of new varieties for high WUE that could improve wheat productivity under water-limited environments. Considerable potential for further improvement in wheat productivity in semiarid areas seems to depend on effective conservation of moisture and efficient use of limited water. Different crops, soil and water management strategies should be adjusted according to the conditions that prevail in the various semiarid areas. Wheat productivity can be significantly improved by integrating the soil and water conservation approach and the regulated cropping system with cultivating drought-tolerance and water-saving cultivars.

Keywords Semiarid area • Dryland wheat • Physiological adaptation • WUE improvement

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16.1 Introduction

Global demand for wheat is growing faster than realized gains in genetic yield potential. Currently the increase in the yield potential of wheat is <1 % per year in most regions (Reynolds et al. 2000). In China, research into improving wheat production has focused on improving production in the semiarid areas with low to medium yields. This research has required the development and dissemination of wheat production technologies that could lead to a sustainable more stable wheat yield in these areas (Shan 2002).

Periods of drought alternating with relatively short periods of water availability are conditions common to many semiarid areas of the world (Richards et al. 2002). Typical semiarid areas in China are characterized by water deficits and low productivity, resulting in marginal ecological conditions. Annual rainfall in this area is ca. 350–550 mm. The distribution of precipitation during spring, summer, autumn and winter is 12–15, 46–65, 20–35 and 1–3 %, respectively, with the majority of rainfall occurring from July to September. High intensity rainfall events occur mainly as a result storm activity (Shan and Chen 1993). Wheat growth response to this highly variable water environment is complex and uninsurable because of numerous climatic conditions such as: the variability in the frequency of dry/wet periods; variable drought levels; the speed of drought onset; and varying patterns of soil water deficit and/or atmospheric water deficit.

In semiarid areas, the potential of higher wheat yields exists. Water conservation is the biggest challenge to the realization of high wheat yield in semiarid areas. It is important to use the limited water resources efficiently. The objective of this review was to understand some beneficial effects of wheat response to water deficit under variable conditions. We also discuss how to improve wheat WUE, and exploit drought-resistance and water-saving potential for improving wheat production in China's semiarid areas.

16.2 Wheat Adaptation to Water Deficit and Variable Conditions

Wheat drought tolerance is complex and the numerous mechanisms involved are still unclear. Research on the effects of water deficits on the physiological processes at the molecular level has shown that some enzymatically mediated processes increase but others decrease (Loggini et al. 1999). For instance, root/shoot communication is being increasingly studied at the molecular level (Davies and Zhang 1991; Chandler and Robertson 1994; Giraudat et al. 1994; Griffiths and Bray 1996). A crop's sensitivity to drought varies during different growth stages. This provides an opportunity to choose the ideal moment for crop irrigation (Blum 1996). Furthermore, a crop's drought response, including the degree of yield reduction, varies in the different growth stages, especially those associated to seed yield. Wheat's physiological processes are serially affected by drought. The order of these effects is: growth, stomatal movement, transpiration, photosynthesis and translocation (Shan and Chen 1998; Deng et al. 1999, 2000a). These findings allow irrigation scheduling to be designed to minimize wheat yield loss.

16.2.1 Wheat Drought-Tolerance During Seedling Establishment

Wheat seedling establishment under water deficit conditions (Bray 1997; Singh et al. 1997), seedling response to stress signals, and the effect of stress in the regulation of gene expression have been widely researched. Such work allows a better understanding of processes that occur in response to drought stress at the molecular level (Bray 1997; Singh et al. 1997; Chrispeels and Maurel 1994; Alejandra et al. 1997). In particular, findings have been reported on hydrolysis in seed germination (Banik et al. 1996), anabolism during seedling establishment (Toyomasu et al. 1998), plumule elongation growth (Collett et al. 2000), protein and gene regulation by plant hormones (McCourt 1999) and water absorption mechanisms during seedling establishment under water deficit conditions (Maurel 1997; Johansson and Karlssona 1998).

Crops are less tolerant to drought during the germination and seedling stages (Nielsen and Nelson 1998; Desclaux et al. 2000). Deng et al. (1999) showed in spring wheat that the plumule elongation stage is the most sensitive to water deficit. Therefore, under water deficit conditions, the maintenance of anabolism and slow growth are strongly associated with ATP energy levels in cells, because seedling establishment involves the energy-requiring metabolic reactions. Deng et al. (2002b) suggested that the mechanism of seedling drought-tolerance involved regulating ATP energy levels to change the ratio of catabolism to anabolism, resulting in the accumulation of osmotic component and the depression of osmotic potential in growing tissue. Under these conditions the ability of water uptake in seedlings is increased, allowing reduced seedling growth during water deficit conditions.

In response to declining soil moisture, Whan et al. (1993) suggested that indeterminate cultivars that have early/vigorous seedling establishment accumulated a relatively large biomass by the beginning of the seed filling stage. These cultivars were able to remobilize accumulated photosynthates. Therefore, these cultivars were best adapted to drought conditions. Water stress inhibited plumule elongation and reduced seedling vigor, resulting in shorter coleoptiles potentially resulting in poor seedling establishment and reduced yield. To achieve better establishment and higher yields under water-limited conditions, the use of longer coleoptile length is probably one of the best approaches. Long coleoptile wheat plants or lines could be used to test and select the desired level of seedling establishment. In wheat, the availability of molecular markers for selected coleoptiles-length genes can enhance selection efficiency. High throughput markers are being developed for genes of interest and the efficiency of implementation of these markers was assessed and optimized in the Australian CSIRO wheat-breeding program (Richards et al. 2002).

16.2.2 Water Use Efficiency and Root–Shoot Relations of Wheat Plant

The current research in the wheat water-use efficiency and root–shoot relationship at the molecular level is important, but it should be accompanied by research at the whole plant level. In wheat, the success of seed yield depends primarily on the efficiency of leaves in controlling water loss, including the effectiveness of roots in water uptake in competition with other plants. Dehydration tolerance depends on molecular level traits, such as osmotic adjustment, water transduction in plant tissue and how water deficiency affects enzyme-mediated processes. Clearly, drought tolerance/avoidance will contribute to successful wheat production under semiarid conditions. Avoidance of severe water deficit requires coordination at the plant level between the control of water loss from transpiring shoots and water absorption through root systems. Using gas exchange and Carbon-13 stable isotope methods Zhang and Shan (1998) demonstrated the sequence of WUE in modern wheat cultivars as follows: irrigated varieties > varieties of both irrigated and dry land > dry land varieties. Zhang et al. (2002) showed that in wheat evolution from 2n→6n, WUE at the plant level was positively associated with increasing ploidy chromosomes, while root system size and root/shoot ratio decreased with the increase of ploidy chromosomes under drought and irrigated conditions. The growth of root systems adversely affected WUE (Zhang et al. 2002). This negative association resulted in decreased root redundancy as ploidy chromosomes increased, which then increased the WUE of the wheat plant. These findings suggested that using genetic breeding is important to clarify the water-saving potential of wheat.

A deep-rooted system is synonymous with increased soil water uptake and better performance under drought conditions. However, the root system of cultivars grown in a particular region/climate could be adapted to those conditions meaning that further improvement was redundant. Research on whether current wheat cultivars have the ability/inability to extract all available soil-water is still required (Angus and van Herwaarden 2001). If soil water remains after harvest then a genetic improvement in rooting depth and/or distribution may be required. However, this trait is difficult to measure. The simplest way to increase rooting depth and root distribution of crops is to increase the duration of the vegetative period (i.e. the period up to anthesis). In some cases, this may be achieved by early or late sowing of the flowering genotypes. Greater osmotic adjustment may result in more root growth and increase the ability for the plant to extract additional soil water. However, selection for osmotic adjustment is relatively difficult, although a novel method of selection during the haploid stage in wheat has been demonstrated (Morgan 1999).

16.2.3 Photosynthetic Characteristics of Wheat Under Drought Conditions

Under drought conditions, stomatal closure and inhibition of chloroplast activity reduce photosynthesis (Farquhar and Sharkey 1982). Stomatal closure increases the resistance to CO_2 diffusion into the leaf. Inhibition of chloroplast activity at low soil water potential reduces the capacity to fix available CO_2, which cannot be overcome by increased CO_2 concentrations (Boese et al. 1997). Although stomatal closure generally occurs when plants are exposed to drought, in some cases photosynthesis may be controlled by the chloroplast capacity to fix CO_2 when compared with increased diffusive resistance (Faver et al. 1996). However, how photosynthesis adapts to drought-type environments is unclear.

In semiarid environments, photosynthesis was variable under different soil moisture regimes (Deng et al. 1996). Under gradual soil drying conditions, wheat exhibited a higher photosynthetic rate than under fast soil drying conditions. Under gradual drying conditions osmotic adjustment increased, while under more rapid soil drying conditions osmotic adjustment remained constant. Osmotic adjustment allows for photosynthetic and growth maintenance via stomatal and photosynthetic regulation (Turner 1986; Shangguan et al. 1999). The evidence showed that under mild and/or moderate soil water deficit conditions, photosynthetic depression occurred from stomatal closure or limitation, but not from biochemical reactions. However, under severe soil water deficits, non-stomatal factors including limiting enzymes may have been responsible for photosynthetic capacity decline (Kalt-Torres et al. 1987; Du et al. 1996, 1998). Photosynthetic decline at midday was mainly induced by severe vapor pressure deficit (VPD), with stomatal limitation suggested as the major cause (Schulze 1986; Xu and Shen 1997). Under natural semiarid conditions, this decline usually resulted from a soil water deficit that induced a decline in leaf water potential. Deng et al. (2000a) reported that soil water deficit and high VPD simultaneously induced the midday decline in photosynthesis, indicating that both stomatal and non-stomatal limitations were responsible for the photosynthetic decline in spring wheat under a semiarid environment.

Under water deficit conditions, the plant is able to synthesize abscisic acid (ABA) in the root system. ABA is transported via the xylem to leaves causing several ion channels which regulated the guard cells that trigger stomatal closure (Slovik and Hartung 1992; Schulze 1994). This may be linked to the role of farnesylations that have been associated with ABA signal conduction (Grill and Ziegler 1998; Pei et al. 1998). The chloroplasts' capacity to fix CO_2 indicated that the Rubisco holoenzyme is assembled in a catalytically inactive form then activated by Rubisco activase (RCA) (Portis 1992; Mott et al. 1997).

Deng et al. (2000b) indicated that the significant decline in stomatal conductance at midday was parallel to the decline in photosynthetic rates resulting from severe water vapor deficit. The deviation of stomatal conductance between the control and soil moisture deficit treatments was closely related to the leaf water status that was affected by soil moisture deficit. Based on these findings the following hypothesis was proposed: molecular mechanism of stomatal conductance variation and intercellular CO_2 concentration oscillation is closely linked with ABA-reduced stomatal response and activation status of the enzyme Rubisco affected by circadian oscillation of RCA.

16.3 Compensatory Effect of Limited Irrigation in Wheat

Loomis and Connor (1992) suggested three strategies to improve water use in dry areas. First, maximize crop evapotranspiration (ET). Second, maximize crop transpiration as a fraction of total evapotranspiration. Third, maximize crop WUE. Consistent with these strategies under water limited conditions, Deng et al. (2002a) proposed three different supplemental irrigation strategies to achieve maximum yield gain (200 mm of supplemental water); greatest WUE (100 mm of supplemental water) and highest irrigated WUE (60 mm of supplemental water). In semiarid conditions the water threshold quantum for limited irrigation of spring wheat is 60 mm.

Previous studies widely reported that yield loss is associated with drought at different stages of plant development (Mary et al. 2001; James et al. 2001). Villareal and Mujeeb-Kazi (1999) showed that crown root initiation and anthesis are the two most critical stages in wheat that affect yield loss from drought stress. Liang et al (2002) demonstrated that the drying-rewatering alternation had a significant compensatory effect on reducing transpiration, increasing WUE and maintaining wheat growth under drought conditions.

Deng et al. (2002a) demonstrated in Guyuan County (Ningxia Uh Autonomous Region; mean annual precipitation/temperature 450 mm/6.5 °C, respectively), a single irrigation of 600 m^3/ha applied at the jointing stage (equivalent to 30 % of irrigated volume of water for a full cropping season with the highest yield) yielded up to 75 % of the highest yield. This resulted in a 2.8 kg increase in grain yield per cubic meter of water. The optimum time for limited irritation for spring wheat was during the jointing stage, which is the critical water deficit period. However, in wheat, the optimum irrigation time was not consistent with highest yield improvement. Therefore, it seems important to make a distinction between the critical growth stage at which yield is significantly reduced by drought from that at which supplemental irrigation results in the highest yield improvement.

16.4 Effect of Soil Fertilization on Wheat WUE

Drought and low soil nutrition are the main limiting factors of dryland wheat production in the semiarid/eroded loess areas of China. Fertilizer supply of the wheat plant is essential for increased grain production in the low yielding areas of semiarid area. These areas have low nutrition in soils because of severe water loss and soil erosion. Adequate fertilizer supply can be achieved through the use of organic fertilizers, for example animal manure applications, incorporating crop residues and including legumes in rotations (Shan and Chen 1993). Chemical fertilizers are also used to increase grain production and supplement the crop's nutrition. Under natural rainfall conditions the application of nitrogen and phosphorous fertilizers considerably improves wheat yields. However, the amount and temporal distribution of rainfall greatly influence the efficiency of wheat to uptake the fertilizer, especially for nitrogen. Therefore, rainfall variability greatly increases the risk of using fertilizer in dryland environments. Usually, wheat crops recover only 30–50 % of applied nitrogen (Raun and Johnson 1999). The rest is lost either dissipated into the atmosphere or as leachate in the soil profile/ground water (Harmsen et al. 1983).

Most of the soils in the loess region are calcareous and these soils are usually distributed on the eroded hilly tops, with N and P being the most limiting nutrients in hilly loess (Shan and Chen 1993). The deficiency results from the high pH and runoff (Wei et al. 2000). The increases in crop yield and WUE from N fertilizer application were observed in several dryland areas where crops were grown on the same land for several years (Shan and Chen 1993). Liu et al. (1998) indicated that maximum yield and highest WUE were achieved under an optimum fertilizer input of 90 kg N and 135 kg P_2O_5 per hectare in the semiarid field conditions of hilly loess area near Ningxia. In spring wheat, increased fertilizer application was positively correlated with grain yield and WUE (correlation coefficients: 0.959 and 0.894, respectively). Increasing fertilizer levels significantly increased fertile spikelets number, kernels per spike and kernel weight. Fertile spikelets number was sensitive to fertilization, whereas kernel number and weight was mainly affected by plant density. Fertilization applied in spring wheat improved root system development, enhancing root growth in the cultivated soil layer (0–20 cm). Ameliorated root systems showed improved crop water use and nutrient absorption, resulting in increased crop yield and water use efficiency. Liu et al. (1998) highlighted the compensatory effects of improving inorganic nutrition on efficient water use in dryland wheat production.

16.5 The Effect of Water Stress in Wheat: Assimilate Translocation Grain-Filling

In addition to carbohydrate assimilation, crop yield is related to assimilate translocation and partition in grain. Study on the regulatory mechanisms of assimilate translocation could prove the physiological basis for the high yield and WUE of wheat. In this study, two winter wheat varieties (*Triticum aestivum.* L, var. Changwu-134 (drought-resistant) and var. Shaan-253 (drought sensitive)), were cultivated in field plots protected from natural rain events from October, 2007 to June, 2008 at the Institute of Soil and Water Conservation, Yangling in Shaanxi Province. Two different water treatments were applied after greening and jointing stages. The treatments were: (1) optimal soil water treatment (the soil water content was 70–80 % of the field water capacity); (2) soil drought treatment (the soil water content was 45–55 % of the field water capacity). The post-anthesis dry matter accumulation and remobilization in vegetative organs were investigated. The photosynthetic traits and antioxidase activities of flag leaves, including carbohydrate metabolism and related enzymes' activity in the stem, leaf sheath and grain were determined. Grain yield, harvest index and WUE were measured and calculated with the main findings from Wang et al. (2009):

1. Drought stress reduced grain weight of Changwu-134 and Shaan-253 (7.84 and 23.36 %, respectively) 35 days after anthesis in the main spike. Drought stress significantly decreased dry matter accumulation in the vegetative organs. Water stress had no effect initially, when dry matter was remobilized from leaf, stem and leaf sheath, whereas there was an increase in remobilization velocity during the

late grain-filling in Changwu-134. In contrast, in Shaan-253 the commencement of dry matter remobilization in the leaf/leaf sheath occurred earlier in the drought treatment compared with control, while the commencement of dry matter remobilization in stem internodes was affected by drought. A significant increase in remobilization rate was found in middle and late grain-filling periods. Under drought conditions, the remobilization rate of pre-anthesis C-reserves increased in Shaan-253, grain weight was more dependent on pre-anthesis reserves. The grain weight of Changwu-134 was associated with the post-anthesis accumulation of photosynthate, an important factor for grain yield formation. Therefore, contribution rates of different vegetative organs to grain yield was ranked as: stem, leaf and leaf sheath. The effect of reserve accumulation change in the same vegetative wheat plant organ on grain weight was closely related to the distance to spike, where increasing distance showed the greater effect of dry matter accumulation and remobilization on grain weight.

