Environmental Challenges and Solutions 1

Series Editor: Robert J. Cabin

Carl F. Jordan

An Ecosystem Approach to Sustainable Agriculture

Energy Use Efficiency in the American South

Springer

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Environmental Challenges and Solutions

Volume 1

Series Editor

Robert J. Cabin, *Brevard College, Brevard, NC, USA*

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I dedicate this book to my former graduate students. As each completed his or her work, I asked myself, "What have I learned from the work of this student?" As I wrote this book, I realized that each contributed in a unique way toward the development of ideas presented here.

Their names and contributions are

- **Krista Jacobsen**, A systems analysis of an organic agro-ecosystem – Spring Valley Ecofarm
- **Yolima Carrillo**, Food chains in the soil ecosystem – Spring Valley Ecofarm
- **Josh Egenolf**, Intensive grazing management – Spring Valley Ecofarm
- **Kathleen Raven, Jason Mann**, Agricultural education – Spring Valley Ecofarm
- **Britt Faucette**, Sediment control measures for construction activities – Spring Valley Ecofarm
- **Rodrigo Matta Machado, Eleanor Green, Jonathan Reichlen**, Nutrient dynamics in agroforestry – Piedmont region, Georgia
- **Han Xingguo, Rosa Guedes, Robert Potter, Dowon Lee**, Soil organic matter and phosphorus solubilization in highly weathered soils of the Georgia Piedmont
- **Justin Ellis**, Diffusion of innovations among small scale farmers – Georgia Mountains
- **Christopher Uhl, Jiragorn Gajaseni**, Energy use efficiency in shifting cultivation – Venezuela – and in rice cultivation – Thailand
- **Florencia Montagnini**, Mixed species forest plantations – Costa Rica, Brazil, Argentina
- **Paul Wojtkowski**, Economics of agroforesty – Bahia, Brazil
- **Jess Parker, Jeff Luvall**, Effect of disturbance on energy flow in a rain forest – Costa Rica
- **Robert Buschbacher**, Impact of cattle in an Amazonian pasture, Venezuela
- **Manuel Maass**, Ecosystem management for erosion control – Mexico
- **Rita Mesquita**, Ecosystem recovery – the Biological Dynamics of Forest Fragments Project, Brazil
- **Garo Batmanian**, Reforestation of degraded pastures – the Carajas Project, Brazil
- **Suzanne Kolb**, Reforestation of degraded pastures – the Atlantic Forest Project, Brazil
- **Charles Russell**, Environmental problems of monoculture plantations – the Jari Project, Brazil
- **Christian Castallanet**, Participatory Action Research – Brazil
- **Cornelius Burns**, Adaptation of ecological communities – El Yunque, Puerto Rico
- **Christopher Miller, Eduardo Asanza, Jay Becker**, Use of ecologically adapted species for economic production – Ecuador
- **Kristina Laidlaw**, Environmental outreach – Costa Rica
- **Julie March, Laura Ediger, Jeffrey Stoike**, Political ecology – the impact of agricultural policy on rural communities – Brazil, China, Panama

Preface

In 1943, I spent a boyhood summer on a small potato farm in Northern Maine. The plow and the potato sprayer were pulled by a team of Belgian draft horses, Bob and Barney. Manure for fertilizer was shoveled by hand. The one-room school house nearby closed during potato picking season, so the children could help. Life was hard, but that is just the way things were.

But agriculture elsewhere had begun to change. In the Mid-West, threshing machines had already replaced scythes and flails to separate grain from stalks and chaff from grain. Self-propelled combines that combined reaping, threshing, and winnowing into one process were becoming common. Draft animals had already given way to clumsy steam-powered tractors of the early 1900s, and the change to gas- or diesel-powered tractors had just begun. Life on a farm was becoming easier. But the really big revolution in agriculture was only starting. It was an energy revolution that far surpassed all the gains that had occurred in agriculture in the previous 5,000 years. Engineers and scientists had learned how to substitute abundant fossil fuel energy for hand and animal labor, and inefficient steam-driven engines. The impact was tremendous. Farming was accomplished by machines that were powered by petroleum and by chemicals that were synthesized from oil. Nitrogen fertilizer became readily available as a result of the energy-intensive Haber–Bosch process. Geneticists bred crop varieties that could take advantage of the new technologies. Everyone benefitted. Life seemed to be better. Farmers no longer had to toil in the hot sun or cold rain. For city dwellers, food was cheaper, and meat, which was generally unavailable in the 1940s, was plentiful. Farm productivity increased so much that before the end of the twentieth century, the number of farmers in the U.S. dropped to less than 4 % of the population. Farming had become "more efficient". In just a few decades, the energy revolution had transformed agriculture. The change in food production was as great as any social or technical revolution in history. It was the essence of "progress".

But for every action, there is an equal and opposite reaction. The revolution in agricultural energy affected the environment in many ways: dead zones in the Gulf of Mexico from fertilizer runoff in Midwestern grain fields; extinctions of honey-bees from excess pesticides in fruit and nut orchards; soil erosion where plowing and drought combined to reduce vegetative cover; rapid spread of disease where crops have been planted in endless monocultures; aberrant behavior of farm animals confined in cramped pens; drying up of aquifers due to wasteful use of irrigation water; and loss of ecological knowledge and farming experience as machinery replaced humans. These impacts have been documented in scores of books, from Rachel Carson's *Silent Spring* to Michael Pollan's *The Omnivores Dilemma*. Wendell Berry's *Bringing it to the Table* chronicled the social problems created by "progress" – the steady decline of rural communities and the rise of agribusiness. These critics have called the new agriculture "unsustainable" because of the social and environmental damage that it caused. But what has ever been "sustainable" in a world that is constantly changing? I have wrestled with this problem throughout my professional career, first as an environmental scientist for the Atomic Energy Commission where I tracked radioactive isotopes in the environment, and then as a Research Professor at the University of Georgia's Institute of Ecology (now Odum School of Ecology), where I studied the environmental impact of land management, from monocultures in the Brazilian Amazon to organic farms in Georgia.

During my career, I have written many books and scientific publications. In some ways, the effort has been frustrating. My primary interest was applying scientific knowledge to management problems, but in most cases I was constrained to publishing in the standard scientific format. There was little room to discuss limitations of the scientific method to solving environmental problems and to suggest alternative ways for scientists to understand how ecosystems function. Gene Odum pinpointed the problem when he said "Scientists are good at identifying environmental problems, but are not of much use in solving them." The reason is that the most common scientific approach to environmental challenges has been reductionistic, that is, an analysis of ecosystem components. In the case of agriculture, some scientists focus on insect pest control, others on soil fertility, weed control, plant breeding, and so forth. The hope is that someone somewhere will put it all together to come up with a farming system that is more sustainable. This rarely happens. Scientists cannot solve agricultural problems when their vision is confined to a narrow segment of the farm.*

In contrast to reductionism, this book takes a systems approach, that is, it looks at properties of entire ecosystems such as energy use efficiency and efficiency of nutrient cycling, properties that emerge from the interactions of all the components of a farm and that form the basis of sustainability. In the scientific literature, there are discussions here and there of ecosystem properties, but rarely if ever have they been used to analyze agricultural sustainability. Framing solutions to agricultural problems in terms of ecosystem properties can increase the understanding of sustainability and of ways to achieve it. Solutions in the American South based on such an understanding are the basis for this book.

Athens, GA, USA Carl F. Jordan
Fall, 2012

*"Never trust an expert." Anonymous farmer.

Acknowledgments

The inspiration for the ideas that I present in this book include:

- **Howard T. Odum**, who started my career with a term at the U.S. Atomic Energy Commission. His characterization of modern agriculture as "potatoes made of oil" inspired this book.
- **Eugene P. Odum**, who encouraged me throughout my 35 years at the University of Georgia. About my excursions to the tropics, he would often say, "Carl, that research is fine, but you need to do something for the people of Georgia who pay your salary." So I did – I started Spring Valley Ecofarms, a farm in Athens, Georgia, dedicated to research in sustainable agriculture and to education and outreach for students from K-12 through Ph.D.
- **Frank B. Golley**, always ready to take a morning break and discuss the problems of agriculture. It is not the problems *of*, he would say to me, the problem *is* agriculture.

I thank Drs. Alan Covich and Robert Cabin for their helpful comments on a draft manuscript of this book.

Contents

Chapter 1
A Systems (Holistic) Approach to Sustainable Agriculture

Abstract While natural ecosystems require only sunlight to maintain themselves, agricultural ecosystems require energy subsidies in the form of fertilizers, irrigation, and pesticides. "At what rate should these energy subsidies be applied?" is the basic question for achieving agricultural sustainability. The answer is using energy inputs efficiently, that is, at a point where there is maximum energy output (yield) per unit energy input (fertilizers, pesticides etc.) Energy use efficiency is one of several ecosystem characteristics, but from the viewpoint of sustainability, it is the most important because of the increasing cost and scarcity of fossil fuel subsidies, and the pollution caused by energy waste. Energy inputs to provide maximum yield occurs at a rate which is higher than that which provides maximum energy use efficiency. Maximizing yield does not mean maximizing sustainability because the effort to increase yield (energy output) through increasing energy inputs beyond a certain point results in a decrease in efficiency for every additional unit of yield. Maximizing yield does not take into consideration the cost of that increased yield. Although farming to maximize energy use efficiency instead of yield may result in a decrease in gross energy output, it increases net energy output. Any decline in yield from farming for energy use efficiency is compensated for by decreased costs of energy inputs and pollution clean-up costs that occur from operating beyond the point of maximum efficiency. In economic terms, managing for maximum output is producing beyond the point of diminishing returns. Managing for energy use efficiency means getting the most for your money.