2. Soil drought stress resulted in reduced decrement in the post-anthesis photosynthetic active duration. This included a relatively steady phase of chlorophyll content in the flag leaves of Changwu-134 compared with Shaan-253. In Changwu-134, soil drought stress significantly increased the activities of SOD, CAT in the early and middle periods of grain-filling including the activities of POD in the early period of grain-filling and increased malondialdehyde (MDA) content. In Shaan-253, the discordance in active oxygen scavenging system, there was an increased POD activity involving the production of active oxygen. The MDA content of flag leaves showed a significantly rapid rise in post-anthesis period under the drought treatment. Soil drought promoted an increase of soluble protein to resist water stress in the flag leaves of Changwu-134, whereas under similar conditions Shaan-253 could not maintain a normal soluble protein concentration. This resulted in relatively low resistance to water stress. Therefore, under drought conditions, stronger ROS scavenging capacity of antioxidant enzyme system may lighten membrane lipid peroxdation, subsequently maintaining the duration of higher photosynthate supply during the middle and later periods of grain-filling.
3. Soil drought stress led to a significant increase in the total soluble sugar/sucrose content in flag leaves of Changwu-134 than those of Shaan-253 in the early stage of grain-filling. The increased ability of sucrose supply in flag leaves was found in Changwu-134 during the middle and late grain-filling period, while this ability decreased in Shaan-253. The sucrose phosphate synthase (SPS) in flag leaves was the key enzyme determining sucrose synthesis in Changwu-134. For Shaan-253, the increase in flag leaf sucrose content resulted from the joint action of SPS and sucrose synthase (SS), with SS playing a greater role.

Drought stress increased the total soluble sugar/sucrose content of flag leaf sheaths in the two wheat cultivars. Drought delayed the time of carbohydrate remobilization in flag sheath of Changwu-134, but promoted remobilization in Shaan-253. The sucrose content in the flag leaf sheath is highly dependent on changes of SPS and SS activity. The accumulation of sucrose resulted from translocation hindrance during terminal grain-filling in the flag leaf sheath.

16.6 Harvest Index and WUE Under Different Water Treatments

In wheat, the grain-filling stage is the critical period for seed development and yield. In northern China, the wheat grain-filling stage is subjected to different soil and atmospheric moisture levels. Drought is detrimental to the course of wheat grain-filling, thereby decreasing yield. It is important to understand the source-sink relationship under drought conditions during wheat yield formation and the impact on this source-sink regulation cannot be underestimated. Certainly, further research on the effect of water deficit on photosynthesis, the activity of transporting key enzymes and yield of different ploidy wheat during grain-filling stage is required.

Six wheat varieties (two diploid varieties: *Triticum. boeoticum*,*T. monococcum*; two tetraploid varieties: *T. dicoccoides, T. dicoccon;* two hexaploid varieties: Changwu-134 and Shaan-253) were selected. Photosynthetic parameters, sugar metabolism and yield components were measured under different water stress regimes during the grain-filling stage. The pot experiment was conducted to investigate the effect of water deficit on flag leaf photosynthetic rates, sugar metabolism and yield formation. The main findings from Zhao et al. (2010) were:

1. During wheat grain-filling stage the photosynthetic rate of flag leaves in different ploidy wheat reached maximum at anthesis stage, then declined. In comparison, photosynthesis was the most sensitive physiological process during the transition of control level soil-water to severe drought stress. The maximal net photosynthetic rate showed a gradual decrease, with photosynthesis inhibited by drought. In hexaploid wheat the mean maximum net photosynthetic rate (22.03 CO_2 μmol m^2 s^{-1}), was the highest among the six wheat varieties.
2. During the grain-filling stage, the values of the leaf chlorophyll content and stomatal conductance (Gs) in flag leaves of different ploidy wheat changed, with a similar trend in photosynthetic rates. When the wheat grain-filling stage finished, the photosynthetic rate decreased with the reduction of chlorophyll content. Chlorophyll content Descent Phase (RSP value) of hexaploid wheat was slightly higher than that of tetraploid and diploid. The intercellular CO_2 concentration (Ci) of hexaploid wheat remained relatively low, only increasing until 15 days after anthesis. This indicated that the hexaploid wheat flag leaf senesced more slowly than tetraploid and diploid wheat after flowering, with the period of photosynthetic functional maintenance longer compared with other plant parts.
3. Water use efficiency in flag leaves showed a positive association with chromosome ploidy increase. The maximal WUE gradually decreased when soil water conditions changed from control to severe. The maximal WUE of hexaploid species was 7.12 μmol CO_2/mmol H_2O, which were 1.63 and 2.05 times greater than diploid and tetraploid varieties, respectively, reaching the maximum WUE at the beginning of grain-filling stage. The evidence suggests that improved WUE, photosynthetic rate and the duration during post-anthesis are the basis for enhancing grain-filling as the wheat plant evolves from diploid to hexaploid.

4. The relative content of carbohydrate components in stem internode II were stable during wheat evolution from diploid to tetraploid and hexaploid. Carbohydrates mainly accumulated in the stem, with the fructan content being the highest, followed by sucrose content. Fructose and glucose content was the lowest of all the carbohydrates. The relative content of fructanin gradually increased during wheat evolution from diploid to tetraploid and hexaploid. The relative fructan content of Changwu-134 accounted for 72 % of water-soluble carbohydrates, but was the lowest in *Triticum boeoticum*. The main carbohydrate in the stem is fructan where the content increased with wheat evolution. This may be related to transportation during the grain-filling stage.
5. The change of sugar content and the key enzyme activity on different parts of the wheat plant is parallel in wheat evolution from diploid to tetraploid and hexaploid. Fourteen days after flowering, the sucrose content in the flag leaf and the fructose and glucose content of stem were: tetraploid > hexaploid > diploid. The sucrose content in grain and fructan content in stem were: hexaploid > tetraploid > diploid. The activity of sucrose phosphate synthase (SPS) in flag leaves and external fructan hydrolase (ETH) in the stem changed: diploid > tetraploid > hexaploid, while the sequence in SPS activity in grain was: hexaploid > tetraploid > diploid. The trend of SPS activity in stem was: hexaploid > diploid > tetraploid. These findings demonstrated that SPS activity in flag leaves and external fructan hydrolase (ETH) in stem of diploid were higher compared with the others. Main sugar content and key enzyme activity of hexaploid wheat were higher compared with other sugars during the mid-grain-filling stage. Because the sugar metabolism of hexaploid wheat was more active than other wheat materials, large amounts of carbohydrates accumulated in different plant organs.
6. In the evolution of wheat from diploid to tetraploid and hexaploid, the dry weight of root systems initially increased and then declined. The root/shoot ratio decreased gradually, with aboveground biomass, grain weight, seed number, grain yield, harvest index and WUE showing a gradual increase. Water stress was a key factor that influenced the harvest index and WUE during grain-filling stage. In common wheat, drought aggravation ranged from no water stress to serious, resulting in the harvest index initially increasing then decreasing, with values of 41.38, 42.26 and 38.20 %, Whereas water use efficiency for biomass increased gradually with values of 2.39, 2.43 and 2.53 g kg^{-1}, respectively, and WUE for grain yield were 1.06, 1.10 and 1.05 g kg^{-1}, respectively. Therefore, moderate water stress in wheat may improve harvest index and WUE.

16.7 Ecophysiological Approaches for Wheat WUE Improvement

Attaining greater yield per unit of rainfall is an important challenge in the dryland wheat. WUE represents a given level of biomass or grain yield per unit of water used by the crop. Increasing concern of water availability in both irrigated and

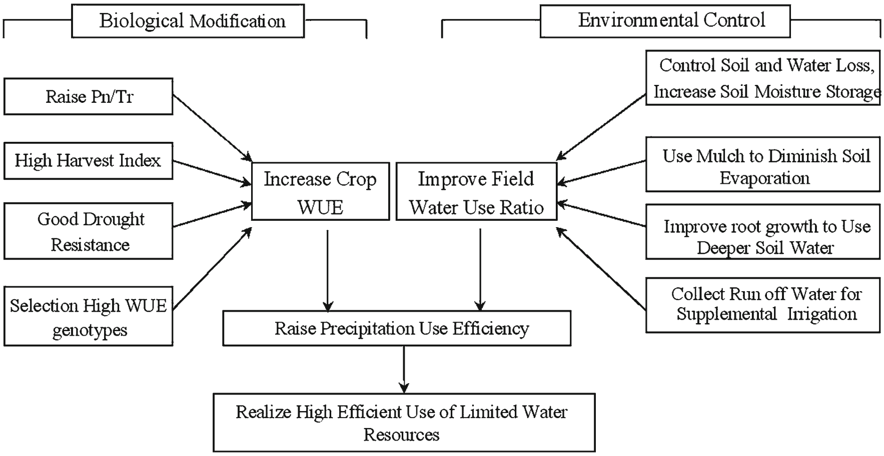

Fig. 16.1 A schematic representation of comprehensive technical approaches to improved crop production in semiarid regions within eroded environments

dryland agriculture has resulted in renewed interest in understanding how WUE can be improved and how farming systems can be modified to increase WUE (Hatfield et al. 2001). Maximizing WUE may be more suited in areas where water, but not land, is limited (Oweis et al. 2000). There is a real-time requirement to understanding wheat-growth response to water deficit. The possibility exists to combine the knowledge of crop adaptation and water use with available technology to efficiently control limited water resources.

The effective use of rainfall and the optimization of WUE are critical for promoting increased wheat yield in dryland farming systems (Shan 1998). These can be summarized in Fig. 16.1.

Variable water conditions in semiarid environments are the major issue influencing crop growth. Water-saving agricultural practices must be designed and implemented. Central to such research should be the investigation of the relationship between the effect of drought stress on crop physiological processes and the yield formation ability.

In the southern hill country of Ningxia Uh Autonomous Region, China, where the mean annual rainfall is approximately 450 mm, the spring wheat yield was 0.75–2.25 tones/ha with the water consumption at 280 mm. This is approximately 62 % of the annual rainfall (Shan and Chen 1998). The above figures show the possibility for a considerable improvement in using the surplus rainfall. Increasing the use of the surplus rainfall requires a comprehensive approach including: prevention of water loss and soil erosion; elimination of topsoil evaporation; extraction of water stored in deeper layers and the steady heightening of the absorbable share of water by crops. For example, in the semiarid Loess Plateau water-saving techniques involves: capturing more rainfall by constructing leveled terraces on high-yield farms; the use of harvested rainwater for limited irrigation; tillage practices that conserve water and soil; the introduction of drought-tolerant varieties and the application of manure and fertilizer. In addition, in low-yielding dryland wheat production, the use of chemical fertilizer has played a major role (Deng et al. 2000b; Shan 2002). In a 10-year period (1980–1990), dryland wheat production in the area doubled its annual output. The main contributing factor to this change was the use of chemical fertilizer (Shan and Chen 1993).

Changes in soil management practices including a reduction of soil surface evaporation have been successful in some locations (Gregory et al. 2000). It is possible to increase WUE by 25–40 % through soil management practices that involve tillage. Li and Xiao (1992) demonstrated that the use of a mulch crop for field cover using green manure plants, crop residue, or plastic film protects the soil from moisture loss through reduced soil water evaporation, and reduced soil erosion. These practices significantly improve soil fertility and water conservation. Concurrently, there was an increase in wheat yield and WUE in the low crop yield in the surveyed areas. Xu (1992) showed that mulching significantly improved water conservation and soil fertility, resulting in large increases in dryland wheat yield. When 30 tones/ha of green manure was used on fallow land, about 50 mm of water was conserved, soil organic matter and nutrients were enhanced, crop yield increased by 2.25 tones/ha and WUE increased 23 %. Numerous results across different climatic regions suggest that straw mulching significantly improves a fields ability in water uptake, soil-water supply and reducing soil evaporation (Zhang and Guo 2000; Wang et al. 2002; Xu et al. 2002). In semiarid area, straw mulching is an important water conservation technique to economize the limited water supply, along with reducing excess plant uptake of soil nutrients. Research emphasized that straw mulch does not change a crop's gross water consumption when compared with the control. However it does change the proportion between soil evaporation and plant transpiration. This is suggests that straw mulch improves water efficiency where resources are limited, resulting in improved crop productivity.

Genetic advances in grain yield under rainfall conditions have been achieved by empirical breeding methods. Progress has been slowed because of the large genotype x season and genotype x location interactions arising from unpredictable rainfall, a common feature of drought-prone environments. Understanding factors that may limit and/or regulate crop yield provides an opportunity to identify and screen for physiological and morphological plant traits. This would allow crops to increase the efficiency of water use and yield under natural rainfall (Richards et al. 2002).

WUE is broader in scope than most agronomic applications and must be considered at the watershed, basin, irrigation district, or catchment scale. The main pathways for enhancing WUE where irrigation is limited would be to: increase the output per unit of water (engineering and agronomic management aspect); reduce water loss to unusable sinks; reduce water degradation (environmental aspect) and reallocate water to higher priority uses (societal aspect) (Howell 2001). These practices infer that when water conservation techniques are adjusted to local conditions, combining water and soil conservation through reducing tillage and adjusting the cropping system using drought-tolerant varieties, an increase in wheat productivity could be achieved.

16.8 Perspectives

In the last decade, our understanding of processes underlying wheat response to drought has rapidly progressed, particularly at the molecular and whole-plant level. Knowledge of these processes is necessary to improve crop management and breeding techniques. Hundreds of plant genes that are induced under drought have been identified (Chaves et al. 2003). A range of tools, from gene expression patterns to the use of transgenic wheat plants, are being used to study the specific function of these genes and their role in wheat plants adaptation to water deficit and WUE (Sivamani et al. 2000). However, because wheat responses to drought are complex, the functions of many genes are still unknown. The new tools that operate at molecular, whole-plant and ecosystem levels are revolutionizing our understanding of plant response to drought, and our ability to monitor it. For example, Carbon isotope discrimination ($\Delta^{13}C$) is a measure of the $^{13}C/^{12}C$ ratio in plant material relative to the value the same ratio of the air on which plants exchange carbon. The $\Delta^{13}C$ is positively related to the ratio of the intercellular CO_2 concentration and the atmospheric CO_2 concentration. Therefore, $\Delta^{13}C$ is correlated with WUE. Consequently $\Delta^{13}C$, because of its convenience and relatively cheap cost, has become an indicator of differences in WUE. Recently this method has been used for high WUE breeding in wheat (Condon et al. 2002). Other techniques such as genome-wide tools and thermal or fluorescence imaging may allow the genotype–phenotype gap to be bridged, which is essential for faster progress in WUE research.

One possible way of increasing the yield potential of wheat in semiarid areas is to manage transpiration by increasing water use, since highly efficient use of limited water is determined by crop water use and WUE. The increase in transpiration efficiency may result from an increase in photosynthetic rate and a decrease in stomatal conductance. Wheat under drought stress has a self-regulatory process for enduring this condition. These range from metabolic adaptation to reduced growth. If the drought does not damage the crop beyond a critical threshold, then some physiological compensation will take place once the water supply is resumed, thus minimizing the impact of the water deficit on wheat growth and yield (Shan 1998; Deng et al. 1996). Often the highest water efficiency in farmland irrigation is achieved compared with an abundant water supply (Stewart et al. 1983; Turner 1990; Deng et al. 2002a). Limited irrigation refers to a system of crop management in which dryland cultivation is integrated with limited water supply in an irrigation network when in a water-deficient area. For example, when an irrigation network is only able to supply part of the water needed for wheat growth (Kang et al. 2002).

Considerable potential for further improvement in wheat productivity in semiarid environments depends on the effective conservation of moisture and efficient use of limited water resources (Shan et al. 2002). Different crops, soil and water management strategies should be adjusted according to the conditions that prevail in the various semiarid areas. The combination of soil and water conservation practices with cropping system adjustment through the cultivation of drought-tolerant wheat varieties, productivity could be significantly improved.

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Chapter 17
Vegetation Restoration on Loess Plateau

Kyoichi Otsuki, Norikazu Yamanaka, and Sheng Du

Abstract Various measures of soil and water conservation on the Loess Plateau since 1950 have increased vegetation coverage and rapidly reduced sediment load to the Yellow River to the middle Holocene level. The Grain-for-Green project, launched in 1999 as part of National Ecological Environmental Construction Plan, has strengthened afforestation/reforestation on the fragile slopes common in the region. However, vegetation recovery has produced both favorable and adverse effects such as soil desiccation and deterioration of indigenous ecosystems. Adverse effects of *Robinia pseudoacacia*, a major afforestation species native to North America, are the most serious and distinct. Therefore, with a focus on this species, a strategy for vegetation restoration on the plateau is discussed in this chapter. First, ecophysiological and ecohydrological features of *Robinia pseudoacacia* are addressed by comparing with indigenous *Quercus liaotungensis*. Then, a strategy to improve existing *Robinia pseudoacacia* plantations and integrated measures for proper vegetation management are proposed.

Keywords *Robinia pseudoacacia* • *Quercus liaotungensis* • Afforeatation • Reforestation • Vegetation restoration • Soil and water conservation

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17.1 Problems of Vegetation Restoration on the Loess Plateau

The Loess Plateau is an arid or semi-arid highland of north-central China overlain by a mantle of loess which is wind-deposited, fine-grained yellow alluvium. Given its erodible soil, sparse vegetation and heavy summer precipitation, the plateau is highly subject to soil and water runoff; it has transported large amounts of sediment to the Yellow River since 500,000 BP (Shi et al. 2002). About 90 % of the sediment load of the river is provided by soil erosion from the plateau (Douglas 1989; Shi et al. 2002; Wei et al. 2006; Peng et al. 2010; Miao et al. 2011). Intense human activity coupled with rapid population growth severely degraded the environment, especially by increasing soil erosion and water runoff. Sediment yield began to increase around 2500–3000 years BP (Shi et al. 2002; Peng et al. 2010) and then rose abruptly around 1000 years BP to the 1950s (Peng et al. 2010) in response to successive deforestation and agricultural activity along rivers and on steep slopes. Erosion landforms featuring barren lands, rills, gullies and ravines were everywhere.

To remedy this situation and implement sustainable development in areas where the economy is backward and the ecosystem is vulnerable, restoration of the ecological environment by revegetation together with construction of level terraces, check dams and reservoirs has been carried out since the 1950s (Wei et al. 2006; Peng et al. 2010; Miao et al. 2011). Sediment load at Huayuankou on the lower reach of the Yellow River was $3.0–7.2 \times 10^8$ ton/year during the middle Holocene of 6000–3000 years BP, and $15.0–16.0 \times 10^8$ ton/year around 1000 years BP (Peng et al. 2010). The soil and water conservation practices and watershed management along with precipitation decrease have been effective to reduce runoff and sediment load since the late 1970s (Peng et al. 2010; Miao et al. 2011).

In 1998, the Chinese government issued the "National Ecological Environment Construction Plan" and launched a project called "Grain-for-Green" in 1999, aimed at converting farmlands with slopes greater than 25° to forests or grassland (Fan 2003). Grain-for-Green has successfully increased forest and grass areas (Cao et al. 2009; Miao et al. 2011) and contributed to the reduction of sediment load in the Yellow River (Miao et al. 2011). The effects of soil and water conservation practices and watershed management have significantly enhanced, which exceeded those of precipitation decrease since 2000 (Peng et al. 2010). The sediment load delivered to the sea decreased to 1.18×10^8 ton/year during 2000–2007, approximately equal to the middle Holocene value (Peng et al. 2010). However, various problems related to vegetation persist. The largest problem is single species revegetation. Typical single species revegetation is monoplantation of exotic *Robinia pseudoacacia*, the third most prevalent afforestation/reforestation tree in the world, following eucalyptus and poplar (Sakio 2009).

Robinia pseudoacacia has been extensively planted in the plateau since the 1950s, and has become the major tree species in the region (Wu and Liu 2003; Guo et al. 2005; Qiu et al. 2010; Zheng et al. 2011; Wang et al. 2012). It has a number of advantages such as symbiotic nitrogen fixation, fast growth in youth, ease of reproduction, and high specific gravity wood. Consequently, it has been widely planted for a number of purposes. These include reforestation of denuded land, soil improvement, service as a backbone of the agroforestry system, and provision of a diverse range of products including paneling, firewood, livestock foliage and nectar (Boring and Swank 1984; Bongarten et al. 1992; Groninger et al. 1997; Feldhake 2001; Swamy et al. 2002; Wu and Liu 2003; Wu et al. 2002; Lee et al. 2004). However, the expansion of *Robinia pseudoacacia* has triggered debates on adverse effects (Guo et al. 2005; Qiu et al. 2010; Zheng et al. 2011). Most of the following environmental problems have been observed in monocultures of the species: (1) reduction in streamflow by excessive use of soil water (Zhang 1996; Gao et al. 2000; Shi and Li 2001; He et al. 2003; Han 1990); (2) retarded tree growth, often manifest as small old trees (Hou et al. 1991); (3) unstable ecosystems owing to little natural regeneration (Taniguchi et al. 2007); (4) poor organic matter on forest floors (Tateno et al. 2007; Qiu et al. 2010); (5) deterioration of the native ecosystem (Lee et al. 2004); and (6) loss of biodiversity (Sakio 2009; Renato et al. 2012).

Given the severely dry environment, trees planted on the plateau must survive, grow and sustainably nurture proper ecosystems (Cao et al. 2009). In this chapter, ecophysiological and ecohydrological aspects of exotic *Robinia pseudoacacia* are discussed by comparing with indigenous trees such as *Quercus liaotungensis*. Sustainable vegetation restoration on the plateau is also considered.

17.2 Environment in the Marginal Area of Forest on Loess Plateau

A case study was conducted at Mt. Gonglu (latitude 36°25.40′N, longitude 109°31.53′E) at altitude 1,353 m a.s.l. in Yan'an city of Shaanxi Province. Observation stands of 20 × 20 m were placed in a *Robinia pseudoacacia* plantation (about 25 years old), and in an indigenous *Quercus liaotungensis* forest (30–50 years old) at a distance of 150 m in 2002. An open space between these stands was set as a control plot. The *Robinia pseudoacacia* stand was on a southeast-facing slope with declination 26°. The *Quercus liaotungensis* stand and open space were on a southwest-facing slope with declination 22°. Management of the *Robinia pseudoacacia* plantation ceased a long time ago.

On the Loess Plateau, precipitation decreases toward the northwest so forests are disappearing in that direction (Fig. 4.1). Yan'an is within the ecological transition area between forest and grass in the forest steppe zone (zone II in Fig. 4.1). In Yan'an, annual average air temperature is 9.5 °C and precipitation 528 mm. Typical climatic features are cold dry winters and hot humid summers (Fig. 17.1). Precipitation from November to February represents less than 10 % of the annual amount, and that from July to September about 60 %. Spring is the most critical season for vegetation. In that season, evaporative demands such as temperature, vapor pressure deficit (VPD) and solar radiation increase steeply, while soil water remains scarce. Therefore, the soil surface easily dries up and strongly overheats, which hinders vegetation germination.

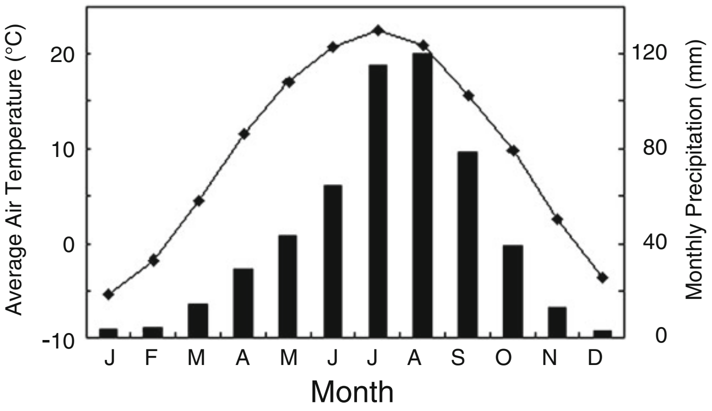

Fig. 17.1 Monthly precipitation and air temperature in Yan'an (1952–2003)

Although Yan'an is in a marginal area for forest, there is almost no natural vegetation because of anthropogenic influences. Secondary vegetation has also been extensively destroyed. Survivings are poor secondary vegetation recovered owing to the recent policy of closing mountain and prohibiting pasturage. More than 85 % of revegetation tree species in the district are *Robinia pseudoacacia*.

At the Mt. Gonglu site, tree density of the *Robinia pseudoacacia* stand was 3,425 trees/ha. This is typical of dense *Robinia pseudoacacia* plantations (3,000–4,000 trees/ha) for firewood and charcoal in China. The stand consisted of only two species, of which *Robinia pseudoacacia* constituted about 93 % in both number and basal area at the breast height (Yamanaka et al. 2006). On the other hand, the *Quercus liaotungensis* stand consisted of 12 tree species, with density 2,375 trees/ha. *Quercus liaotungensis* represented about 28 % in number and about 54 % in basal area at breast height (Yamanaka et al. 2006). Almost 90 % of *Robinia pseudoacacia* had diameter at breast height (DBH) 10–15 cm, whereas that of *Quercus liaotungensis* varied from 5 to 30 cm. These results indicate that the *Robinia pseudoacacia* plantation is an artificial forest of uniform age and its succession was somehow restrained, whereas the *Quercus liaotungensis* is a reproductive biodiverse forest for this dry environment. Based on these results along with the information of the major tree species in the forest steppe zone of the plateau shown in Chap. 4, we assume *Quercus liaotungensis* to be the major tree species forming a local climax community.

17.3 Ecophysiological Aspects of *Robinia pseudoacacia* and *Quercus liaotungensis*

We must understand the ecophysiological aspects of prospective tree species for proper vegetation restoration. Drought tolerance is the most important aspect in arid and semi-arid areas.

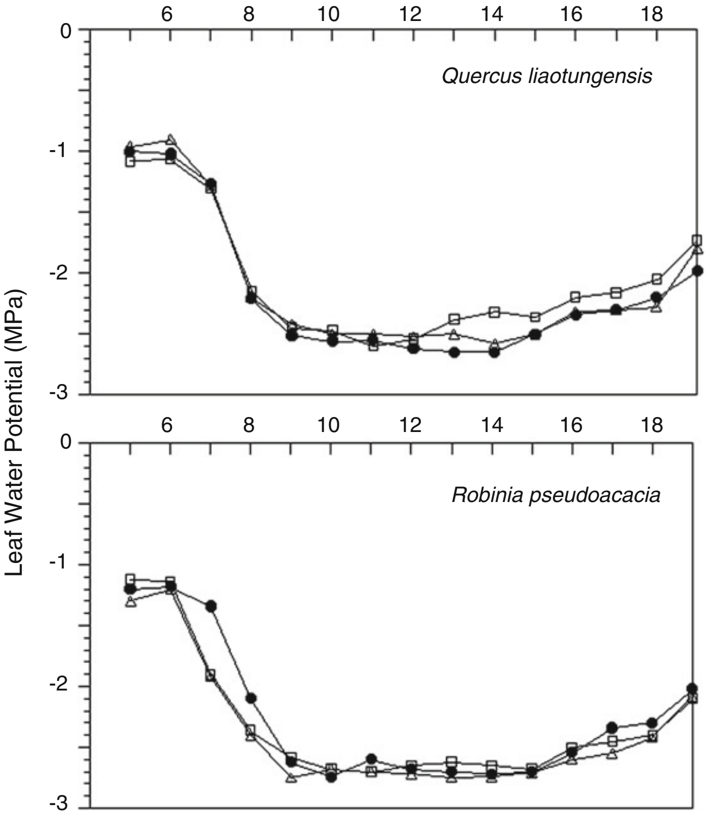

Fig. 17.2 Daily variations of leaf water potential at Mt. Gonglu sites on August 2, 2002. Curves in each panel show values of three different trees (Yamanaka et al. 2006)

17.3.1 In Situ Drought Stress

In situ drought stress is generally measured by leaf water potential, which indicates the energy status of leaf water. A lesser leaf water potential indicates that leaves have greater dry stress.

Figure 17.2 shows daily variations of leaf water potential of three different trees the *Quercus liaotungensis* and *Robinia pseudoacacia* at the Mt. Gonglu site. Leaves gradually took on water at night and the leaf water potentials reached maxima near predawn. Thus, the predawn leaf water potentials indicate the in situ maximum energy status of leaf water. These potentials of *Quercus liaotungensis* were about −1.0 MPa, and those of *Robinia pseudoacacia* were −1.2 to −1.3 MPa (Yamanaka et al. 2006). These results indicate that both trees were subjected to intense dry stress relative to trees growing in humid areas where predawn leaf water potentials are generally 0.0–0.5 MPa.

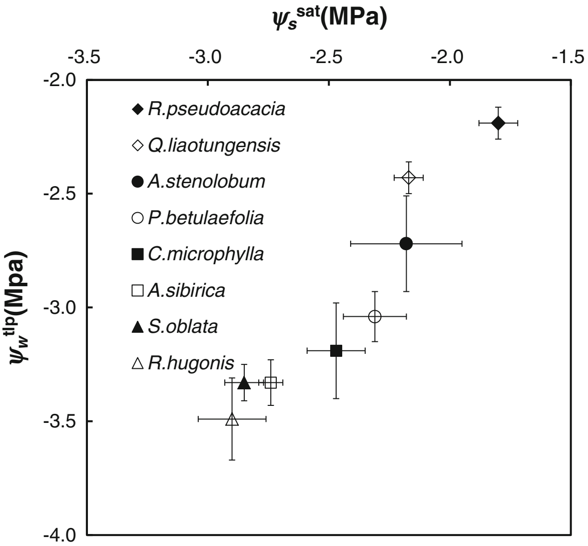

Fig. 17.3 Relationship between ψ_w^{tlp} and ψ_s^{sat} of trees growing at Mt. Gonglu sites, from data of Yan et al. (2013)

After sunrise, leaf stomata open to initiate photosynthesis and release water vapor from the stomatal cavity. Therefore, leaf water potentials steeply declined after sunrise and dropped to the lowest around 9 a.m. (Fig. 17.2). They began an upward trend after sunset and gradually increased toward dawn. Both daytime leaf water potentials were less than −2.5 MPa, which reveals that both survived and grew under extreme dry stress. Minimum leaf water potential of the *Robinia pseudoacacia* was less than that of the *Quercus liaotungensis*, which shows that the *Robinia pseudoacacia* had greater dry stress than *Quercus liaotungensis*.

17.3.2 Drought Tolerance

Drought tolerance may be diagnosed by the relationship between leaf water potential at the turgor loss point (ψ_w^{tlp}) upon the initial plasmolysis and the osmotic potential at full turgor (ψ_s^{sat}) when sufficient water is absorbed. The relationship between ψ_w^{tlp} and ψ_s^{sat} of the trees growing at the study sites is shown in Fig. 17.3. Points toward the upper right corner indicate lower drought tolerance. Among the eight sampled tree species, the *Robinia pseudoacacia* point is at the uppermost right, which indicates that it had the weakest drought tolerance, less than that of *Quercus liaotungensis*. Species having stronger drought tolerance than *Quercus liaotungensis* were other indigenous low trees and shrub trees.