Other ecosystem properties that affect agricultural sustainability are nutrient cycling efficiency, stability (resistance and resilience), diversity, productivity, respiration, decomposition and ability to discharge pollutants.

Keywords Agricultural sustainability • Sustainable agriculture • Agricultural energy use • Energy use efficiency • Ecosystem properties • Agricultural ecosystems

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1.1 Energy Efficiency

Inefficient use of energy is the root cause of agricultural unsustainability. Pollution is energy gone to waste. Extinction of beneficial insects is an inefficient allocation of the energy used to control insect pests. Monocultures decrease the energy use efficiency of crops, forests, and livestock. Industrial mechanization replaces energy inherent in natural and social capital with fossil fuel energy that decimates communities and environments in rural America. Reliance on increasingly expensive and exhaustible fossil fuel energy contributes to the unsustainability of modern agriculture (Johansson et al. 2012).

Inefficient use of energy is caused by an obsessive focus on maximizing yield (gross energetic output) while ignoring energetic costs. Sustainability depends not on maximizing yield, but on maximizing net energetic gain (gross energy output minus energy input). A successful business does not focus solely on gross income: to determine profits it must also consider costs. Likewise, sustainable agriculture must focus on energetic costs as well as yields. Yield alone does not define profit – or sustainability. It is the yield minus the inputs that determines profits and sustainability.

1.2 A Systems Definition of Agricultural Sustainability

Agriculture is a process that transforms energy from the sun and from fossil fuels (here called energy subsidies) into energy for human consumption. A systems definition of agricultural sustainability is based on energetic use efficiency. The more efficiently that energy subsidies are used by a farmer, the more sustainable is that farm. Efficiency is determined by the output/input ratio.

Murphy and Hall (2010) have called the output/input ratio EROI, or energy return on energy invested.

$$EROI = \frac{EG}{EI}$$

Where

EG = Units of energy gained
EI = Units of energy invested

The reciprocal of the EROI ratio, an input/output analysis of systems, was originally developed to determine the efficiency of economic systems. When applied to ecological systems, it has been called Network Environ Analysis (Fath and Patten 1999; Patten and Fath 2001) (Box 1.1).

Energy "invested" means energy invested by humans. It does not include the energy from the sun used in photosynthesis, and in naturally occurring ecological functions such as nitrogen fixation by rhizobial bacterial. It does include inputs such as tractor fuels, fertilizers, pesticides, and human labor. Inorganic fertilizers and pesticides are embedded energy, because it requires considerable fossil fuel energy to

Box 1.1

Analyzing the energy inputs and outputs of agricultural systems dates back more than 30 years (Black 1971; Steinhart and Steinhart 1974; Cox and Atkins 1979; Fluck and Baird 1980).

Box 1.2

The cost of energy inputs should consider not only the energetic value of those inputs, it must also consider the energy costs of obtaining the energy that produces those inputs. The amount of energy needed to obtain a given amount of petroleum is increasing. The cost of energy derived from older shallow oil wells is less than the cost of that from deep wells, or from natural gas obtained through "fracking" (fracturing) of shale rock. As the energy costs of obtaining energy increase, the costs of energy invested will increase. Costs include not only extraction costs, but pollution clean-up costs that result from drilling. Another example is the energetic cost of fresh water. If the source of fresh water for irrigation is desalinized sea water, then the energetic cost of desalinization would have to be included in the energy invested (EI) part of the EROI equation. These cost differentials have not been considered in the examples given later in this text, but as energy become increasingly scarce, they should be used in future calculations.

Box 1.3

We recognize that calories in the form of glucose and carbohydrates are not the only value of food. Fats and proteins also are important. A more sophisticated analysis would need to consider the amount of glucose energy embedded in a unit of protein energy.

manufacture them. So when we talk about energy subsidies in industrial agriculture, we are including the energy costs of synthesizing fertilizers such as ammonium nitrate and insecticides such as malathion, as well as applying them to the field (Box 1.2).

The EROI measure of sustainability asks, "How much energy output in the form of food can be had from one unit of energy input in the form of fossil fuels, or from other energy subsidies supplied by humans?" (Box 1.3). The greater the output of energy per unit of input, the greater the sustainability. Sustainability is determined by energy use efficiency. EROI tells us which agricultural practices are most energy efficient, and therefore most sustainable. It guides us toward energy efficiency and sustainability (Box 1.4). Odum and Pinkerton (1955) suggested that the "optimum" rate of energy input occurs not where energy efficiency is greatest, but rather where

Box 1.4

Energy returned on investment is the basic parameter needed for research on biofuels such as ethanol made from corn. If the ratio is less than one, it means that more energy is used in creating the biofuel than is gained through the production process, and the effort results in a net loss of energy.

the addition of one energy unit at the margin results in a change from plus to minus in energy use efficiency. Up to that point, each unit of energy input results in greater than one unit of output. Beyond that point is where each additional unit of energy input results in energy output that is less than one unit of energy input.

The so-called increase in agricultural efficiency over the past half-century is based on a calculation of the amount of time that a farmer needs to produce a given amount of yield, and the amount of land needed to produce a given amount of yield. Number of available field hands was the factor limiting agricultural production on a farm, and the amount of land available for agriculture limited national production. The increase in farmer efficiency has been considered a good thing, in that fewer farmers are needed now than in the past, with the result that many more people can pursue other aspects of society. The increase in land use efficiency also has been considered good, because this allowed more land to be set aside for parks and conservation reserves. But increases in farmer efficiency did not come about because farmers worked harder. It came about because farmers were able to take advantage of energy subsidies that powered huge combines, fertilized the fields with nitrogen, and killed insects with pesticides. From the point of view of energy, the efficiency of a farmer has actually decreased since the 1950s. And while land use efficiency (output per acre) has increased, the energy output per unit energy input has decreased. It has been these transitions that has caused the decrease in agricultural sustainability.

1.3 Is Energy Efficiency the Key to Sustainability?

Increasing efficiency of energy use results not only in decreasing demand on scarce or expensive energy reserves, it also means decreasing the amount of energy that is wasted through conversion into air and water pollution. However, some economists argue that increasing the efficiency of energy use will *not* help conserve energy (Michaels 2012). Their argument is that increasing the efficiency of energy use will lower the price, thereby increasing the demand. The result is that the amount of energy used will stay the same, or even increase. The argument makes sense, according to the law of supply and demand for goods that have an elastic demand (demand changes as price changes). They used the example of air conditioners. Higher energy efficiency reduced the cost of cooling, so more people were able to buy them, and energy use increased. However demand for food is relatively inelastic (demand is unrelated to price), except for luxury items. Higher efficiency of production for staple foods such as bread will not increase demand, but rather conserve energy.

Some analysts argue that there is such a vast supply in the U.S. of low-cost coal, tar sands, and natural gas that energy shortages are unlikely in the foreseeable future (Mone 2012). Therefore, we don't have to worry about increasing efficiency. However, the law of unforeseen consequences is likely to apply. In the 1950s, we thought that energy shortages were unlikely because of atomic energy. The unforeseen problem was how to dispose of nuclear waste. In the present day case of coal, there is environmental disruption caused by mountaintop mining (Grist 2012). Extracting oil from Canada's tar sands results in high levels of greenhouse gas emissions (Best and Hoberg 2008). Hydraulic fracturing of subsurface rock to obtain natural gas causes methane contamination of drinking water (Osborn et al. 2011). There is increasing evidence that climate change is being caused by increased carbon dioxide in the atmosphere resulting from fossil fuel burning (American Meteorological Society 2012). Government leaders may decide that the environmental costs of mountain top mining, tar sands extraction, hydraulic fracturing, and fossil fuel burning are worth paying, in order to increase economic activity. Nevertheless, those decisions will increase the economic cost of energy, just as surely as a decrease in availability would increase the cost.

1.4 Why Does Agriculture Need Energy Subsidies?

The First law of Thermodynamics states that energy can be changed to mass, and mass to energy, but energy and mass cannot be created. This means that for an agricultural system to be sustainable, more cannot be taken out of the system than is put back in. For an agricultural system to be sustainable, energy outputs from the system must be compensated for by energy inputs into the system.

Most people understand very well that you can't take more out of your bank account than you put in. They don't understand very well that soil is like a bank. Stored in the soil bank are energy and nutrients in the form of decomposing humus. Soil micro-organisms utilize the energy to make the nutrients available to crops, and to give the soil permeability. Harvesting the crop removes nutrients. To get more out of the soil, you have to put energy and nutrients back in (Box 1.5).

From where does the energy come from that is stored in the soil? The sun, through the process of photosynthesis that makes the leaves and wood where energy and nutrients are stored, and that then decompose into the organic matter in the soil. In natural ecosystems, that is enough. But in agricultural systems, energy and nutrients are removed from soils through cultivation and harvest. Agricultural systems must have energy subsidies, or they will gradually lose their productive power. In modern industrial systems, the energy subsidies are fertilizer and pesticides, and the fuel used by tractors to apply them to the fields.