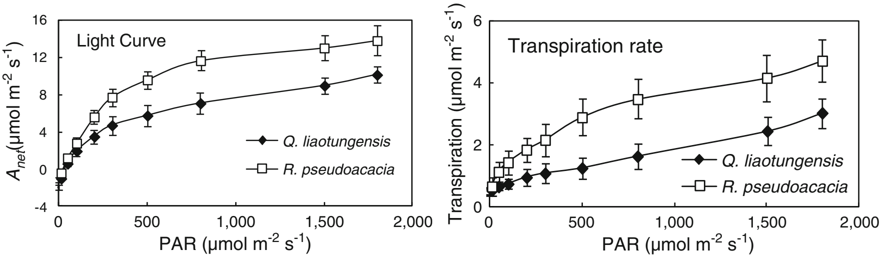

Fig. 17.4 Relationship between photosynthetically active radiation (PAR) and photosynthesis and transpiration rates (Du et al. 2007)

17.3.3 Water Use Efficiency

Water use efficiency (WUE) is the ratio of biomass production to water consumption. There are several ways to calculate it, depending on the fields and range of spatial scales. Leaf WUE is generally expressed by the ratio of photosynthesis rate to transpiration rate.

Sun and Ma (2002) measured leaf WUEs of 2 year-old seedlings of nine afforestation/reforestation tree species (four coniferous and five broadleaved species) grown under sufficient water conditions. They found that *Robinia pseudoacacia* and *Rhus typhina* had the highest transpiration rates, but their WUEs were almost identical to those of the other trees, except for larger values in the morning.

Du et al. (2007) measured leaf WUEs of 2 year-old seedlings of *Robinia pseudoacacia* and *Quercus liaotungensis* grown under sufficient water conditions. They discovered that photosynthesis and transpiration rates of *Robinia pseudoacacia* were higher than those of *Quercus liaotungensis* regardless of light intensity. However, WUE of *Robinia pseudoacacia* was less than *Quercus liaotungensis* (Fig. 17.4).

Yan et al. (2010) measured leaf WUEs of 1.5 year-old seedlings of four afforestation/reforestation tree species grown under different soil water condition. They found that *Robinia pseudoacacia* with higher photosynthesis and transpiration rates was most sensitive to soil drying among the four species.

Shangguan and Zheng (2008) measured leaf WUEs of 15–20 year-old trees of *Robinia pseudoacacia* and *Pinus tabulaeformis* Carr. growing in six locations of the western Loess Plateau. They ascertained that photosynthesis and WUE of *Robinia pseudoacacia* greatly exceeded those of *Pinus tabulaeformis* Carr. in the southern, wettest locations, but decreased northward, whereas those of *Pinus tabulaeformis* Carr. gradually increased; both were nearly identical in the northernmost, driest locations.

Water use efficiency can also be calculated using δ^{13}C. Based on δ^{13}C analysis of 12–20 year-old *Robinia pseudoacacia* and *Pinus tabulaeformis* Carr. growing on the central plateau, Koretsune (2009) reported that *Robinia pseudoacacia* had lower water use efficiency and less conservative water use than *Pinus tabulaeformis* Carr.

These results imply that *Robinia pseudoacacia* consumes a large amount of water to sustain a high photosynthesis rate, whereas indigenous trees such as *Quercus liaotungensis* and *Pinus tabulaeformis* Carr. are more adaptive to the arid environment by having lower photosynthesis and less water consumption.

17.4 Ecohydrological Aspects of *Robinia pseudoacacia* and *Quercus liaotungensis*

17.4.1 Overstory Canopies and Solar Radiation

Radiation environments were considerably different between the *Robinia pseudoacacia* and *Quercus liaotungensis* stands at Mt. Gonglu (Fig. 17.5).

In the defoliation period from November to March, the radiation environment of the overstory canopies and forest floors were almost identical. Albedos were about 0.15 from October through March. Transmittances rapidly increased from about

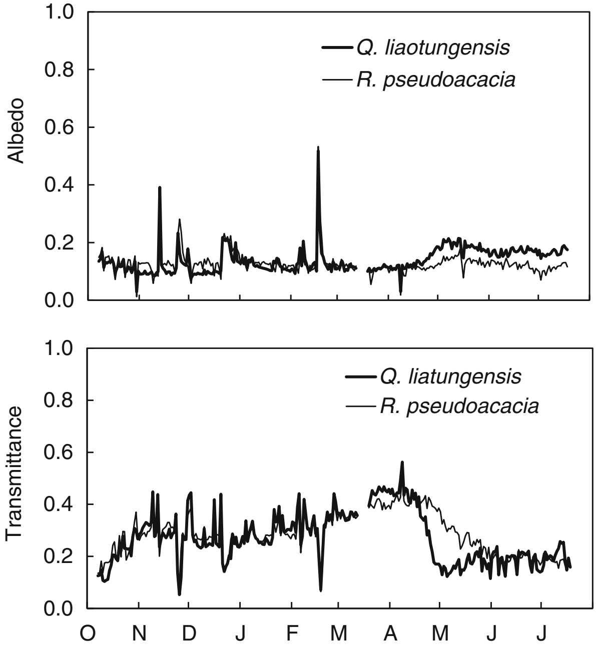

Fig. 17.5 Seasonal variation of albedo and transmittance at Mt. Gonglu sites, from October 2004 to July 2005 (Otsuki 2008)

0.15–0.30 in October and remained constant until March. The rapid increases of transmittance imply that defoliation terminated in October in both stands.

In contrast, during the foliate period, the radiation environments were different. Albedo of the *Quercus liaotungensis* stand increased to about 0.2, and that of the *Robinia pseudoacacia* stand remained about 0.15. Transmittance of the former stand rapidly decreased from 0.4 to 0.2 within about 2 weeks from mid April to early May. Conversely, transmittance of the *Robinia pseudoacacia* stand gradually decreased from 0.4 to 0.2 over about 5 weeks, from mid April to late May. After June, overstory canopies of both stands were fully foliated and their transmittances remained the same, at about 0.2. These results imply that the overstory canopy of the *Quercus liaotungensis* stand rapidly closed and reduced transmittance of solar radiation, whereas the scarce overstory canopy of the *Robinia pseudoacacia* stand permitted solar radiation to reach the forest floor in early spring.

17.4.2 Understory Canopies and Wind Speed

Stand structures of *Quercus liaotungensis* and *Robinia pseudoacacia* at Mt. Gonglu site were considerably different. Branches of *Quercus liaotungensis* extended laterally and intricately, whereas those of *Robinia pseudoacacia* extended vertically along the stems. Understory vegetation of the *Quercus liaotungensis* stand consisted of relatively dense shrubs and herbaceous plants every year. In contrast, forest floor of the *Robinia pseudoacacia* stand was almost exposed or covered by herbaceous plants, depending on previous autumn–winter precipitation. When precipitation during the prior autumn and winter was scarce, understory vegetation in the *Robinia pseudoacacia* stand was poor. Therefore, the *Quercus liaotungensis* stand was laterally closed, whereas the *Robinia pseudoacacia* stand was laterally opened.

Average forest floor wind speeds (0.5 m above the soil surface) were 0.2 m/s in the *Quercus liaotungensis* stand and 0.4 m/s in the *Robinia pseudoacacia* stand, and corresponding average 10-min maximum forest floor wind speeds were 2.7 and 4.1 m/s, respectively. The differences in the wind speed may be mainly attributed to the difference in stand structure mentioned above.

17.4.3 Soil Surface Coverage and Soil Temperature

The soil surface of the *Quercus liaotungensis* stand was fully covered by leaf and branch litter. In contrast, the soil surface of the *Robinia pseudoacacia* stand was mostly exposed without litter. This difference of understory vegetation and litter could cause a large variation in soil temperature.

Figure 17.6 shows daily maximum soil surface temperature of the *Quercus liaotungensis* and *Robinia pseudoacacia* stands at Mt. Gonglu site. Both temperatures were nearly identical during the foliate season when their overstory canopies

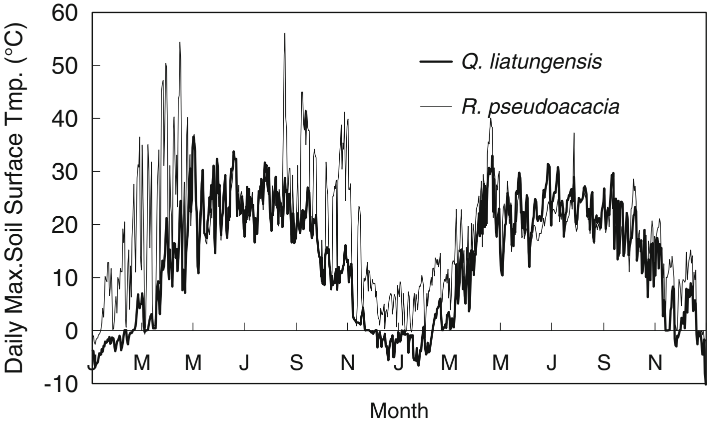

Fig. 17.6 Seasonal variations of daily maximum soil surface temperature at Mt. Gonglu sites in 2003–2004 (Otsuki 2008)

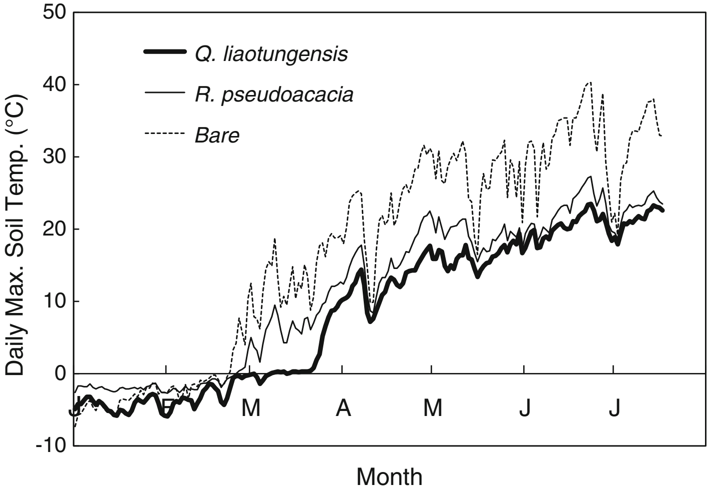

Fig. 17.7 Seasonal variations of daily maximum soil temperature at a depth of 10 cm at Mt. Gonglu sites, from January through July 2005 (Otsuki 2008)

were closed. However, in the defoliate season, these temperatures in the *Robinia pseudoacacia* stand largely exceeded those of the *Quercus liaotungensis* stand. In 2003, daily maximum soil surface temperatures of the *Robinia pseudoacacia* stand were very high, often exceeding 40 °C and sometimes 50 °C. However, the difference of these temperatures was relatively small in 2004. Understory vegetation of the *Robinia pseudoacacia* stand in 2003 and 2004 was very different. The forest floor in that stand was scarcely covered by understory vegetation and exposed soil surface in 2003, but mostly covered by herbaceous vegetation in

2004. These results imply that fluctuation of understory herbaceous vegetation in this stand strongly influences soil temperature.

Figure 17.7 shows daily maximum soil temperature at a depth of 10 cm (T_{s10max}). T_{s10max} of the *Robinia pseudoacacia* stand exceeded 0 °C in late February, whereas that of the *Quercus liaotungensis* stand exceeded 0 °C in late March. In the open space, solar radiation directly reaches the soil surface regardless of season. In the *Robinia pseudoacacia* stand, considerable amounts of solar radiation may directly reach the soil surface because of the sparse overstory and understory canopies and exposed soil surface. A rapid rise of soil temperatures in the open space and *Robinia pseudoacacia* stand beginning in late February may be attributed to melting of soil ice caused by increasing air temperature and solar radiation during spring, and to subsequent soil drying owing to soil water loss by evaporation. On the contrary, solar radiation reaching the soil surface in the *Quercus liaotungensis* stand may be small because of the dense cover of understory vegetation and thick layer of litter. This radiation regime can delay melting of soil ice in that stand until late March. These results suggest that this stand avoids drought damage during spring by retaining soil water with the gradual melt of soil ice. Soil in the *Robinia pseudoacacia* stand was prone to be dry and hot. This was because of high water loss from soil evaporation generated by relatively strong wind and solar radiation with increasing air temperature.

17.4.4 Soil Hardness and Infiltration Ratio

The difference of forest floors greatly impacts the soil environment. Soil hardness of the *Quercus liaotungensis* and *Robinia pseudoacacia* stands and open space were measured using a compact Yamanaka-type soil hardness tester with a cone 18 mm in diameter, 40 mm in height and 12°40′ in apex angle. Measured soil hardness was 6.4, 13.0 and 20.8 mm, respectively. The small value of the *Quercus liaotungensis* stand may be attributed to the thick layers of litter and humus. The large values of the *Robinia pseudoacacia* stand and open space are attributable to the crust formed on the soil surface (soil hardness of 20 mm is the index of the plough pan in the Tokachi district of Hokkaido, Japan). Soil infiltration rates were inversely related to soil hardness, and the descending order of soil final infiltration rates were *Quercus liaotungensis* stand (160.7 mm/h), *Robinia pseudoacacia* stand (99.1 mm/h), and open space (55.0 mm/h). These values are small compared to the average soil final infiltration rate of forest in Japan (258.2 mm/h). The infiltration rate of the *Robinia pseudoacacia* stand corresponds to the average of upland fields in Japan (89.3 mm/h).

According to soil water content data (Fig. 17.8), soil water content at a depth of 5 cm in both stands rapidly increased in response to precipitation. However, the response to precipitation in deeper soil of the *Robinia pseudoacacia* stand was weaker relative to that of the *Quercus liaotungensis* stand. These results imply that runoff readily occurred in the *Robinia pseudoacacia* stand because of less forest

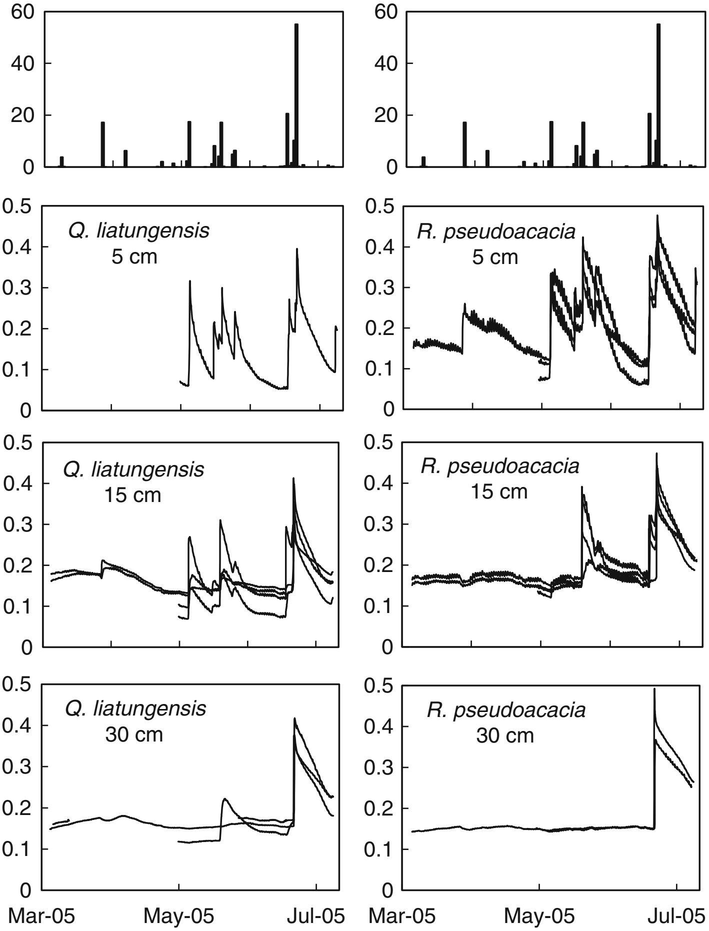

Fig. 17.8 Relationship between precipitation and soil water content (SWC) at various soil depths at Mt. Gonglu sites, from March through July 2004

cover of understory vegetation and litter, and lower infiltration rate of the soil (Zhang et al. 2004).

17.4.5 Tree and Stand Transpiration

Du et al. (2011) made measurements of sap flow of the *Robinia pseudoacacia*, *Quercus liaotungensis* and *Armeniaca sibirica* stands at the Mt. Gonglu sites by the Granier-type heat dissipation method (Granier 1987). They reported that *Robinia pseudoacacia* had greater sap flow increases in response to precipitation, suggesting a high water demand and strong influence of soil water conditions on transpiration. The *Robinia pseudoacacia* showed relatively late stomatal response to increasing VPD. The wide-peak pattern of diurnal sap flow course also suggests relatively low stomatal regulation. Sap flows of indigenous *Quercus liaotungensis* and *Armeniaca sibirica* were not very sensitive to changes in soil water conditions.