Box 1.5

You can put energy such as nitrogen fertilizers into the soil and get food out when you harvest your crop, and you can eat that food and get energy out, as when you metabolize your lunch. But the world cannot sustainably consume more energy than farmers put in the soil.

Box 1.6

When we say that energy, not water is the limiting factor in agriculture, we are talking about areas that have a reasonable potential for agriculture, such as regions with a permanent vegetative cover. To say that water is a factor limiting agriculture in the Sahara, or even in the Arizona desert, is like saying that temperature limits agricultural production on the Antarctic ice cap. Deserts and ice caps are not agricultural areas.

1.5 Energy as a Limiting Factor

Energy is the factor limiting agricultural sustainability. If there is enough energy, all other limiting factors can be overcome. Because of recent droughts in the South and Midwest, agricultural experts have increasingly voiced the opinion that water, not energy, will be the factor limiting production. What they really mean is that water, at its current price, will be limiting. Water can always be obtained, if enough energy is used to get it: through digging deeper wells; through piping it from the Great Lakes to the Great Plains; through piping it from Northern California to Southern California; through building new dams; through utilizing glaciers; or through harvesting rain water. The Texas legislature, fearful that water shortages could imperial rice growers that flood their fields, is considering tapping the state's emergency fund to finance water projects (Bustillo 2013). Even at a high price however, it may not be possible in some cases to undertake such massive works as cross country pipelines due to political considerations. Desalinizing sea water is another option. It is already used in locations lacking fresh water resources, but rich in cash such as Dubai (Box 1.6).

1.6 Other Views of Sustainability

Everyone thinks they know what sustainability is, until a diverse group of people try to come up with a definition.

> Some people consider sustainable agriculture to be a philosophy, while others say it provides guidelines for choosing practices. Still others view it as a management strategy. Some consider it to be another name for organic farming. Some have defined the concept as maximum economic yield. (Francis et al. 1990).

> **Box 1.7**
> A partial list of books that have contributed to the discussion of sustainable agriculture is given in the appendices.

A Farmer's Definition:
A farmer might define sustainable agriculture in terms of his or her particular situation: "If I can avoid bankruptcy and keep the family farm, that's sustainable farming." In this case, one could say that money is the factor limiting agricultural sustainability. The more profit a farmer makes this year, the more money would be available to buy the energy necessary for future farm activities. The price of energy, of course, varies over time, depending on discovery of new reserves and other factors. From the farmer's point of view, it is the price of energy that determines sustainability.

An Ethical Definition:
Aldo Leopold (1949a) defined sustainable management in terms of ethics: "A thing is right when it tends to preserve the integrity, stability and beauty of the biotic community. It is wrong when it tends otherwise."

An Agronomist's Definition:
Sustainable agriculture involves the successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources (CIMMYT 1989).

Scientific Definitions:
The National Research Council (1989) defined sustainable agriculture as: "Long term maintenance of natural resources and agricultural productivity, minimal adverse environmental impacts, adequate economic returns to farmers, optimal crop production with minimized chemical inputs, satisfaction of human needs for food and income, provision for the social need of farm families and communities". More recently, Pretty (2008) reviewed 19 scientific publications on concepts and principles of agricultural sustainability and concluded that "Systems high in sustainability can be taken as those that aim to make the best use of environmental goods and services while not damaging these assets."

United Nations Definition:
Giovannucci et al. (2012) in a United Nations Publication defined agricultural sustainability as "Increasing global agricultural productivity to meet the needs of nine billion people while acknowledging and working within the limits of natural systems" (Box 1.7).

1.6.1 Critique of the Definitions

We can understand the farmer's viewpoint, but for those concerned with the future of agriculture, sustainability has a time line that extends beyond the economic viability of a particular farm. Leopold's definition is religious. All the other definitions are circular.

Box 1.8

"Sustainability" has replaced "Conservation" as the buzz word for non-destructive management of ecosystems. As an undergraduate at the School of Natural Resources, Univ. of Michigan in the 1950s, I was taught that the definition of Conservation was "Wise Use". It turned out that some people thought that snowmobiling in Yellowstone Park was a wise use. ("When I use a word, *it means what I want it to mean*; neither more, nor less"–Humpty Dumpty to Alice in Lewis Carroll's 1871 book "Through the Looking Glass.")

Box 1.9

Some publications, such as IAASTD (2009) and Levin and Clark (2010) deal with sustainable development, a much broader subject which includes reduction of poverty, improvement of livelihoods, human health and nutrition, and promotion of development that is socially equitable, environmentally sound, and economically stable. Bettencourt and Kaur (2011) asses the emerging field of sustainability science as having an emphasis on the management of human, social, and ecological systems seen primarily from an engineering and policy perspective. The Brundtland Report (1987) included what is now one of the most widely recognized definitions of sustainable development: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." These definitions also are tautologies.

The problem with circular definitions is that they can mean anything that you want them to mean (Box 1.8). The problem with the agronomist's definition as well as that of the United Nations is defining "human needs", in light of different standards of living. All would agree that three meals a day and shelter are reasonable needs, and while some people in developed countries may "need" an SUV, does everyone in the world need one? The National Research Council's scientific definition also is not helpful, because one person's "adverse environmental impact" is another person's "mark of progress". The difficulty with Pretty's definition is, who determines "best use", and how do we know when an asset is "damaged"? The energy use efficiency definition of Agricultural Sustainability overcomes these problems. It is neither circular nor religious. Energy inputs and outputs can be measured, and measurements can be duplicated (Box 1.9).

1.6.2 Panarchy

Gunderson and Holling (2002) posit that there is no such thing as infinite sustainability in agriculture, or in any other type of system either, from industrial to social systems.

Fig. 1.1 The icon illustrating the concept of Panarchy at the entrance to Spring Valley Ecofarms, Athens, Georgia

A system begins with a rapid growth or exploitation stage, in which resources are readily available. In the conservation stage, resources become limiting to growth, and the system continues, but levels off to a plateau or steady state. At the beginning of the release stage, some type of disturbance disrupts the system beyond its capacity to recover, and it begins to disintegrate. In the renewal stage, reorganization begins by recycling the elements and material remains from the previous system. The process is called "Panarchy". I have used the symbol of Panarchy (Fig. 1.1) at Spring Valley Ecofarms, a research and teaching farm in Athens Georgia, to represent the growth of the cotton industry in the South (yellow), its dominance throughout the 1800s

Box 1.10

Lance Gunderson and C. S. Holling, in their book *Panarchy: Understanding Transformations in Systems of Humans and Nature* explained their use of the word, by saying: "The term [panarchy] was coined as an antithesis to the word hierarchy (literally, sacred rules). Our view is that panarchy is a framework of nature's rules, hinted at by the name of the Greek god of nature, Pan. Its essential focus is to rationalize the interplay between change and persistence, between the predictable and unpredictable. Panarchy portrays renewal of a new resource, Phoenix-like, from the ashes of the old resource."

The Phoenix is a mythical sacred fire bird found in the mythologies of the Arabians, Greeks, Romans, Egyptians, Chinese and Indians. It is described as a bird with a colorful plumage and a tail of gold and scarlet (or purple, blue, and green according to some legends). It has a 500–1,000 year life-cycle, near the end of which it builds itself a nest of twigs that then ignites; both nest and bird burn fiercely and are reduced to ashes, from which a new, young phoenix or phoenix egg arises, reborn anew to live again. Is the myth of the Phoenix a metaphor for the agricultural cycles observed by these peoples?

(green), its decline in the early 1900s (gray), and the emergence of a new system of organic agriculture on the land that once was cotton fields (yellow again) (Box 1.10).

Although no systems are infinitely sustainable, the rate at which they progress toward disintegration is influenced in part by the type of agriculture employed in the system. If cotton farmers in the days of the Southern plantations had used more sustainable methods on their relatively shallow soils, collapse of the system might have been delayed. The rate toward disintegration also is influenced by the size of the soil reservoir. In the Midwest of the U.S. where crops are grown on the deep, highly fertile loess deposits, the soil is a buffer which has slowed the deterioration of the agricultural systems. But slowing does not mean stopping. Half of the topsoil of Iowa has been lost during the last 150 years, and 40 % of the rich soil of the Palouse region in Northwestern U.S. has been lost during the past 100 years of cultivation (Pimentel and Kounang 1998).

1.7 What Is a System?

To understand how ecosystem analysis can help improve sustainability, we first need to understand the nature of systems. A system is a group of interacting parts. These interacting parts create a system with properties that cannot generally be predicted from the properties of the components acting alone. System properties are distinct from the properties of components (Golley 1996). To understand the properties of systems, it helps to know the role of the parts. But to understand the role of the parts, it helps to know the properties of the systems.

1.7.1 Mechanical Systems

In an Auto Parts store, there are shelves and bins in which are located batteries, spark plugs, fuel pumps, brake pads, valves, brake cylinders, coolant radiators, and many other parts. Each part has its own properties and characteristics, and are themselves sub-systems of a larger system. But the store is not a system because there are no interacting components. Only when the parts are components of a higher hierarchical level system – the automobile or truck – do we see emergent properties. As parts or components are combined to produce an automobile or truck, new properties emerge that were not present or not evident at the level below. What are some of these emergent properties? Speed, acceleration, load capacity, fuel efficiency, crash resistance and passenger comfort, to name a few. Can emergent properties of a car be predicted by knowledge of the component parts? Engineers can make reasonable predictions, but car buyers still want to see for themselves. The fuel efficiency that is advertised in a dealer's showroom is determined, not by the predictions of engineers, but rather by actual testing on the road.

Feedback in mechanical systems. A property of mechanical systems that keeps them stable is feedback, that is, information transmitted from devices that measure the performance of the system to the control center of the system. Such a device on an automobile is cruise control. It keeps the car going at a steady "stable" speed. If the cruise control is set at the speed limit, whenever the car deviates from the set point as a result of going up or down a hill, information is transmitted to the fuel delivery system to either increase or decrease the rate that fuel is injected into the engine. If we consider the driver as part of the automobile system, then we have a more sophisticated control system, that can respond to stop lights or congested traffic.

1.7.2 Biological Systems

1.7.2.1 Human Bodies

An example of a biological system is the human body. Let's take the example of a football player. What are some properties of a football player? Ability to throw a football; ability to run fast; ability to learn complicated plays; ability to lead a team. Could a medical doctor evaluate these abilities in a young man? Most medical doctors specialize in a body's sub-systems such as the nervous system, the muscle system, the bone structure, the circulatory system the digestive system, the lungs, the pituitary gland, and so on. Each of these body parts is a system in and of itself, each with its own properties. If a group of these specialists got together and examined a prospective football player, could they predict whether this young man could become a good football player? They could tell the young man whether or not he had a reasonable expectation of playing football. But would their opinion convince a coach? Before a coach would draft this young man, the coach would want to see, on the practice field, how far and how accurately the young man could throw the football, how fast he could run, how well he could tackle, and other system properties that are important for winning football games.

Box 1.11

A common finding among scientists studying only one species is that their species is a "keystone" species, that is, a species that has so many interactions with other species that if confers an outsized influence on the ecosystem. My definition of a keystone species is "The species I happen to by studying". That is because my rigorous, detailed studies have revealed many, many more unsuspected interactions and influences that I doubt occur for other species.

1.7.2.2 Feedback in Human Bodies

Does the human body have a set point that keeps body functions stable? It does not have an exact set point the way an automobile does when on cruise control. Rather it has a range of "normal" temperatures from 97 °F (36.1 °C) to 99 °F (37.2 °C) depending on time of day. Temperatures above this range (hyperthermia) and below (hypothermia) are caused by disease or exposure to extreme temperatures. The body's internal feedback system kicks into action to try to restore a normal temperature.

1.7.2.3 Ecological Systems

Ecological systems, such as forests, lakes, and agricultural fields are more like the human body as a system than the automobile as a system. The properties of the mechanical and electrical parts of an automobile are standardized and can be measured accurately. In contrast, human bodies and ecological systems are not all exactly alike. Just as the circulatory system in one human body differs slightly from that in another body, so the energy flow in one ecosystem varies from that in another, even though both ecosystems may be forests.

Like human bodies, ecological systems are composed of many subsystems, each having its own characteristics and properties. The soil sub-system is an example. It consists of a matrix of mineral soil and organic matter. This matrix provides the energy and nutrients for the "soil community", a vast array of microbes, protozoans, round worms, arthropods, and even small mammals that determines the characteristics of the soil that supports other sub-systems such as the crop/insect system (Box 1.11).

1.8 Control in Ecological Systems

Ecosystems do not have a discreet set point for functions such as nutrient cycling and productivity. Rather the control is diffuse, involving hundreds of feedback loops and synergistic interactions in subsystems. As Odum (1989) has pointed out, natural systems do not have set points; they are not absolutely homeostatic. Control at the biosphere level is not accomplished by external, goal-orientated thermostats, or other mechanical feedback devices. Rather, control is internal and diffuse, involving many feedback loops. In fact, natural systems are constantly changing. It is the constant change that allows the system to survive always in a new and slightly different form.

An example is regulation of the nutrient cycle in mature forests. As a forest matures, the canopy of the largest trees forms a cover that increasingly shades the forest floor. Decomposition of leaf and wood litter on the soil surface slows down, and nutrients are accumulated in a layer of humus. Because of the accumulation, fewer nutrients are available in the soil for uptake by plants. Gradually, the low availability of nutrients weakens the trees. A big, senile tree dies and forms a "gap", that is, an opening in the canopy through which light streams to the forest floor. Because of the increased temperatures on the forest floor, decomposition increases. More nutrients become available, and there is less competition for them, because one of the big trees is gone, and smaller trees increase their growth rate. The system is maintained, though not at a fixed set point.

Indirect effects can be as important or more important than direct effects in maintaining systems stability. On Isle Royal in Lake Superior, the dynamics of the browse-moose-wolf food chain (Moffat 1993; Vucetich and Peterson 2004) are particularly illustrative. When the wolf pack is low, the moose herd grows and can overexploit the available browse, leading to an overall decline in health of the moose population. With fewer wolves, the major interaction is between the browse and the moose. The interaction is direct in that when the browse is decimated, the herd begins to starve. In contrast, when wolves are present, there is an indirect feedback between the wolves and the browse: the moose herd grows; the browse is overexploited; the browse declines; the health of the moose herd declines, resulting in a larger number of easy prey; more moose are taken by the wolves; grazing pressure on the browse declines; browse productivity increases; the moose herd grows; and so on. The populations of these components do not remain steady; rather they fluctuate within limits tolerable to all populations concerned.

The examples of feedback systems here were taken from naturally occurring ecosystems. But the idea of maintaining control by encouraging feedback can also be applied to agricultural systems. For example, in order to keep beneficial insects (predators on pest insects) in the vicinity of a vegetable garden, it is important for the beneficials to receive feedback. The feedback they receive is the nutrition they get when they eat the pests. So you don't want to wipe out all the pests with insecticide. You want to leave enough pests so that the beneficials are motivated to stick around in case there is another outbreak of pests.

1.8.1 Homeostasis

The maintenance of relatively constant conditions by active feedback control has been described by the term *homeostasis*. It is a property of stable systems. Lovelock

(1979), in his book *Gaia: A New Look at Life on Earth* uses Gaia (*Gaia* is Greek for the concept of Mother Earth) as shorthand for the hypothesis that the biosphere is a self-regulating entity with the capacity to keep our planet healthy by controlling the chemical and physical environment. He explains that Gaia is a complex entity involving the earth's biosphere, atmosphere, oceans, and soil. The totality constitutes a feedback or cybernetic system that seeks an optimal physical and chemical environment for life on the planet.

The Gaia hypothesis suggests that the biotic community plays a major role in keeping the chemical composition of the oceans and atmosphere relatively constant. The contrary hypothesis is that purely abiotic geological processes produced conditions favorable for life and that organisms merely adapted to these conditions. The question then is: Did physical conditions change first and life evolve to those conditions, or did both evolve together? As evidence for the hypothesis that the changes coevolved, Lovelock compared the atmosphere of the earth with that of the planets mars and Venus, where it is unlikely that life exists. Earth's low carbon dioxide and high oxygen and nitrogen atmosphere is completely opposite from the conditions on those planets. Photosynthesis, which evolved soon after the first appearance of life earth, removes carbon dioxide from and add oxygen to the atmosphere. The accumulation of fossil fuels is evidence that photosynthetic activity in the geologic past often exceeded the reverse gaseous loss due to respiration. Therefore, it may be logical to conclude that the biotic community is responsible to the buildup of oxygen and the reduction in carbon dioxide over time. Models of the evolution of the earth's atmosphere have indeed suggested that atmospheric oxygen levels rose naturally, but not immediately as a consequence of photosynthesis and the evolution of life as it now exists on earth (Kasting 1993). Newly published work by Oduro et al. (2012), provides a tool for tracing and measuring the movement of sulfur through ocean organisms, the atmosphere and the land in ways that may help prove or disprove the controversial Gaia theory.

Critics of the Gaia hypothesis argue that for the atmosphere and life on earth to be a cybernetic (feedback) system, a control system and a set point must exist, neither of which is evident in the global cycles of gases. Without a control, they argue, there can be no feedback system; that is, co evolution could not have occurred. But the world, like an ecosystem, is not in homeostasis but in dynamic equilibrium. Lovelock did not use the term homeostasis as meaning static or stable at a set point. He meant it to mean fluctuating, but within the physical and chemical limits necessary to sustain life. The ongoing world-wide experiment in global warming will test this hypothesis.