Sun and Ma (2002) measured sap flows of various trees by the heat pulse method (Swanson and Whitfield 1981). They discovered that individual tree transpiration of *Robinia pseudoacacia* was of a higher rank, and its stand transpiration was considerably greater than that of *Pinus tabulaeformis* Carr.

These results suggest that *Robinia pseudoacacia* require substantial water to grow and are thus sensitive to drought, whereas indigenous tree species can manage water consumption conservatively under both drought and wet conditions.

17.4.6 Soil Water and Tree Growth

Soil desiccation is one of the most serious adverse effects of afforestation and reforestation (Hou et al. 2000; Li et al. 2008; Chen et al. 2008; Cao et al. 2009). Since *Robinia pseudoacacia* can consume considerable amounts of water and extend roots down to 8–10 m in soil, long-term desiccation in deep soil layers is evident (Hou et al. 2000; Li et al. 2008). Yang et al. (1994) reported that *Robinia pseudoacacia* did not grow well on drought-prone upslopes, but did on lower wet slopes. Yang et al. (2004) grew one-year seedlings of *Robinia pseudoacacia* and pine under different soil moisture conditions. They found that water use and growth of *Robinia pseudoacacia* were greater than those of pine, but slowed under dry conditions.

Although *Robinia pseudoacacia* has the advantage of fast growth in degraded environments without adequate nutrients, it has the disadvantage of requiring substantial water for growth and relatively poor drought tolerance. In arid or semi-arid areas, after growing fast and covering degraded surfaces, *Robinia pseudoacacia* growth tends to be retarded in the "small old tree" stage, because of its large water consumption to the point of soil desiccation.

17.5 Strategy for Proper Vegetation Management on the Loess Plateau

17.5.1 Improvements of **Robinia pseudoacacia** *Plantations*

Robinia pseudoacacia is the main forestation species on the Loess Plateau because of its features of symbiotic nitrogen fixation, fast growth in youth, ease of reproduction and high specific gravity wood. Because of the aforementioned ecophysiological and ecohydrological features, adverse effects of exotic *Robinia pseudoacacia* plantations have recently become obvious not only on the plateau but also worldwide (Lee et al. 2004; Sakio 2009; Renato et al. 2012). However, these plantations are extensive on the plateau and have contributed to a reduction of soil and water runoff (Guo et al. 2005). The potential long-term benefit of *Robinia pseudoacacia* for improvement of soil chemical properties (Qiu et al. 2010; Wang et al. 2012) and their contribution to carbon fixation (Zheng et al. 2011) in the dry, degraded areas of the plateau have also been reported. Sun and Ma (2002) showed that *Robinia pseudoacacia* plantations may have better functions of water resource conservation than non-forested land if plantations are properly managed. Therefore, dealing with existing plantations and their succession into sustainable forest ecosystems are of concern (Guo et al. 2005; Chen et al. 2008; Cao et al. 2009).

There are many overpopulated *Robinia pseudoacacia* plantations (3,000–4,000 trees/ha) in China because their use for firewood and charcoal has declined in recent years. These are the plantations that have degraded the environment. Yang (1996) reported that rational densities of young broadleaf forest should be 750–1,000 trees/ha in areas with annual precipitation 400–500 mm/yr, and 1,000–1,500 trees/ha in areas with annual precipitation 500 mm/yr. Wang (2001) reported that production of a *Robinia pseudoacacia* stand with 3,330 trees/ha was markedly inferior to those of lower density, and its appropriate stand density was about 1,000 trees/ha. Sun and Ma (2002) proposed that the stand density should be managed around 750 trees/ha because the plantation could not obtain sufficient water to match possible transpiration when it reached 10–20 years old. These reports suggest that plant density of *Robinia pseudoacacia* plantations should be gradually reduced by intermediate cutting and thinning, and kept around 1,000 trees/ha during the luxuriant growth period. On the plateau, this would avoid low-yield, low-quality and low-benefit plantations (Guo et al. 2005, and also prevent soil desiccation (Sun and Ma 2002).

Zheng et al. (2011) measured photosynthesis and growth of juvenile (6 years old) and mature (18 years old) *Robinia pseudoacacia* on sunny (southeast-facing) and shady (northwest-facing) slopes with plant densities 1,650–1,815 tree/ha. The results showed that the mature plantations on sunny slopes had less transpiration, photosynthesis, photosynthetic carbon fixation capacity and growth than those on the shady slopes. This implies that slope aspect and stand age are important to the growth of *Robinia pseudoacacia* and the environment. Fu et al. (2003) investigated soil water content in five transects of various land uses including *Robinia pseudoacacia* plantations. They asserted that more attention should be paid to selection and arrangement of land use (cropland, fallow land, grassland, forest, orchard, intercropping land and shrubland) on slopes and in catchments not only for soil and water conservation but also for biodiversity via the supply of a variety of habitats.

17.5.2 Measures for Proper Vegetation Management

Measures taken on the Loess Plateau since the 1950s have been actively and widely reviewed in recent years because of the emerging adverse effects and need for ecologically sustainable development (e.g., Guo et al. 2005; Chen et al. 2008; Chen et al. 2008; Cao et al. 2009). Based on achievements of this research, the following measures should be implemented to ensure proper vegetation restoration on the vulnerable plateau.

17.5.2.1 Proper Selection of Vegetation with Consideration of Soil Water Conditions

Appropriate vegetation should be selected with consideration of soil water conditions. First of all, climate, especially precipitation and temperature that determine the regional soil water condition, should be taken into account (Cheng and Wan 2002; Chen et al. 2008). Then, location, such as slope aspect and position (Fu et al. 2003; Zheng et al. 2011) plus proximity to water such as rivers, lakes, ponds and water table, should be considered for adaptation to the local soil water condition. Both water quantity and quality should be considered, because salinity is a serious problem on the plateau.

17.5.2.2 Proper Forest Management Combined with Soil and Water Conservation

Effective forest management should be carried out not only for vegetation growth but also for soil and water conservation. This is because large-scale soil desiccation in deep soil layers has become a serious environmental problem on the plateau (Chen et al. 2008; Cao et al. 2009). Thinning to control the feasible density and productivity of vegetation depending on species, age and environment (including climate and location) is a primary forest management tool. When trees or shrubs in forests become mature, density should be reduced by intermediate cutting or thinning to suit the environment. In regions with annual precipitation 400–500 mm/yr, rational densities of conifer and broadleaf trees should be 1,200–2,000 and 1,000–1,500 trees/ha, respectively (Chen et al. 2008), and about 1,000 trees/ha for *Robinia pseudoacacia*.

Artificial rainwater harvesting is also an effective means for maintaining vegetation growth and reducing soil desiccation.

Although the amount of information on feasible densities of trees for their growth and soil and water conservation has grown, information on nutrient acquisition and conservation has not been well investigated. For *Robinia pseudoacacia*, Hou et al. (1991) and Wu and Liu (2003) reported poor soil nutrients in these plantations, whereas Qiu et al. (2010) and Wang et al. (2012) reported that this species improved soil chemical properties. Thus, forest management to improve and conserve soil chemical properties requires more investigations.

17.5.2.3 Transition to Mixed Forest and Mixed Land Use

Mixed forests including trees, shrubs and grasses are robust ecosystems that have biodiversity, disaster resistance, and effective soil water use. Such forests are favorable for soil and water conservation, wind breaking and sand stability (Guo et al. 2005; Chen et al. 2008; Cao et al. 2009). Thus, transforming unmanaged, fragile single-species plantations, once successful in early stages on the plateau, into mixed forests is an effective means for sustainable vegetation coverage. Mixed land use, such as forest, grass, shrub, crop, orchard and fallow (depending on aspect and location on a slope) is also an effective measure for rehabilitating degraded slopes and improving the environment and biodiversity (Fu et al. 2003).

17.5.2.4 Restoration of Indigenous Vegetation

Indigenous vegetation is effective to rehabilitate the environment and develop sustainable ecosystems because it has survived for long periods by adjusting to the rugged, dry environment. Therefore, the following should be strengthened during artificial vegetation recovery and rehabilitation (Cao et al. 2009; Chen et al. 2008): (1) restoration and protection of indigenous vegetation, if possible by enclosure with fences; (2) proactive revegetation using indigenous species where their mother or young trees are lost; and (3) transformation of plantations with inappropriate exotic species and exorbitant productivity into forests with suitable indigenous species.

17.6 Conclusion

The blowing yellow sand of the Loess Plateau has strongly affected the environment and ecosystem of the Yellow River (the second longest river in China and seventh longest in the world) basin, and also of the world. Various measures of soil and water conservation on the plateau since 1950 have increased vegetation coverage and reduced soil and water runoff to the level of the middle Holocene. However, both favorable and adverse effects have recently emerged. Moreover, the rehabilitated environments have also caused new environmental problems, such as shortages of sediment in the Yellow River estuary (Peng et al. 2010; Wang et al. 2010a, b). Therefore, a long-term and river basin-level strategy for vegetation management on the plateau should be continuously executed to keep up with changes to the environment and ecosystem of the basin.

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Part V
Future of the Loess Plateau

Chapter 18
Recent Changes on the Loess Plateau: Land Resource Development and Rapid Urbanization

Ming-Quan Lü, Zi-Lan Xia, and Ji-Jun Wang

Abstract The economy of the Loess Plateau of China has been developing rapidly in recent years and therefore the region's share of the national economy has steadily increased. The plateau is rich in energy resources and their exploitation is the driving factor for economic development of the region. However, this development has come at the expense of the natural environment. Because of implementation of the Grain-for-Green Project, the land resource structure has greatly changed, characterized by a decrease in cultivated land and an increase of forestland. Orchard land has expanded, especially in Weibei Loess Plateau, where the apple fruit industry is enjoying sound development. However, the plateau is characterized by extensive urban sprawl, although the total amount of urbanization is still low by Chinese standards.

Investment in ecological improvement and environmental protection via the Grain-for-Green Project in the Western Regions has greatly developed the society and economy. Even so, the gap between the Loess Plateau region and eastern region continues to widen. Moreover, the degree of coupling between economic and ecological systems is low. Therefore, an ecological compensation system for resource exploitation should be established.

Keywords Energy resource • Land resources • Socioeconomic development • Urbanization

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18.1 Socioeconomic Development Level and Industrial Structure in the Loess Plateau

The economy of the Loess Plateau has grown steadily from 1997 to 2006 because of strong national policy support, for example China's Western Campaign (also mentioned as *Western Development Program*). For instance, the Gross Domestic Product (GDP) increased from 509.3 billion Chinese Yuan (CNY, which was around 0.16 United States dollars as of May 2012) in 1997 to 1,769.3 billion CNY in 2006 (Fig. 18.1). From 1998 to 2001, the proportion of GDP dropped slightly and reached 6.24 % in 2001, owing to rapid development in other regions, and then it sharply peaked at 8.35 % in 2006.

Annual growth rate in all provinces was above 10 %, and in some it even attained 18 %. In 1997, the GDP of six provinces (Shanxi, Shaanxi, Gansu, Qinghai, Inner Mongolia, and Ningxia) on the plateau accounted for 6.45 % of the national figure.

Although total GDP in the plateau area showed an increase, per capita GDP in most parts of the region remained below the national average, and this gap was much wider than that in eastern China (Fig. 18.2). For instance, the per capita GDP in Gansu Province was only 34.8 % that of the eastern region in 2000, and then dropped to 32.7 % in 2006. A notable exception was Inner Mongolia, where per capita GDP exceeded the national standard after 2004. In general, the economy on the Loess Plateau has developed somewhat in recent years, but the region's overall

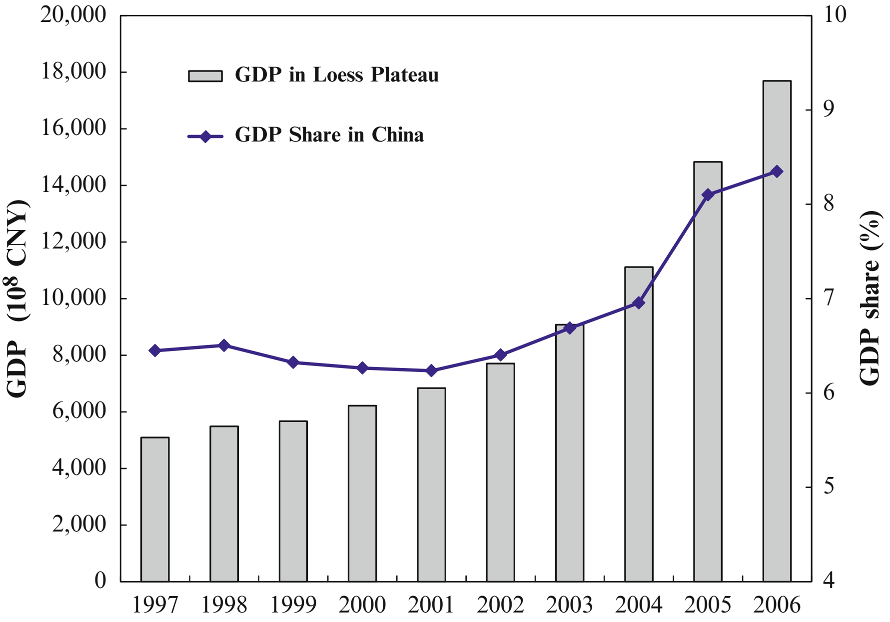

Fig. 18.1 GDP of Loess Plateau and its share in the national economy from 1997 to 2006 (from NBS 1998–2007)

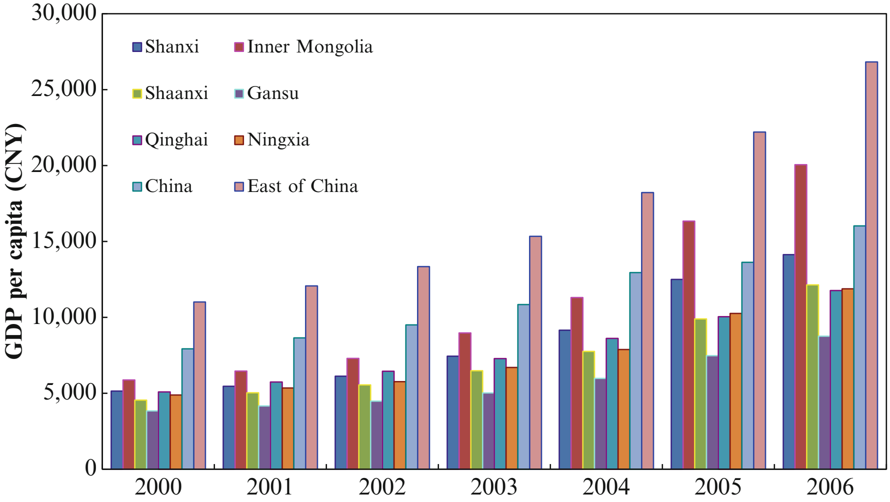

Fig. 18.2 GDP per capita for six provinces on Loess Plateau from 2000 to 2006 (from NBS 2001–2007)

development is still below the national average and the gap with Eastern China has gradually widened.

The structural changes of economy, especially that of industry, contributed to economic growth, and this in turn resulted from development of the economy and allocation of resources. The industrial structure determined the distribution of resource quality and economic development speed and quality.

Table 18.1 shows a continuous optimization of industrial structure in the Loess Plateau area. In 2003, the share of secondary industry in Shanxi Province alone was above the national average of 52.9 %. This saw a tremendous development through 2006, except in the Gansu and Inner Mongolia provinces. Although industrial structure was in constant optimization, there were many problems during the process of transformation.

As shown in Table 18.2, the income level in both urban and rural areas of the Loess Plateau was below the national average. In 2006, when disposable income of urban residents (their ability to purchase goods or services) was 11,759.45 CNY, Inner Mongolia had the highest per capita disposable income (10,357.99 CNY) of urban residents and the lowest Engel’s coefficient (30.31), a measure of income spent on food. Gansu Province had the lowest per capita disposable income (8,920.59 CNY) of urban residents among the six provinces on the plateau, and Qinghai had the highest Engel’s coefficient (36.24). Per capita income in rural areas, which was one-fourth to one-third that of urban residents, was much lower. Accordingly, Engel’s coefficient of rural residents was about 7 % higher than urban residents in the plateau provinces.