1.8.2 Optimum Efficiency for Maximum Power Output

Control in systems can come from sources external, as well as internal to the system. Odum and Pinkerton (1955) in their classic paper "*Time's speed regulator: The optimum efficiency for maximum power output in physical and biological systems*"

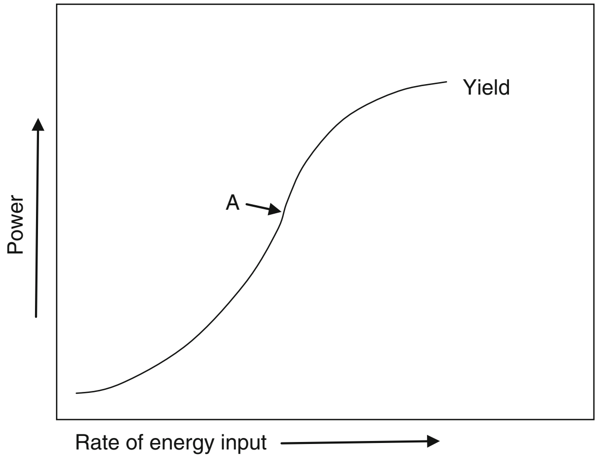

Fig. 1.2 Power (yield per unit time) as a function of rate of energy input. Up to point *A* (the inflection point), yield (for example, bushels of corn per acre per year) increases as rate of energy input (such as rate of fertilizer application) increases. Beyond this point, yield (energy output per unit time) decreases as rate of energy input increases. This point represents the optimum efficiency for maximum power output

have shown that there is a rate of energy input to a system that is optimum for maximizing yield. At low rates of energy input, energy use efficiency is high, but power output is low. As rates of energy input increase, power output increases rapidly, at least for a while. But at a certain point, the increase in power output as a function of energy input rate begins to slow down (Fig. 1.2). The speed of trucks provides an illustration. At a low speed (40 mph), fuel use efficiency (miles per gallon of gas) is high, but the generated horsepower of the truck is low. At high speeds (100 mph), fuel use efficiency is low, (a lot of the fuel energy is lost as heat and carbon pollution) but generated horsepower is high. At an intermediate speed, say 65 mph, there is the maximum power generated per gallon of gasoline burned. The energy use efficiency at this point is the optimum for maximum power generation. This is the speed at which the truck driver should operate, so as to maximize profits. At low speeds, profits are lost due to long delivery times. At high speeds, profits are lost because of high fuel costs due to inefficient combustion.

Energy input to attain maximum energy use efficiency (sustainability) does not occur at the point of optimum efficiency for maximum power output (point A in Fig. 1.2), but occurs below this point. Nevertheless, economically rational farmers would tend to operate at this point. Below this point, power output (rate of crop production, or yield) increases faster than the increase in input rate (Box 1.12). At the input rate at point A, the farmer is getting the maximum power (yield) possible by increasing input rates. Above point A, the increase in yield decreases as a function of increasing input rates. Nevertheless, the farmer may choose to operate beyond this point in order to further maximize his power output, just as the truck

Box 1.12

Yield, like power, is a measure of rate. It is the rate at which farm products are produced, and is usually calculated on the basis of output per year. However, greenhouse growers may calculate yield on the basis of output per month, or even per week. Ecologists usually use the term "productivity" when they are measuring the rate at which an ecosystem synthesizes biomass, usually on a yearly basis.

Box 1.13

Hall (1995) described how resource managers can control energy flow to obtain the optimum efficiency for maximum power output in fisheries. In streams stocked with a low level of predatory cutthroat trout, there can be considerable invertebrate food per predator, and the fish use relatively little food-searching energy per unit of food obtained. Because of few trout however, output is low. With a high fish-stocking rate, food becomes less available per fish, and each fish has to use more energy searching for it. Productivity per fish stocked is lower . Maximum productivity occurs at intermediate fish-stocking rates.

driver may choose to drive at 100 mph in order to get to his destination more quickly. His gross income will increase, but his net income will decrease.

An example of "Time's Speed Regulator" for biological systems comes from one of my Brazilian students, Garo Batmanian, who carried out a project that looked at the culture of "Castanheiros", Brazil nut harvesters in the Amazon rain forest. Brazil nut collection is a type of extractivism, but it is benign in that it does not damage the trees. The only energy required is that expended by the Castanheiros as they walk along a path through the forest between Brazil nut trees (named after girl friends or movie stars) that are scattered throughout the forest. It is a energy efficient, low input system, but yield per worker and per hectare of forest is low. In other regions of the Amazon, there are Brazil nut plantations, where rates of energy inputs are modest (every few months, workers clear the underbrush to eliminate competition that stresses the trees). It is nut production at optimum efficiency for maximum power output, or yield. To my knowledge there is no high input Brazil nut production in the Amazon, but there is nut production in some pecan orchards of the American South that appear beyond the optimum efficiency for maximum power output. The trees there are regularly sprayed and fertilized, and the ground beneath them kept clear. When time comes for harvest, a heavy machine with clamps on the front grips a tree and shakes it till all the nuts fall off. Following that is a truck with a vacuum system that sucks up the nuts (Box 1.13).

1.9 Boundaries of Ecological Systems

The boundaries of agricultural ecosystems are straightforward – the edge of the field or pasture. For natural ecosystems, the most obvious example of a boundary is the shore line of a lake. The lake, with its populations of algae, fish, and amphibians is distinct from the dry land communities that surround the lake. The boundaries of some of today's forests are easy to see. In colonial days, pioneers when clearing the land for agriculture, often left a grove of trees to supply firewood. The boundaries of these groves still can often be found in old abandoned farms. However, the boundary of many forests may be indistinct. An example is the boundary between the forest ecosystem in Eastern Minnesota, and the prairie ecosystem in Western Minnesota. There is a gradual transition that shifts one way or the other, depending on the frequency of fire and drought (Buell and Buell 1951).

A convenient way to delimit the boundaries of an ecosystem is to look at interactions. The boundary exists where the amount of species interactions within the ecosystem is greater than the number between that ecosystem and another. Along a topographic gradient from dry upland to moist bottomland in Southeastern forests, composition of tree species changes from oak-hickory to tulip poplar and river birch. Certain species of bird may travel between these two types, but feed and nest solely in one. For example, prothonotary and Swainson's warblers use the bottomland hardwoods. Upland hardwood habitat supports the whip-poor-will, wood thrush, and cerulean warbler (Trani 2008). In the example of a pond, most of the food chain interactions are within the pond. The small fish eat the algae, the large fish eat the small fish. Once in a while, a frog that lives in the pond will hop out to capture some insects that live along the shore. Energy flows across the shoreline boundary in many lakes because organic matter such as riparian leaf litter and wood are transported by wind and water along streams and into lakes. Nevertheless, the lake shore comprises a convenient way to delimit the ecosystem, with the leaf litter and frogs considered as inputs and outputs of the system.

1.10 The Value of a Systems (Holistic) Approach

1.10.1 Holism: The Foundation for Ecosystem Analysis

In the lobby of the Odum School of Ecology at the University of Georgia, there is a bust of Dr. E.P. Odum, founder of the School (formerly Institute) of Ecology, and the author of *Fundamentals of Ecology,* the work that introduced countless students and researchers into what in 1953 was a new approach to ecology: The Ecosystem Approach. Beneath the bust are inscribed the words: *An Ecosystem is greater than the sum of its parts.* The idea that a system is greater or more than the sum of its parts has been traced to ancient philosophers, but its application to ecology was new. Koffka (1935) who used the concept in the field of Gestalt Psychology, said "it

Box 1.14

Within the past few decades, there have arisen a number of University centers and funding initiatives focused on the concept of "biocomplexity". This is a result of scientists trained in the reductionist mode of thinking being exposed to the fact that entities, at all levels of organization from cells to ecosystems, react to stimuli in complex and counter-intuitive ways that reflect the interactions of the multiple components that comprise that level.

is more correct to say that the whole is *something else* than the sum of its parts". The critique is applicable to ecosystems.

The idea that an entire ecological system has properties that are *something else* than the sum of its parts is holism. Holism is a study of the properties of whole ecosystems, such as forest stands and agricultural croplands. Holism captures all the interactions and indirect effects that occur among species in an ecosystem. A systems approach provides a powerful representation of the ecological interactions among species and highlights their global interdependence

In contrast, reductionistic research focuses on species or parts of ecosystems, and has often neglected the effect of multiple species interactions on properties of the whole ecosystem. Reductionism examines one interaction at a time. An example would be the effect of a new type of insecticide on the plum curculio. an insect pest of peach and plum trees. Reductionism would tell you how completely the insecticide killed the pests. It would not tell you the effect upon bees needed to pollinate the plums. Reductionism, studying only the linear interactions between components of an ecosystem, usually leads to unanticipated side effects, or unintended consequences when applied to management problems (Box 1.14).

A classic example resulting from linear reductionistic thinking was the policy in the American West of trying to kill off all the wolves, because they preyed upon deer that were desired by hunters. The unintended consequence of this was that without wolves to control the deer population, the deer herd , in many regions, swelled beyond the carrying capacity of their ecosystem, and many starved to death (Leopold 1949b) (Box 1.15).

1.11 Holistic Properties of Sustainable Systems

1.11.1 Energy Use Efficiency

Because energy is the ultimate limiting factor in all living systems, we have defined energy use efficiency as the criterion upon which ecosystem sustainability is based. Energy Returned on Investment of Energy (EROI) or energy use efficiency is the amount of energy yield resulting from the application of energy subsidies such as

Box 1.15

A recent approach to holistic resource management has been called "adaptive management". Researchers try something, and if it works, good, if not, try something else. Fifty years ago this was sometimes called the "Let's throw on another ton of fertilizer and see what happens" approach to agricultural research. It treated the ecosystem as a black box with little understanding of what is going on inside the box. The difference now with adaptive management is that the resource manager or farmer can make an educated guess as to what will happen, based on a knowledge of the components of the system.

fertilizers synthesized by fossil fuels. The more efficiently that energy subsidies are converted into yield, the lower amount of subsidies that are needed. The lower the subsidies, the more sustainable the system. Figure 1.3 shows energy flow through natural systems. Since there is no subsidy, efficiency cannot be calculated. Energy flow through primitive agricultural systems is shown in Fig. 1.4. The energy subsidy is small. It consists of the work of the farmer and his horse. Yield may low, and the farmer may only be able to feed his immediate family, or it may be high enough that he can sell some of his corn and buy a better plow. Efficiency may depend on the farmer's skill, or it may depend on variables beyond the control of the farmer, such as amount of rain. In modern industrial agriculture, (Fig. 1.5), production is high, but the efficiency of energy used for production is low (Box 1.16).

The energy yield in calories of output per unit calorie of input subsidy for grains in modern agriculture ranges from 1.4 for peanuts to 3.84 for corn. For potatoes, the yield is 1.33, and for apples it is 1.6 (Pimentel and Pimentel 2008). For dry land rice, yield is 2.2, but for paddy rice, the yield is 20 cal (Steinhart and Steinhart 1974). The high yield of paddy rice is due to a unique service of nature. Rice paddies are flooded to control weeds, and also to allow the growth of the water fern azolla, which has a symbiotic relationship with cyanobacteria that fix nitrogen from the atmosphere. It is the weed control and the nitrogen availability that makes paddy rice so energy efficient.

Energy yield efficiency for meat and poultry is low because energy has to travel an extra step through the food chain. For broiler chickens, the yield is 0.25, and for turkey, 0.1. Beef is 0.03, and lamb is 0.02 (Pimentel and Pimentel 2008). Meat is usually not consumed for its calories, but for protein, which requires calories to synthesize.

Ethanol made from agricultural "biofuels" such as corn has received a lot of recent attention as a possible way of lowering the need for petroleum derived energy, and of reducing carbon emissions from automobiles. In the past, biofuels have been criticized because they cost more energy than they produce due to fertilizers and pesticides to grow the biofuels, and to the energy cost of converting raw biofuels into ethanol. However recent studies suggest that production of ethanol from corn is becoming more efficient (Liska et al. 2009). Recent efforts at many locations have been directed at using woody biomass as feedstock for fuels (BREC 2012), since

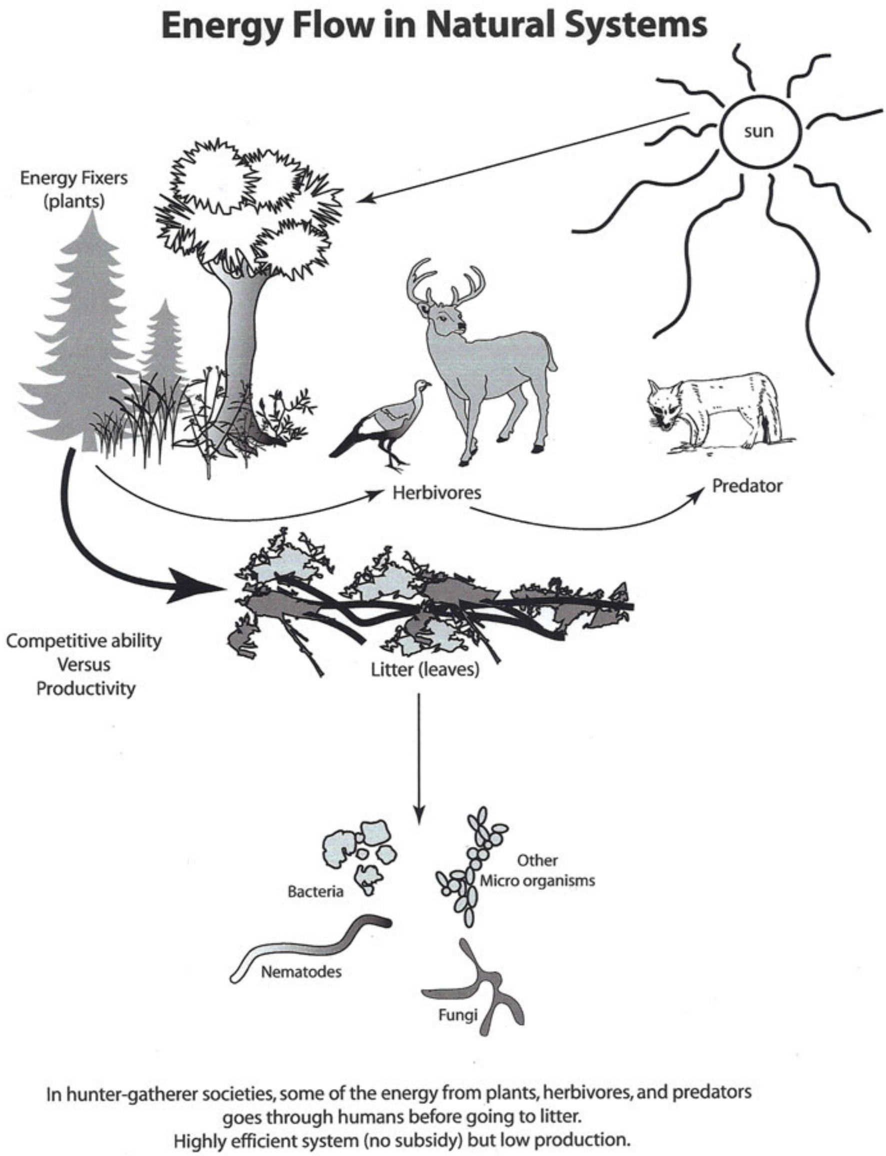

Fig. 1.3 Theoretical energy use efficiency in a natural ecosystem. There is no fossil fuel subsidy to aid production, so it is a highly efficient system with regard to the need for energy subsidies

forests often grow on lands not suitable for agriculture. However, trees have evolved defense mechanisms against decomposition, and thus they are more difficult to convert to fuel than corn and sugar cane. Algae, also being researched as a biofuel, has fewer defense mechanisms, but the tanks and greenhouses needed to produce algae make their production expensive.

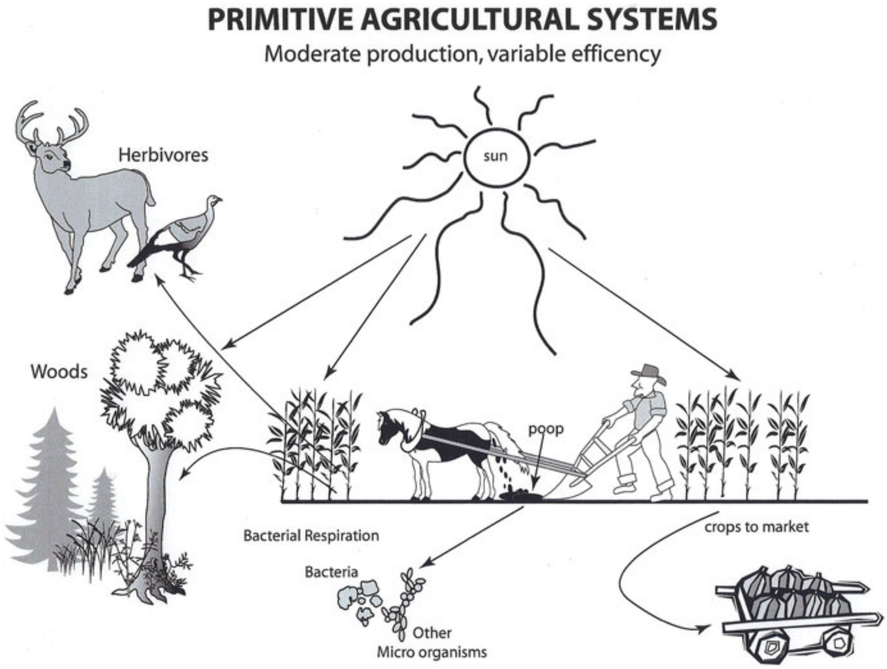

Fig. 1.4 Theoretical energy use efficiency in farms before the advent of industrial agriculture. Efficiency would be low on poor soils, higher on more fertile soils

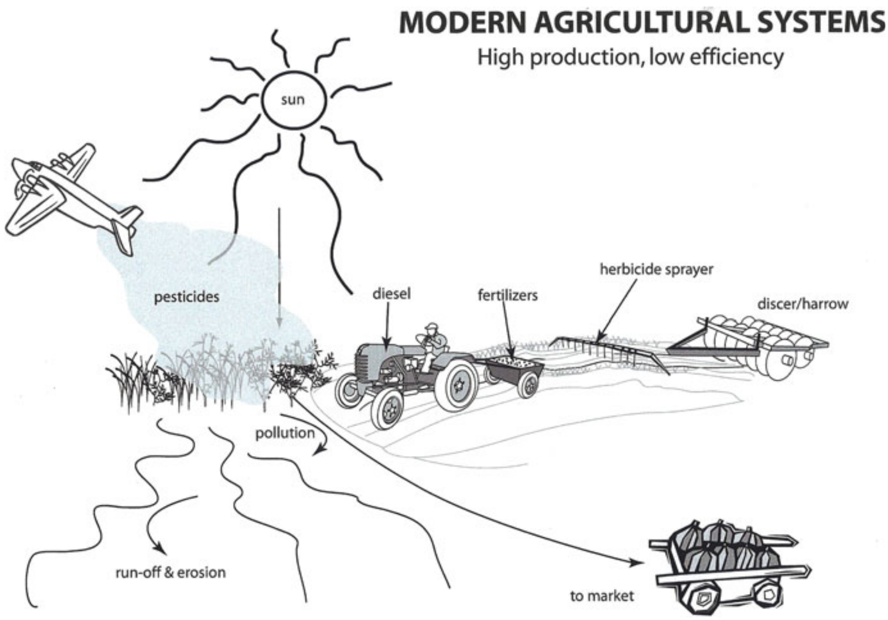

Fig. 1.5 Theoretical energy use efficiency in industrial agriculture. Efficiency is low because of energy lost to heat during energy transformations

Box 1.16

Throughout this book, the calorie, or the kilocalorie is used as the measure of energy in organic matter, including food. It is the traditional unit of heat energy into which other types of energy can be transformed. The joule has traditionally been used for mechanical and electrical energy.