Table 18.1 Proportion of three industries on Loess Plateau (%) in years 2003 and 2007 (from NBS 2004–2008)

Province (autonomous regions)	2003			2007		
	Primary industry	Secondary industry	Tertiary industry	Primary industries	Secondary industries	Tertiary industries
Shanxi	8.8	56.6	34.6	5.8	57.8	36.4
Inner Mongolia	19.5	45.3	35.2	13.6	48.6	37.8
Shaanxi	13.3	47.3	39.4	10.8	54.2	34.9
Gansu	18.1	46.6	35.3	14.3	47.3	38.4
Qinghai	11.8	47.2	41.0	10.6	53.3	36.0
Ningxia	14.4	49.8	35.8	11.0	50.8	38.2
China	14.8	52.9	32.3	11.3	48.6	40.1

Primary industry in the economy extracts or harvests products from the earth, and includes agriculture (both subsistence and commercial), forestry, farming, grazing, hunting and gathering, fishing, and quarrying

Secondary industry manufactures finished goods. All manufacturing, processing, and construction is within the secondary industries, including metalworking and smelting, automobile production, textile production, chemical and engineering industries, energy utilities, engineering, breweries and bottlers, and construction

Tertiary industry is the service industry. This sector provides services to the general population and to businesses, including wholesale and retail sales, transportation and distribution, entertainment, restaurants, clerical services, media, tourism, insurance, and banking

Table 18.2 Income gap between urban and rural residents of Loess Plateau in 2006 (from NBS 2007)

	Urban area		Rural area	
Provinces	Per capita disposable income (CNY)	Engel coefficient (%)	Per capita disposable income (CNY)	Engel coefficient (%)
Shanxi	10,028	31.4	3,181	38.5
Inner Mongolia	10,358	30.3	3,342	39.0
Shaanxi	9,268	34.3	2,260	39.0
Gansu	8,921	34.5	2,134	46.7
Qinghai	9,000.35	34.2	2,568	42.1
Ningxia	9,177	33.9	2,760	41.4
China	11,759	35.8	3,587	43.0

Per capita disposable income is calculated by taking collective income earned from all sources (wages, government transfers, rental income and others) minus taxes, savings and some non-tax payments, and dividing by the total population

Engel's coefficient reflects the living standard. Generally speaking, the proportion of income spent on food falls as income rises

18.2 Land Resource and Its Change

The implementation of ecological restoration projects on the Loess Plateau reconfigured land use. This section addresses the changing characteristics of land use at three scales. This includes the regional scale of the plateau in north Shaanxi Province, the county scale of Wuqi County in that province, and the small watershed scale of

Table 18.3 Land use changes on Loess Plateau in north Shaanxi Province, from 1988 to 2004 (after Zhou and Ren 2010)

Land use types	Area in 1988 (ha)	Area in 2004 (ha)	Area change 1986–2004 (ha)
Cultivated land	2,364,549	1,501,732	−862,817
Orchard land	68,307	336,947	268,640
Forestland	2,644,288	3,240,053	595,765
Grassland	2,690,611	2,686,012	−4,599
Other agricultural land	265,199	66,055	−199,144
Construction land	10,200	181,389	171,189
Total	8,032,954	7,830,799	−202,155

Table 18.4 Land use changes of Wuqi County, from 1988 to 2004 (after Lü et al. 2010)

	Land area (ha)			Area variation
Land use types	1990	2001	2007	1990–2007 (ha)
Cultivated land	124,296	22,613	20,091	−104,205
Orchard land	5,459	57,094	57,068	51,609
Forestland	33,241	130,103	174,462	141,221
Grassland	205,461	159,173	117,177	−88,284
Construction land	4,589	5,785	6,318	1,729
Unused land	6,099	4,408	4,059	−2,040

Wangdonggou Watershed. The Loess Plateau in north Shaanxi Province includes 29 counties, with total population 6.46 million in 2005. Wuqi County is known as the "demonstration county of the Grain-for-Green Project," owing to large areas converted from farmland to forestland and grassland, so the changing characteristics of its land resources are clear. Wangdonggou Watershed is in Changwu County of Shaanxi Province, where it is suitable for planting fruits and, there has been dramatic land use change there in recent years.

18.2.1 Land Use Change and Its Implications

In the latter three areas, land use change was apparent over the past 30 years, characterized by the decrease of cultivated land and grassland area, increase of orchard land and forestland, and expansion of urban construction and industrial and mining land (Tables 18.3, 18.4 and 18.5) (Lü et al. 2010; Zhou and Ren 2010). As seen in Fig. 18.3, land use changes were related to social and economic activities.

On the plateau of north Shaanxi Province, the area of cultivated land decreased from 2.36 million hectares in 1988 to 1.50 million hectares in 2004. The decrease of cultivated land in Wuqi County was more obvious. The main reason for this decrease was national policy, especially the implementation of certain ecological restoration projects. The area of cultivated land impacted total grain yield. However, converting

Table 18.5 Land use changes in Wangdonggou Watershed, from 1986 to 2007

Land use types	Area in 1986 (ha)	Area in 1994 (ha)	Area in 2007 (ha)	Area variation 1986–2007 (ha)
Cultivated land	272	229	142	−130
Orchard land	27	113	225	198
Forestland	145	248	275	130
Grassland	113	27	25	−88
Other agricultural land	219	128	72	−147
Construction land	54	85	91	37
Total	830	830	830	0

Data Source: Changwu Ecological Observation Experimental Station, Chinese Academy of Sciences

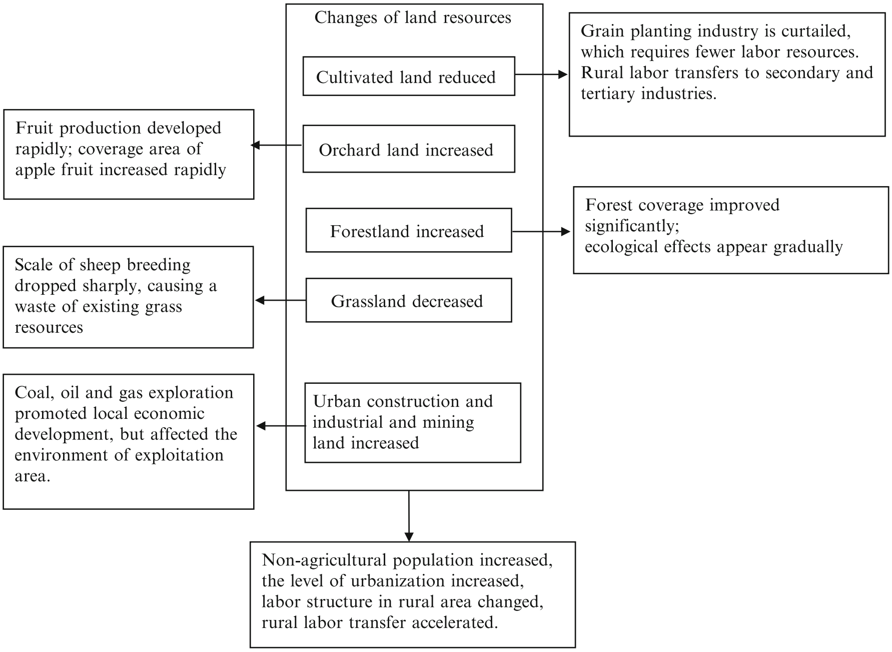

Fig. 18.3 Land resource changes, causes and related impacts on Loess Plateau (after Zhou and Ren 2009)

degraded cultivated land to forest could indirectly increase unit area grain yield of present cultivated land. On the other hand, cultivated land reduction could accelerate rural labor transfer from grain planting to secondary and tertiary industries. According to household surveys in Wuqi and Mizhi counties on the plateau (Li and Xie 2011), household economic structure changed a great deal, from incomes mainly dependent on grain planting to immigrant worker salaries in cities. In the case of low grain planting industry efficiency, economic output value from grain production was less than other industrial activities. Rural labor flowed to construction, trade and catering, transportation and other non-agricultural industries.

Thirty percent of family rural labor abandoned grain planting to become immigrant workers in cities. These people had been engaged in farming activities in rural areas for 40–60 years, and their educational backgrounds were at the elementary and junior high school level (Li and Xie 2011). A large number of rural surplus laborers transferred to secondary industries, which promoted development of local industry, as well as construction, transportation, storage, trade and catering, and other tertiary industries. This broadened income channels for farmers, and promoted the county's economic industrialization and urbanization.

18.2.2 Significant Increase in Orchard Land

In recent decades, the area of orchard land has risen significantly on the Loess Plateau. Weibei Loess Plateau in Shaanxi Province (located in 106°20′E–110°40′E, 33°N–39°N; elevation 800–1,200 m) is suitable for planting apple trees. This area is 400 km long and 275 km wide, and is the only place where seven natural requirements for apple growing are satisfied (Bai et al. 2003). To take advantage of superior natural characteristics, the Shaanxi Province government decided to establish a high-quality apple commodity base in Weibei Loess Plateau. Through 2009, 25 such high-quality apple bases have been created, and 20 different apple varieties across 0.41 million hectares of land have been planted. Provincial apple output reached 8.05 million tons in 2009 (SPBS 2009). The main reason for the apple orchard increase was the economic benefit brought by apple planting. In Luochuan County, Shaanxi Province, about 20 % of households had income from growing apples in excess of 100,000 CNY, and 50 % had more than 300,000 CNY.

Wangdonggou Watershed in Changwu County, Loess Plateau exemplifies the development of the apple fruit industry. The area of orchards was only 22 ha with production value 8,300 CNY in 1986; in 2007, these figures reached 223.5 ha and 6,179,200 CNY. According to household survey data from the watershed (unpublished data: Changwu Ecological Observation Experimental Station, Chinese Academy of Sciences), the economic output value of apple planting was 5,800 CNY per hectare, approximately five times greater than that of corn planting. As a result, Shaanxi has become the second largest apple producing province in China. The fruit industry has become one of the greatest sources of economic growth.

18.2.3 Increase in Forestland and Decrease in Grassland

Another characteristic of land structure change on the Loess Plateau is the increase of forestland and decrease of grassland. A free grazing system caused heavy destruction of the ecological environment. After many years of implementation of the policy forbidding pasturing by closing hillsides in the plateau area, vegetation coverage improved significantly and grassland gradually transformed into forestland. Following implementation of the policy forbidding pasturing, the breeding industry changed from pasturing to captive breeding, which caused breeding costs to rise and breeding scale to decrease.

18.3 Current Situation of Urbanization on the Loess Plateau

There has been little urbanization on the Loess Plateau until recent years. Now, however, urbanization has entered a rapid development phase, along with rapid economic growth. Following the exploitation of energy resources, mining land on the plateau areas has increased significantly, urbanization has accelerated, and city land is expanding. The urban construction land and mining land areas in the Loess Plateau region of northern Shaanxi increased from 10,199.6 ha in 1988 to 171,188.9 ha in 2004, an approximate 15-fold increase over 16 years. Urban sprawl in Inner Mongolia, derived from Defense Meteorological Satellite Program Operational Linescan System (DMSP/OLS) night-light data, increased from 1,360 km^2 in 1996 to 1,889 km^2 in 2000 to 3,045 km^2 in 2008 (Zhang 2010).

GDP in the northern Shaanxi province increased at a yearly rate of 10 %, and urbanization extent at an annual rate of 1 %, jumping from 21.4 % in 1999 to 31.9 % in 2009. Zhao and Zhou (2002) indicated that the essential force of urbanization was early-stage industrialization, service industry development, and innovation of new industry in later periods. At present, large-scale development of energy in the region greatly contributes to urbanization. Industrial activities concentrate labor resources and improve the urban infrastructure and services system, which attracts the rural population to the city and expands the urban area. Moreover, the improvement in agricultural production has liberated more of its labor force. Combined with the huge gap between urban and rural economic and social benefits, as well as the impetus of ecological management projects such as the Grain-for-Green Policy, this has prompted the rural population to migrate to urban areas and has accelerated the trend. The coupling of these kinds of forces has quickened urbanization on the northern Shaanxi of Loess Plateau.

However, the shortage of water resources and the vulnerable ecological environment of the plateau limited this urbanization. Cities and towns that grew by exploiting resources of a vulnerable ecological environment were subject to the pressure of water resources and that environment. The damage to that environment in turn stressed the urban development scale and space structure optimization, and delayed urbanization development (Lei et al. 2008).

18.4 Mineral and Energy Resource Development and Its Implications

18.4.1 Status of Mineral and Energy Resource Development

Here, coupling refers to two or more systems with the same characteristics and affinity trend becoming a new system with a more advanced structure function (Wan and Li 2002). Coupling between the economy and eco-environment on the Loess

Plateau was weak. Drawing on the system theory put forward by Bertalanffy, a coupled coordinated development model of an ecological economic system on the plateau was established, and evaluation criteria and basic types of coordinated development of the ecological economic system were proposed. County-level coupled coordinated development of the ecological economic system was also addressed, based on local characteristics. Interactions between the ecological and economic systems on the plateau can be divided into four development stages—seriously disordered, mildly disordered, low-level coordinated, and high-level well-coordinated (Zhang et al. 2011). According to Zhang et al. (2011), about 62.7 % of counties were in serious disorder, 30.1 % in mild disorder, and 7.1 % in low disorder. For different development processes, the eco-environment system has a lag response to the economic system. The relationship between economic and ecological systems evolves to coordinate direction through the coupling process. Ultimately, ecological and economic composite systems develop from the low-level coordinated stage to the high-level, well coordinated stage. The low level of coupling development of the ecological-economic system on the Loess Plateau resulted from an uncoordinated relationship between the three industrial structures and the eco-environment, which further restricted economic growth and sustainable environment protection. To explore a suitable economic development path, industries should be adjusted to each county's environmental resource endowment.

There is a wide range of energy resources on the Loess Plateau including coal, oil and natural gas, particularly in Inner Mongolia, Shaanxi and Shanxi Provinces. In recent decades, the exploitation of energy resources has promoted the local economy. For example, the 2007 GDP in Ordos City in Inner Mongolia Autonomous Region increased to 115.09 billion CNY, from 10.03 billion CNY in 1998. Likewise, Yulin City in Shaanxi Province realized rapid economic development, with GDP of 67.23 billion CNY in 2007. Although the exploitation of energy resources brought local economic benefits, the economy could not develop sustainably because the mining industry was the only pillar industry. The question of how to maintain sustainable development after resource exhaustion in locales where dependence on non-renewable resources remains high has not yet been answered.

18.4.2 Implications of Mineral and Energy Resource Development

The exploration of resources caused a wide range of negative side effects. Large-scale coal mining caused mine areas to collapse, vegetation to degrade, and water resource shortages. These environmental damages led to natural disasters. The Loess Plateau is water deficient, with annual precipitation between 300 and 600 mm. Shanxi Province was one of the most important coal energy bases in China, with a production of 0.634 billion tons representing 25 % of total national coal output in 2008. Although there were economic benefits brought by coal production, water shortages and environmental disasters increased. Coal production contaminated 1.5 billion m^3 of water resources, representing 1/8 of the entire provincial water resource (Shao et al. 2011). Ecological damage and environmental contamination loss caused by coal production was about 61 CNY ton^{-1}. From 1978 through 2004, Shanxi Province produced seven billion tons of coal, with associated environmental loss reaching 500 billion CNY. Such environmental destruction in the province has restricted follow-up development.

The northern part of Shaanxi Province was another energy resources base with the same problem as Shanxi Province. In that region, the Kuye River is the water source for agricultural and industry production in Shenmu and Fugu counties. Its river runoff was 0.51 billion m^3/yr between 1980 and 1996, and periods of no runoff became common after 2000, according to hydrologic data. The main factor contributing to this water shortage was coal mining (Fan 2004). A modest exploitation strategy should be implemented to ensure the resource can bear sustainable development. First, the resource quantity should be surveyed in detail, and the scale of exploitation fit to the bearing capacity of the environment and that quantity. Taking coal mining as an example, the annual level of coal production should account for the amount of disposable water resources.

To minimize resource exploitation and associated negative externalities, it is vital to set up an ecological compensation system. In this system, the agent exploiting non-renewable resources should pay for restoring the environment. This system can incentivize the exploiter to use resources sustainably and protect the environment. Huo et al. (2008) researched payments for soil and water conservation ecosystem service relative to energy resource exploitation in Shaanxi Province. Resource exploitation destroys environmental soil and water resources. The ecological compensation for energy exploitation could be determined as follows—coal 8 CNY per ton, oil 35 CNY per ton, and natural gas 0.015 CNY m^{-3}.