Scientists generally use the metric term hectare for a unit of area, and kilogram for a unit of weight. Applied practitioners and farmers in the U.S. generally use the term acre for a unit of area and pound for a unit of weight. Calculations are much easier to make in the metric system, but U.S. customary units are the standard for economic transactions in the U.S. This book, as a bridge between theory and practice uses both.

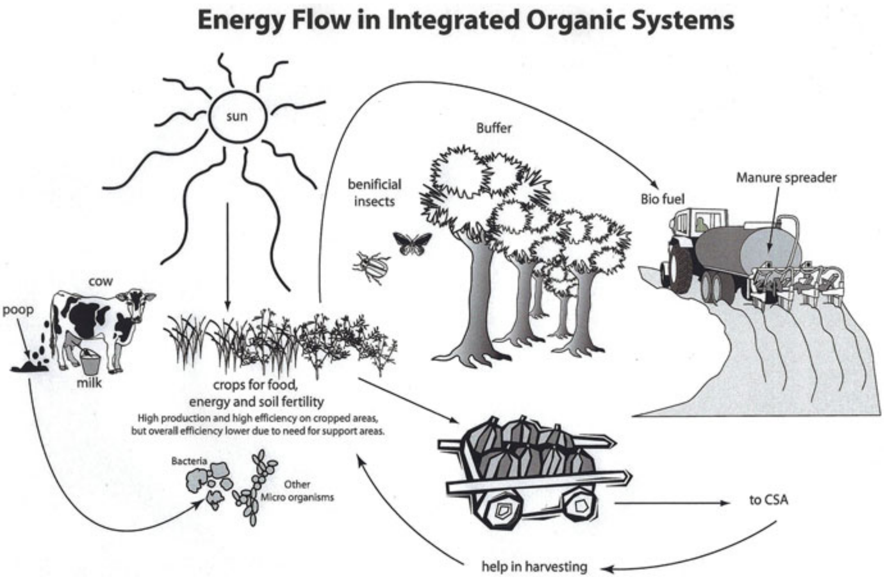

Fig. 1.6 Theoretical energy use efficiency in organic agriculture. The only fossil fuel subsidy shown is the manure spreader. The fossil fuel subsidy for the ecosystem is small, yet production is high because the fossil fuel subsidy is supplemented by the energy contributed by the soil micro-organisms. The energy source for the microorganisms is the pool of carbohydrates and other organic compounds that constitute the manure

Organic agricultural systems take advantage of the energy subsidy provided by soil organic matter (Fig. 1.6). The microorganisms in the soil store nutrients, and release the nutrients at a rate slow enough that plants can take up the nutrients before they are leached or volatilized. The microorganisms also improve soil properties such as porosity which allows easier penetration by roots and better drainage

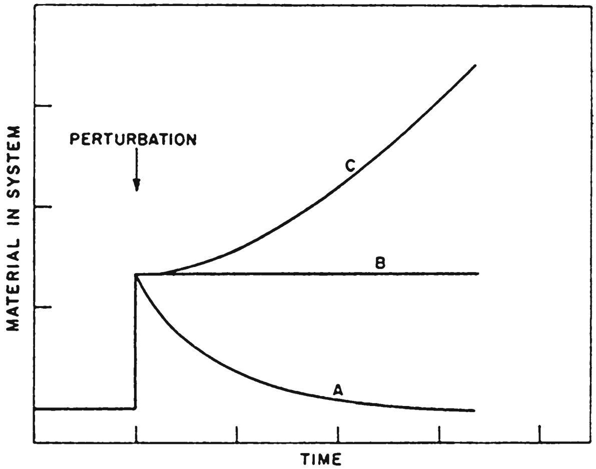

Fig. 1.7 Response of a stable system (*line A*), unstable system (*line C*), and an. unstable but bounded system (*line B*) to. a perturbation. Systems respond monotonically

of water. As a result, fewer energy subsidies are needed and the energy use efficiency is higher. The manure spreader in Fig. 1.6 requires fossil fuels to operate, and this is an energy subsidy to the agricultural field. However, chemical fertilizers are not needed, since nutrients are derived from the manure of the animals grown on the farm. Energy use efficiency is high in the field where the crops are growing, since few subsidies derived from fossil fuels are needed. However the animals that produce the manure require areas in which to graze, so the pastures represent an energy subsidy for the crop.

1.11.2 Stability

Stability, resistance, and resilience are properties that are easy to understand in physical terms. Imagine a bowl with a steel ball balanced on the rim. This is an unstable system, because the slightest puff or air would send the ball down into the bowl. However, the ball in the bottom of the bowl is a stable system because: it is resistant – the ball resists any effort to push it up the side; it is resilient – if the ball is forced up the side, it rolls back to the bottom as soon as the force is relaxed.

Figures 1.7 and 1.8 show responses to a perturbation of a stable ecological system, an unstable system, and an unstable but bounded system. A stable system returns monotonically (Fig. 1.7, line A), or with decreasing oscillations (Fig. 1.8, line A). An unstable but bounded system either assumes a new steady-state level (Fig. 1.7, line B), or oscillates, but the amplitude of the oscillations remains constant (Fig. 1.8, line B). An unstable system continues to depart from steady state, either monotonically (Fig. 1.7, line C), or with increasing oscillations (Fig. 1.8, line C).

As an hypothetical example of an agricultural system, let's assume that you have a field of soybeans that is being attacked by aphids. You introduce some lady bird

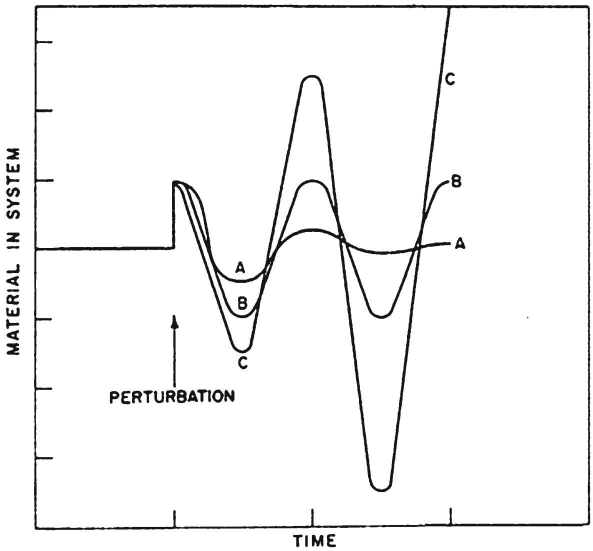

Fig. 1.8 Response of a stable system (*line A*), unstable system (*line C*), and an unstable but bounded system (*line B*) to a perturbation. Systems respond by oscillating

beetles into the system, and they decrease the population of aphids to a negligible level. That is a stable system. But then assume that many of the lady bird beetles fly away, and only a few are left. The aphid populations begin to increase. But the increase in aphids results in a population increase of the remaining beetles, and they again begin to control the aphids. That is an unstable but bounded system. Now assume that for some reason, the beetles all disappear. The aphids then reproduce uncontrollably and destroy all the soybeans. That is an unstable system.

1.11.2.1 Resistance and Resilience

Natural Ecosystems

Resistance. The oak-hickory forests in the Piedmont region of Southeastern U.S. are resistant to fire (Abrams 1992). In pre-colonial days, the landscape was savanna-like, with groves of oak hickory trees interspersed in a grassland with native grasses such as Bluestem and Indian grass. Indians would often set the grasslands ablaze, because fire kills woody vegetation, but for the grasses, it encourages new tender growth that attracts grazers and browsers to hunting areas (Juras 1997). Because oaks and hickories are relatively fire resistant, groves of these trees *resisted* the destructive effect of fire. The spruce-fir forests of Canada are another example of a resistant ecosystem. They are more resistant to the harsh climate and short growing season than most broad-leaved trees. The Spartina marshlands along the Southeastern coast of the U.S. have developed a resistance to salt water that would kill other grass species.

Box 1.17

A large body of information exists on the effect of size of disturbance on ecosystem recovery, and on the plant and animal species involved in recovery. For Amazonian ecosystems, there are results from 33 years of studies by the "Biological Dynamics of Forest Fragments Project", originally called the Minimum Critical Size of Ecosystems Project (Smithsonian 2012). The project created forest fragments of sizes 1, 10 and 100 ha. While most of the studies looked at the ecology of forest fragments that remained after disturbance, other studies such as that of Mesquita (1995) looked at the disturbed areas themselves.

Resilience. The resilience of an ecosystem in response to disturbance depends upon the size of the disturbance, the intensity of the disturbance, and the duration of the disturbance (Jordan 1998).