18.5 Conclusions

Implementation of development strategy and policies on the Loess Plateau has hastened economic growth. At the same time, resident incomes have increased, although overall income was still below that in Eastern China. Urbanization on the plateau was slight until recent years, but it has had marked growth. Agricultural productivity, implementation of the Grain-for-Green Project, and industrial development were the major urbanization driving forces, transferring populations from rural to urban areas and causing urban sprawl. The plateau has abundant non-renewable energy resources, and their exploitation has promoted local economic development. However, because of an uncoordinated exploitation system in certain plateau areas, a wide range of negative side effects appeared. These include damage to the fragile ecosystem, water shortages, and groundwater contamination. What is needed is to improve industrial structure, moderate resource exploitation, and establish an ecological compensation system.

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Chapter 19
Future Development-Related Challenges on the Loess Plateau

Guobin Liu, Atsushi Tsunekawa, Xiaohu Dang, and Sheng Du

Abstract The vulnerable nature of the environment coupled with monoculture agriculture systems have caused poor land productivity in the Loess Plateau region. Moreover, exploitation of mineral resources for energy may arise negative environmental impacts.

Both the *Grain-for-Green* project and *China Western Development Action*, which were launched in the end of 1990s and the beginning of the twenty-first century, respectively, emphasize ecological protection and economic development in this region. In this chapter, we show how ecological restoration and protection have contributed not only to soil and water conservation, but also to regional ecological protection and economic development. Furthermore, we present the challenges faced as a result of such development interventions.

Keywords Ecological restoration • Soil and water conservation • Rural–urban migration and population urbanization • Development-related challenge

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19.1 Characteristics of Recent Socioeconomic Transformation and Development Trends on Loess Plateau

19.1.1 Characteristics of Recent Socioeconomic Transformation

The population of the Loess Plateau over the last 60 years has continued to grow much more rapidly than in the past, especially from the 1950s to 1970s. Since 1949, this population has tripled, reaching to 104 million by 2000. This has put severe pressure on the environment and resulted in imprudent land-use practices. These have caused deforestation, high rates of soil erosion, and depletion of water resources. Farming practice is rainfed agriculture, characterized by low productivity and uncertainty. In the end of 1990s, a major national ecological project called *Grain-for-Green* was launched, which greatly benefitted the people and environment of the Loess Plateau region. The *China Western Development Action* program that was launched at the beginning of the twenty-first century accelerated regional economic and infrastructure development. However, natural and socioeconomic issues remain critical, and comprehensive research is needed to integrate rural economies and ecology.

Specific characteristics for regional socioeconomic development are discussed under the following numbered premises.

1. *Although the rapid growing sectors of native crops and fruits have become the mainstay industries, the monoculture agriculture has led to slow economic development and rural poverty*

   The Loess Plateau is a principal growing region for certain high-quality cash crops and fruits plus characteristic crops, since it has abundant solar radiation and a wide range of day and night temperatures. In recent decades, particularly the 2000s, production of such crops and fruits have dramatically increased. These include apples (*Malus domestica*), yangtaos (*Actinidia chinensis*), pears (*Pyrus* spp.), Chinese dates (*Zizyphus jujuba*), potatoes (*Solanum tuberosum*), and millet (*Panicum* sp.). Such an increase has made it the largest growing area for yangtao and apple. The plateau is also well known for growing Chinese medicinal material and potato.

   Rural areas of the plateau, however, are primarily agricultural, densely populated, and generally poor by national standards (Kuchler 1990). The agricultural economy is characterized by a combination of subsistence farming and market-oriented production, with the local mix depending on geographic proximity to markets and urban areas. The plateau has typical inland agricultural regions outside the range of major urban markets. As a result of water resource shortages and serious soil erosion, development of the agricultural sector remains poor. Monoculture agriculture accounted for 75 % of total sown area (statistical data for Shanxi, Shaanxi and Gansu provinces) in 2005, more than 8.7 times the national average. In those three provinces that year, maize (*Zea mays* L.), wheat

Table 19.1 Average annual food security level on Loess Plateau between 1998–2005

Prefecture	Population number (10^4)	Total grain yield (ton)	Grain yield per capita ($kg.cap^{-1}$)	Grain yield per farmer ($kg.cap^{-1}$)	The food security level
Dingxi	296	747,127	252	282	Insecurity
Guyuan	189	741,061	392	435	Moderate security
Yan'an	200	627,583	312	413	Insecurity
Yulin	348	1,005,331	289	345	Insecurity

(*Triticum aestivum* L.) and potato dominated grain production, and pork was the major livestock husbandry (contributing two-thirds of total meat output).

A vulnerable environment coupled with monoculture agriculture usually brings about low productivity and rural population poverty (Dang and Liu 2012). Farmer income is very low compared with the national average. Statistics show that farmer incomes in Gansu and Shaanxi provinces in 2005 were the second and fourth lowest, respectively, among the 34 provinces (autonomous regions and municipalities). The total poor rural population represents one quarter of the total on the Loess Plateau; thus, it is a key area for poverty reduction intervention.

2. *Demand for food by farm households is high, and this has led to uncontrolled conversion of unsuitable sloping fields to farmland*

Topography of the Loess Plateau is characterized by deeply eroded gullies, as much as hundreds of meters deep (Liu 1999). Because of this, cropland used to be scattered across hillsides. Based on surveys in the provinces of Shanxi, Shaanxi and Gansu, cropland on slopes steeper than 5° contributed 50 % of total arable land. Moreover, because of landform limitations and water shortages, irrigated area constituted less than 25 % in the three provinces. Furthermore, deterioration of soil physical properties by erosion makes soil conditions unfavorable for plant growth, and has imperiled primary production in the region. Soil in the cropland of northern Shaanxi province, for example, has on average around 1 % organic matter content, less than 0.5 % of the national average. As a result, around 70 % of arable land has low to medium agricultural yields. According to statistics from Shaanxi Province between 1990 and 1998, millet yields averaged 232 kg/ha, more than 50 % less than the national average (600–800 kg/ha). These small and declining cereal yields result in great pressure on grain supplies and food insecurity in some prefectures of this region (Table 19.1).

In addition, the dominant agricultural practice of winter wheat cropping continues to be the primary driver for the massive soil erosion and landscape modifications on the Loess Plateau. With its traditional cultivation methods, this crop appears inappropriate for the landform, soil conditions and climate of the region (Wang et al. 2010).

The above factors influence the relationship between environmental change and household behavior. Over the past 1,000 years, the plateau population increased exponentially, from a few million to more than 100 million (Wang et al. 2006). This population pressure combined with the low land productivity to cause rapid expansion of cultivation throughout the loess areas, even on steeply sloped hills (Meng 1996; He et al. 2006).

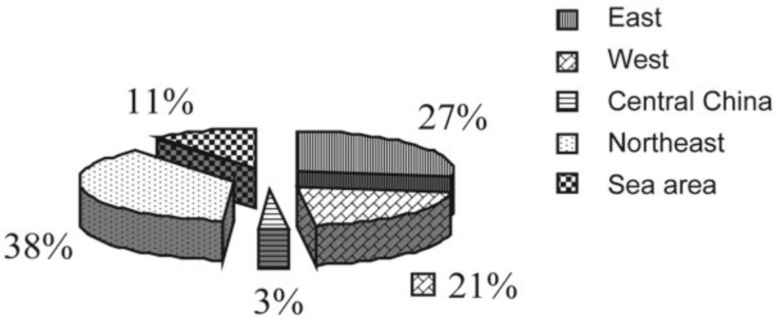

Fig. 19.1 Proportion and distribution of oil resources in China

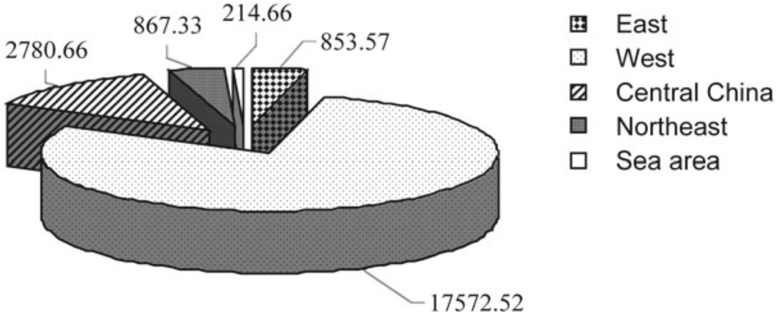

Fig. 19.2 Reserves and distribution of natural gas in China (10^8 m^3)

3. *As an important energy source for China, mineral resources in the Loess Plateau region greatly contribute to national energy security. However, extraction of these resources can have many negative environmental consequences.*

   Coal reserves on the Loess Plateau are estimated at 500 billion tons, representing more than 50 % of the national total. Forty percent of the area of Shanxi has qualified coal resources and shallow buried depth, which makes the province the most important energy source in the country. Shaanxi Province also has 200 billion tons of coal reserves, mainly in its north.

   Aside from coal, there are also major oil and gas resources in the region. According to an assessment of national oil and gas resources in 1993, fossil oil and natural gas are mainly in the northeast, west and east of China. The west, including the Loess Plateau in this definition, accounts for about 21.0 % of oil resources and 39.0 % of natural gas in the country (Figs. 19.1 and 19.2). In Shaanxi Province alone, total proven reserves of oil and natural gas reached 460 million tons and 210 billion cubic meters, respectively. Although extraction from these sources for energy has significantly contributed to the national energy supply and economic development on the plateau, it has had negative environmental impacts. Methods for extraction, processing, handling, transporting and using coal are primitive, with high waste and low efficiency. In some mining areas, poor air and water quality and related health hazards are very serious (Sun and Wang 2010). Although there has been attention to mitigating the environmental costs of coal extraction, more measures should be developed for local environmental decision making and planning.

4. *Rapid growth of labor surplus in agriculture and their rural-to-urban migration on the Loess Plateau*

   Low socioeconomic status, poor climate conditions, massive land degradation, and lack of infrastructure for intensive land use have undermined agricultural growth and decreased the labor-absorption potential of farming in the Loess Plateau region. Moreover, arable lands on the plateau declined sharply because of the *Grain-for-Green* program and urban land expansion over the last 20 years. *Grain-for-Green* (Chap. 10) was launched by the government in 1999 as a sloping cropland retirement program. According to statistics of the State Forestry Administration (SFA), 9.06 million hectares of cropland on steep slopes in the Yellow and Yangtze river basins and other vulnerable places were converted into woodland or grassland between 1999 and 2009. The accelerating urban land expansion is also a reason for reduction of arable lands. The literature shows that urban land in China has increased about 660,000 ha (or 23.9 %); 527,000 ha of cultivated land was transformed into urban land during 1990–1995, and 129,000 ha from 1995 to 2000 (Liu et al. 2005). As a result, there is substantial rural surplus labor in this region, for which ecological-economic implications of the *Grain-for-Green* program are summarized as follows.

   First, if this surplus labor force does not transfer from rural to secondary or tertiary sectors, it will probably return to previous lifestyles and production patterns. This would threaten the achievements of *Grain-for-Green* and other environmental projects.

   Second, people engaged in the agricultural sector in China have better education levels relative to other countries. Fifty-one percent of rural sector workers in India are classified as illiterate (less than primary school), and only 25 % have secondary school educations or more. In Brazil, median education in the rural sector is about 4 years (Henderson 2009). Educational attainment in the rural sector is substantially higher in China. For those still in the labor force in this sector (excluding migrants to cities), a 2006 household survey in Yan'an city of Shaanxi Province showed illiteracy at 6.8 % of this force, with 61 % having completed at least junior secondary schooling. For migrants, 2.3 % were illiterate, with 70 % having at least junior secondary schooling (Wang 2008). These rural migrants to cities have the education to learn new skills in on-the-job training required in the modern manufacturing and service sectors, and to contribute to modern civil society. Further, rural labor flowing into intensive industrialized areas can increase worker productivity. This implies that farmers moving from the rural to urban sector (within or outside the Loess Plateau region), even after accounting for skill differences, would substantially improve personnel productivity. This could raise regional or even national output. In this sense, these 18.4 million rural surplus laborers, representing 43 % of the total labor force (~40 % of 107 million) of the Loess Plateau, can contribute tremendously to rising output of the region.

Third, there is a large and growing urban–rural income gap in China, which was represented by a factor of 3.3 in 2008. This gap reflects low agricultural productivity, because of under-investment in the agriculture sector and small land holding size per agricultural worker. The rural-to-urban transfer of surplus labor would transfer low productivity workers into higher productivity occupations, reduce income inequalities between urban and rural populations, and change the dual urban–rural structure into urban–rural integration to promote sustainable development in both rural areas and cities.

19.1.2 Development Trend on Loess Plateau

19.1.2.1 The New Western Development Program Provides Opportunities for Future Ecological Protection and Economic Development of Loess Plateau

After the Reform and Opening up strategy in 1978, economic development disparity between eastern and western China increased excessively. In 2008, per capita GDP in inland regions averaged 13,513 Chinese Yuan (CNY, around 0.1603 USD as of Feb 2013), or less than half that of coastal regions.[1] The difference was even greater between provinces. Per capita GDP in Shanghai was ten times that of Guizhou Province. In terms of per capita income, inland rural and urban residents earn only about two-thirds of their counterparts in the east. The rural–urban gap in this income is also great—3 times in coastal regions and 3.2 times in inland regions (Peng 2010).

Such a great regional disparity counters realization of the overall economic goal of the Loess Plateau, and produces social issues; it even obstructs healthy development of the country's economy and society. In response to such regionally unbalanced development, the national government implemented the Western Development strategy to support development and construction in western China in 1999. This strategy was aimed at promoting development in underdeveloped regions, reducing regional disparities and achieving coordinated development among regions. The initial plan was to allocate 8.4 billion USD to four key tasks: accelerating infrastructure development with emphasis on water resources; improving ecological conditions with focuses on desertification, soil erosion, and flood control; promoting industrial development; and strengthening science, technology, and education.

Since 2000, the distribution of national key projects sponsored by national fiscal funds and bonds have tended to favor western regions, where in the past decade 143 key projects were begun with total investment over 2,874.2 trillion CNY (Lu and Deng 2011). According to the 12th Five-Year Plan for Western Development (2011–2015), future investment in western China will still concentrate on infrastructure construction, ecological environment protection, education and public health.

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[1] The coastal region includes Liaoning, Tianjin, Hebei, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangxi and Guangdong Provinces. All remaining provinces are classified as inland.

Investment during the Western Development has brought unprecedented opportunities for socioeconomic development to the Loess Plateau, and promoted integration of its economy into the national one. This investment has also contributed to environmental protection and ecological security in the western part of the country. The 12th Five-Year Plan for Western Development clearly states that the next 5 years is crucial for deepening the Reform and Opening up strategy and speeding economic transformation of western China; this is also a key period for building a prosperous society. The plan also clearly designated the Loess Plateau as a major energy and chemical industry base, as well as a demonstration site of modern dryland farming, ecological civilization, and soil and water conservation. All these objectives furnish unprecedented opportunities for development of the plateau.

19.1.2.2 Ecological Migration Versus Improvement of People's Livelihood in Fragile Loess Plateau Region

Ecological migration refers to people leaving their original areas of residence because of a harsh environment in which there is a general lack of poverty alleviation. Such migration can also contribute to restoration of the ecosystem and protection of the vulnerable environment. Such extremely ecologically fragile locations include the Yunnan-Guizhou Plateau (an area of serious "rocky desertification"), Loess Plateau, Three-River Headwaters (headstreams of the Yangtze, Yellow and Lancang rivers), central Tibetan Plateau, and Qinling Mountains area of southern Shaanxi Province. All these are either hotspots of biodiversity conservation or critical ecological zones, and have varying problems of accelerated environmental degradation. They are principal sources of ecological migrants to the rest of China. Ecological migration is a potentially important approach to the accelerated environmental degradation issues. This is because some authors have argued that global trends of increasing rural–urban migration and population urbanization (UNFPA 2007) could provide opportunities for nature conservation, particularly where deforestation is driven by subsistence agriculture (Izquierdo et al. 2011; Wang et al. 2010; Aide and Grau 2004). More importantly, such processes made poor farmers leave poverty-stricken areas and resettle in plains areas more suitable to human habitation. This clearly helps reduce rural poverty in the emigration areas and build a more prosperous society.

Since 2000, the Chinese government has implemented a plan of ecological migration in ecologically fragile areas of the country. So far, about seven million farmers in western China alone have been relocated to better-off locations within or outside provinces in which they lived previously. For example in 2005, the Ecological Protection and Restoration Program (EPRP) in the Three-River Headwaters region conserved and rehabilitated ecological functions through ecological migration, grazing bans, wetland protection, and harnessing of degraded grassland. The EPRP is regarded as another large landmark project, after the Western Development and Qinghai–Tibet Railway. The ecological migration program within the EPRP permitted residents to leave the reserve to restore the ecosystem and protect the environment. On the Loess Plateau, there have already been many successful experiences of ecological migration in the Ningxia Autonomous Region. By the end of 2008, a total of 545,000 of poor farmers in southern Ningxia emigrated from the mountainous area and relocated to plains in the north, an irrigation area along the Yellow River. The 12th Five-Year plan will continue to support ecological migration in central and southern Ningxia. Shaanxi Province also plans to allocate CNY 115.94 billion to relocate 2.4 million poor farmers in southern Shaanxi and 392 thousand in northern Shaanxi, from 2011 through 2020.

In spite of the successful cases above, ecological migration programs in China have drawn some criticism. Through reviewing and identifying seven putative drivers of rangeland degradation on the Qinghai-Tibetan Plateau suggested by published or unpublished literature in Chinese or English, Harris (2010) concluded that the primary environmental rationale behind ecological migration is largely inadequate. Foggin (2011) claimed that ecological migration policy remains an untested social experiment at enormous scale, with potentially devastating long-term (generational) social, cultural and possibly environmental consequences, some of them irreversible. He even asserted that several government policies on ecological migration are threatening not only pastoralist livelihoods and community structure of targeted regions, but also regional stability, because quota-driven resettlements are linked to high levels of unemployment and loss of hope (Foggin 2008). Based on a comprehensive literature review, Foggin (2011) showed that there are already several alternate approaches to conservation, including certain traditional resource management practices and other tried-and-tested forms of local governance, such as co-management schemes (Banks et al. 2003; Reed 2008). In this sense, further research is needed.

19.1.2.3 The Rapid Urbanization Could Generate Employment Opportunities and Development for Rural Surplus Laborers in the Future

The increase of urban population in China over the last 2 decades reached 222 million. More than 10 million people joined the urban population annually from 1990 to 2004. During this period, about 174 million moved from rural areas to cities, representing the largest flow of migration. Rural–urban migration of the Loess Plateau has risen remarkably since 1999, when the *Grain-for-Green* program was launched. In the Shaanxi provincial capital Xi'an, migrant workers made up 46 % of the urban work force. Two million emigrated from Yan'an and Yulin prefectures in north Shaanxi Province as a seasonal labor force. In response to the population explosion in urban areas, urban built-areas have expanded rapidly. In Xi'an, a metropolis within the Loess Plateau region, this area increased by 182 km^2, from 187 km^2 in 2001 to 369 km^2 in 2011.

Aide and Grau (2004) have asserted that, regardless of the motive for rural–urban migration, the abandonment of agricultural and grazing lands will facilitate ecosystem recovery and may provide ecological services for the growing urban population, plus support biodiversity that has attracted widespread conservation interest to the region. In addition, these economic, demographic, and land-use/land-cover dynamics or "forest transition" (Mather and Needle 1998) are similar to what has occurred in Europe and North America; economies shift from agriculture to industry, cities grow, consumption increases, rural areas are abandoned and forests recovered. The *Grain-for-Green* program has been experiencing such a forest transition. From this perspective, the rapid urbanization provides strong employment opportunities for surplus farming labor, contributing to labor transfer and economic adjustment in the era subsequent to *Grain-for-Green*. This also reduces environmental pressure from the rural population, which is favorable to rehabilitation of the degraded ecosystems.

19.2 Ecosystem Rehabilitation and Protection Activities on Loess Plateau

19.2.1 Ecological Restoration and Protection Implemented for Soil and Water Conservation May Also Serve as the Key Ecological Defense for Future Development of the Plateau

Severe erosion in the Loess Plateau region has been a serious ecological and social problem. Average and maximum erosion rates were 150 and 390 Mg ha^{-1} yr^{-1}, respectively (Chen and Luk 1989), which are equivalent to surface lowerings of 1.2–3.1 cm yr^{-1}. This erosion damages soil fertility, particularly on upper slopes, by washing away soil nutrients and preventing organic matter accumulation. Offsite impacts of the erosion are potentially larger. Most of the eroded loess finds its way into the Yellow River, causing serious problems of sediment deposition and reducing reservoir carrying capacity (Greer 1979). Moreover, in the densely populated lower reaches of the Yellow River valley (home to some 200 million people), sediment deposition has raised the level of the riverbed 10 m above that of the surrounding plain, forming an "aboveground river." This produced a very serious flood hazard that has cost millions of lives (Hershkovitz 1993) and severely impaired economic development in the middle and lower reaches.

Ecological and forest rehabilitation programs such as the *Grain-for-Green*, Three- North Shelterbelt network development, and Natural Forest Protection have played important roles in protecting and expanding forest and grassland resources and guarding soil from erosion throughout the last decade. Since the 1970s, vegetation cover in the Yellow River Basin has increased by 18 % and sediment loading in the river has decreased by 400–500 million tons annually. As key ecological defenses, implementation of these programs has undoubtedly contributed greatly to future development of that basin.

19.2.2 Improving Ecosystem Services of Loess Plateau via Ecological Restoration and Protection

19.2.2.1 Integrated Practices of Soil and Water Conservation

Soil conservation measures include those of conservation tillage, biology and engineering (e.g., terraces and check dams). In the last decade, natural restoration has received much attention. It reduces disturbance of wasteland through mountain enclosures, so as to increase vegetation cover and diminish sediment sources. Owing to the complicated situation and landforms, these measures are usually incorporated in the erosion region of the Loess Plateau.

Beginning in 1980, Chinese scientists introduced the concept of "small watershed integrated management," in which a small watershed is a closed drainage area from 4 to 50 km^2. Since then, the concept has been practiced nationwide. This represents an experience drawn from long-term practices of soil and water conservation in China, and is arguably the primary approach for improving the environment and farmer income on the plateau (Li et al. 2000; Lu et al. 1997).

19.2.2.2 Terraces Can Increase and Conserve Soil Moisture and Create Better Conditions for Crop Production

On the Loess Plateau, terracing on sloping farmland have become effective means for enhancing rainfall infiltration and fertilizer conservation, eliminating surface runoff, and reducing soil and water loss (Lu et al. 2009; Chen et al. 2007). Terracing improves conditions for crop growth by providing available water, increasing moisture and nutrient use efficiencies (Li et al. 1994). Zhuanglang County of Gansu Province is often called the "terraced county" in China. Up to 2006, 4,000 ha of fruit, 666.67 ha of vegetables and 10,000 ha of merchandised potatoes were established on terraces. Fruits, starch, grass and pork formed the four major pillar industries. Furthermore, farmer income has grown notably following terrace construction, attaining 1,550 CNY per capita in 2005 (Liu et al. 2011). For example, according to the development index of Gansu Province (Chen 2001), the population carrying capacity of the land in Zhuanglang County increased from 195 people km^{-2} before terracing to 315 km^{-2} afterward.

19.2.2.3 Application of Rainwater Harvesting and Supplementary Irrigation Technology

Water deficiency is the major limiting factor for farming, forestry, animal husbandry, and environmental improvement in most areas of the Loess Plateau. Rainwater harvesting and supplementary irrigation technology have been promoted by research and development agencies since 1993 in Gansu Province, to alleviate water shortages and increase water available to crops for stabilizing agricultural production (Zhao 1996; Li et al. 1999). As an integrated system (Li et al. 1999), such technology consists of three main components—surface water collection (watersheds), water storage tanks, and supplemental irrigation systems.

The advantages of rainwater harvesting and supplementary irrigation technology are that they are simple, cheap, replicable, efficient and adaptable (Reiz et al. 1988). They have superior quality of small scale, and are ideally suited to the socioeconomic and biophysical conditions of semiarid rural areas (Li et al. 1999). Rainwater harvesting and supplementary irrigation technology have also been shown to improve water-use efficiency, reduce soil erosion, improve soil fertility, and raise agricultural productivity (Zhao 1996; Li et al. 1999; Wang et al. 2005). These have become strategic measures for social and economic development in semiarid regions, furnishing effective means of alleviating poverty and facilitating a breakthrough in dryland farming (Deng et al. 2004). In practice, there are several successful engineering approaches to this technology. In the rainfed farming area of southern Ningxia, rainwater harvesting and supplementary irrigation systems have been established and effectively performing since 1995.

19.3 Challenges for Future Ecological-Economic Development

19.3.1 The Vicious Circle of "poor life—more reclamation—environmental deterioration—poorer living"

In Chinese history, there have been such extreme policies as pro-cultivation. Coupled with the vulnerable environment, over-cultivation caused a vicious circle of "poor life—more reclamation—environmental deterioration—poorer living." From the late 1950s through early 1970s when food security was a tremendous challenge for the Chinese government, a grain-dominated agricultural policy structure was widely implemented in the country. The historical lessons indicate that extreme pro-cultivation is not nearly in accord with the natural characteristics of the Loess Plateau, and goes against natural laws. This extreme policy cannot increase grain production sustainably, and damages the ecological environment and aggravates soil erosion. This leads to overall backwardness in agriculture, forestry and livestock husbandry.

Natural conditions are often responsible for the persistence of poverty in ecologically fragile areas of China (Heilig et al. 2006), and such poverty causes ecological deterioration that further aggravates poverty. This is described by a saying in China—"the poorer the people, the more land will be reclaimed; the more land is reclaimed, the poorer the people will be." In many regions, farming on steep slopes and marginal land was common, because of the increasing population pressure. Such conditions did not fully change until the *Grain-for-Green* project, which gave state support to farmers who returned cropped land to ecological vegetation (Chap. 10).

19.3.2 Conflict Between Ecosystem (Nature) Protection and Food-Related Farmer Livelihood

In practice, tree and grass plantation are used as principal measures for soil and water conservation. Basic cropland construction, on which local farmers rely for their livelihood, is ignored. A problem is that once the *Grain-for-Green* government subsidies are ceased, a large proportion of retired land is possibly returned to its pre-program use. This was the case in an afforestation project supported by the World Food Program in Xiji county of Ningxia Hui Autonomous Region during the 1980s. Like *Grain-for-Green*, 52,600 ha of sloping land was afforested and 51,300 ha was planted with grass by that project, representing a third of total county area. This was regarded as the best plantation in the world at that time. However, local farmers cut down the trees and cultivated the grassland as soon as the food and subsidies were halted at the end of the project. The key reason was that their food supply and income sources had not been completely solved. This is a profound lesson for the Chinese government in implementing similar arable-land conversion programs or ecological planning. As declared in previous sections, multiple measures suitable to various social and ecological conditions should be applied separately or together, to achieve both ecological restoration and increases in resident income.

19.3.3 Compatibility Between Implementation of Environmental Projects and Realization and Maintenance of Ecosystem Service Functions

In many parts of northern China, monoculture plantations of several fast-growing tree species were widely established during past decades, along with large national projects for ecological restoration and soil and water conservation programs. Unfortunately, while the plantations contributed to soil and water conservation and increases in regional vegetation coverage, only limited areas with relatively favorable water conditions developed into ecosystems with good productivity and ecological functions. For example, long-term mean precipitation of <200 mm yr^{-1} within arid regions is incapable of supporting forest vegetation, given the 2,500–3,000 mm yr^{-1} of potential evaporation common there (Huang 2006). Natural vegetation in these areas is desert steppe or dryland shrub communities, which have greater water-use efficiency than most tree communities and which have evolved to use soil water sustainably under the environmental conditions. According to the natural vegetation distribution along the climatic gradient across the Loess Plateau, northern and northwest parts (except high mountains) are unsuitable for forest establishment (Chap. 4). Although some successful cases have been reported, overall survival rates of planted trees are very low, mostly around 30 %

(Jiao 2005), even 10 % in some areas with annual precipitation less than 400 mm (Shen et al. 2003).

Another problem of artificial plantations is inappropriate choice of tree species. Fast-growing species, for example poplar (*Populus* L.) and black locust (*Robinia pseudoacacia* L.), have been widely planted in North China, where the water supply may not be sufficient for sustainable growth. The large national project of shelterbelt networks in the northern, northeast and northwest territories produced an ecological belt 400–700 km wide and 4,500 km long, with low productivity and early degradation in many places. In the northern Loess Plateau region, artificial plantations with fast-growing species do not grow well, and so-called “aged small trees” are common. Moreover, a “dry horizon” forms in deep soil layers under such vegetation (Chap. 17).

A similar situation has been found in the *Grain-for-Green* project. According to surveys of the State Forestry Administration on the plateau in early 1999 and 2000, survival rates of planted trees were less than 30 %; for example, only 26.8 % in Jingbian County of northern Shaanxi Province. The local government did not pay enough attention to ecological and economic functions of various vegetations in semi-arid areas. Compared with tree plantation, grass and shrub planting require much less investment and are favorable to most of the plateau. Therefore, a critical step is that plant species selection must abide by the principle of matching species with location.

19.3.4 Stability and Consistency of National Policies Versus Farmers’ Voluntary Participation and Effectiveness of Ecological Restoration Programs

Experience indicates that soil erosion on the Loess Plateau has been closely associated with national policies. The collectivization of land in the 1950s discouraged people from tree planting and forest management, and even from intensive farmland management. Soon after, as part of the attempt to industrialize, a campaign to increase steel production took place in the 1960s, known as the Great Leap Forward initiatives. In many regions, even backyard furnaces fueled by wood charcoal were deployed to produce steel (Yin 1994). Throughout the 1960s and 1970s, forest and grassland was converted to farmland, owing to grain shortage crises and the policy to make arable land. Each of these broad-scale programs resulted in severe destruction of vegetation.

The aforementioned examples reflect problems in decision making, and even in individual program implementation. Factors causing great environmental changes can mainly be attributed to policy instead of technology. Therefore, the direction and stability of national policies should be strongly scrutinized and emphasized, for current ecological reconstruction as well as soil and water conservation.

19.3.5 Cooperation and Coordinated Implementation Among Government Departments Involved in Environmental Projects

Because of long-duration operation under a planned economy system, ecological reconstruction on the Loess Plateau has been undertaken and managed by several government departments. For example, the State Forestry Administration has been charged with administering ecological projects. Other government agencies are responsible for agricultural and livestock production, soil and water conservation, poverty alleviation, but not formally involved in environmental protection. Some problems may be easily avoided by interagency cooperation and coordinated implementation. In addition, regional governments and local communities may be authorized substantial flexibility in implementing restoration efforts.

19.4 Conclusions

Improper farming activities and excessive energy source extraction, coupled with the vulnerable ecosystem of the Loess Plateau, have created environmental problems such as vegetation degradation and severe soil erosion; this has generated the vicious circle of “poor life—more reclamation—environmental deterioration—poorer living.” In response to such ecological-economic issues, numerous actions have been taken by the Chinese government toward ecosystem rehabilitation and protection on the plateau, including large-scale soil and water conservation projects. These were carried out successively from the early 1980s through late twentieth century. Historically successful experiences in the plateau region show that such ecological restoration and protection programs are important to improve ecosystem service functions there. In addition to natural conditions, however, numerous socio-economic factors have affected ecological restoration and protection efforts. Thus, there are many historical lessons and problems that the Chinese government must learn from and address in present and future actions toward ecological restoration and protection on the Loess Plateau. Several challenges need to be met by decision makers at different levels in China. These challenges include the conflict between nature protection and food-related farmer livelihood, incompatibility between ecological restoration measures and natural conditions, and policy instability and inconsistency. For some vigorously debated issues such as ecological migration in ecologically fragile areas, their ecological soundness as well as social and cultural consequences demand further exploration. Nevertheless, the *Western Development Action* provides unprecedented opportunities for coordination between ecological protection and economic development on the plateau. For seizing the opportunities to promote ecologically sound development in this region, there is vast potential for rural industry transformation from primary to secondary or tertiary sectors, reduction of pressure on the rural environment through urbanization, and changes in model for ecological construction management.

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