Size. The Amazon rain forest provides an example of the influence of disturbance size. If a relatively small area of forest (less than a few hectares) is cleared for shifting cultivation and then abandoned after 3 years, the forest will recover its structure and function. The area is small enough so that birds and mammals that transport tree seeds do not hesitate to enter the area and stop in the middle where they defecate the seeds. In addition, 3 years of cultivation is not enough to compact the soil and destroy the nutrients that allow the forest to regenerate. In contrast, when the forest in cut and transformed into cattle pasture, the area affect is much larger, often hundreds of hectares. Most wildlife is hesitant to enter the area and forest seeds are not widely dispersed. The soil becomes highly compacted due to the trampling of cattle hooves. Pastures are colonized by aggressive species that can survive on degraded soils. For example, before the Portuguese came to Brazil and began to clear the land, most of what is now the state of Pará was covered with rain forest. Today, Babassu palm covers many sites in the eastern part of the state because of its ability to grow in degraded soil. It is an aggressive colonizer and is often considered a weed, although its oil has some commercial value (May et al. 1985) (Box 1.17).

Intensity. I have classified intensity of disturbance as mild, moderate, and severe.

- A mild disturbance is one that does not disturb the basic structure and function of the ecosystem. A treefall gap is usually a mild disturbance. The soil community and all of its nutrient recycling functions remain intact. Seedlings and sapling already growing in the opening usually survive. In fact, their growth may increase due to the decreased competition from the older tree that fell or was removed.
- A moderate disturbance is one in which the above-ground structure of the forest is destroyed, but a functioning below-ground community remains. One example is when a large area of forest is blown down by a hurricane. Another is when a

forest is cut down and immediately replaced with a tree plantation. In the latter case, the species composition of the below-ground community may change, but the flow of organic matter from litter into the soil is interrupted only for a short time, and nutrient recycling and conservation functions continue.

- A severe disturbance is where both the above-ground structure of the ecosystem is destroyed and the soil is severely degraded. Lava flow from volcanoes and forest clearing with heavy machinery destroys both the above-ground and below-ground ecosystems. Overgrazed pasture also can be a severe disturbance. The century-long cultivation of the Georgia Piedmont for cotton was a severe disturbance. The topsoil or A horizon which contained the germ-plasm for ecosystem recovery was lost, and the remaining subsoil had very few soil organisms that recycled nutrients and maintained soil structure.

Duration. A single, discrete occurrence, such as a hurricane, may knock down the large trees in a forest, but may not injure smaller trees nor disturb the soil Recovery occurs through growth of the seedlings present, or through the germination of seeds present in the soil before the disturbance. The replacement community may closely resemble the original one.

- An intermediate disturbance would be one of a few years or less, during which time some – but not all – of the soil community is destroyed. Shifting cultivation, where the land is cultivated for 2 or 3 years and then abandoned is an example. The replacement community would depend upon both the surrounding plant and animal communities, and the seeds and sprouts that remained in the soil when the plot was abandoned.
- A long-term disturbance is one in which the disruptive activities continue for decades. Agriculture in the temperate zone is typically a long-term disruption. A farmer may till and cultivate his field for years or decades. Recovery depends upon rebuilding the structure and function of the soil community. Each stage in soil rebuilding is accompanied by a discrete plant community, in the process called "succession".

The most important factor influencing ecosystem resilience is whether the soil remains intact. The El Yunque National Forest in Puerto Rico provides an example. This montane forest is frequently hit by hurricanes. While wind may knock over large trees, seedlings and saplings are limber. They bend but do not break, and respond quickly with increased growth following destruction of the overstory canopy. The amount of rain that falls is more critical. With heavy amounts of rain , the soil that sits like a blanket over the rock below begins to slide. In the upper part of the landslide where the saprolite (chemically weathered rock) is exposed, forest recovery is impeded, but in the lower part where soil from the slide accumulates, recovery is more rapid (Guariguata 1990).

Agricultural Ecosystems

In contrast to natural ecosystems, agricultural systems are intrinsically unstable because they are not resistant and they are not resilient. Stability is achieved only with subsidies provided by farmers. The most unstable agricultural systems are those comprised of annual vegetables. A considerable amount of human and fossil fuel energy must be expended in order to maintain the structure and function of, say, a bed of tomatoes. Unless the soil is periodically weeded, or covered with black plastic weed barrier, “weeds” quickly come in. If they are not controlled, they compete with the tomato plants and reduce their yield or even kill them. In ecosystem terminology, “weeds” are successional species. Successional species are wild plants that have evolved to take advantage of soil that has been cleared. Ragweed, pigweed and bindweed are examples of early successional species that can quickly colonize bare soil because of their light seeds transported by wind. Following these annual weeds are shrubby species such as wild plum that are perennials, but still demand full sunlight. These are followed by tree species which are better long-term competitors because of their greater shade tolerance. Because weeds are a common foe of all farmers, agriculture sometimes has been defined as “The Fight Against Succession”.

Annual grains such as wheat also comprise unstable systems. Because wheat is grown in monocultures over many hundreds of square miles, it is very susceptible to the spread of fungal disease. Because there are no barriers to the spread of disease, it can quickly devastate all the wheat in a region. For this reason, breeders of wheat varieties are continually developing new strains that will remain resistant, at least until the fungus mutates and adapts. Corn fields are another example of an unstable system, because of the corn borer and other insects that destroy the crop unless insecticides are applied.

One reason that annual crops make unstable systems is that the soil must be tilled every year, to prepare the seed bed for new seeds and to help control weeds. A side effect of tilling the soil, with plow, roto-tiller or other mechanical device, is that tilling loosens the soil and exposes it to the erosive forces of rain storms. Erosion carries away nutrient-rich topsoil, and leaves exposed compacted, nutrient-poor subsoil. Because perennial crops such as fruit orchards do not require the soil to be plowed annually, they are somewhat more stable that annuals. They more resemble a stage in ecological succession that would occur if a farm were abandoned and “let nature grow back”. Their deep roots hold the soil in place and prevent erosion.

Grazing systems can be stable if they are established in areas where grazing animals naturally occur, and if care is taken to prevent overgrazing. The Great Plains of the U.S. were once the home of huge herds of grazing bison. They were constantly on the move, looking for new and fresh grass, so overgrazing did not occur. Cattle can be grazed sustainably on natural savannas if they are prevented from overgrazing. New systems of herd management that continually rotate cattle among paddocks in a pasture are helping to overcome the problem of overgrazing that occurs when cattle are continuously grazed in a single pasture (Dartt et al. 1999).

1.11.3 Nutrient Cycling Efficiency

A high nutrient cycling efficiency contributes to the sustainability of ecosystems. High cycling efficiency means that most of the nutrients in the soil are taken up by

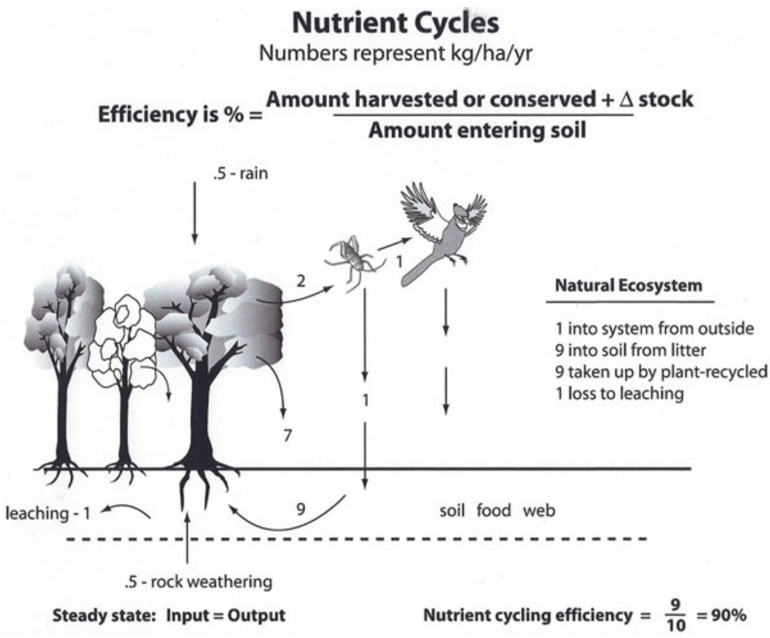

Fig. 1.9 Theoretical nutrient cycle for a mature forest, drawn to illustrate the concept of nutrient cycling efficiency. The numbers in kilograms per hectare could represent any nutrient element except nitrogen and sulfur, which are volatile in parts of their cycle

plants rather than lost through runoff to ground water or streams. Nutrients such as potassium and phosphorus are always entering ecosystems dissolved in rainwater, or from slowly decomposing rocks that underlie the soil. At the same time, there are always losses, from erosion, or from percolation into the ground water of dissolved nutrients. In a stable system, inputs and outputs are small compared to the amount recycled within the system.

Finn (1976, 1978) proposed this idea and called it a "Cycling Index". The cycling index (CI) is determined by calculating the total amount of a nutrient that passes through a compartment per unit time (throughflow = T) and the proportion of the throughflow that returns to that compartment after cycling through the rest of the system (recycled = R).

$$CI = \frac{R}{T}$$

For an entire ecosystem, the cycling index is the ratio between the amount of material that is recycled and the total amount flowing through the system.

A theoretical nutrient cycle is illustrated in Fig. 1.9, to demonstrate how nutrient cycling efficiency can be calculated. Input is equal to output, so the system is in

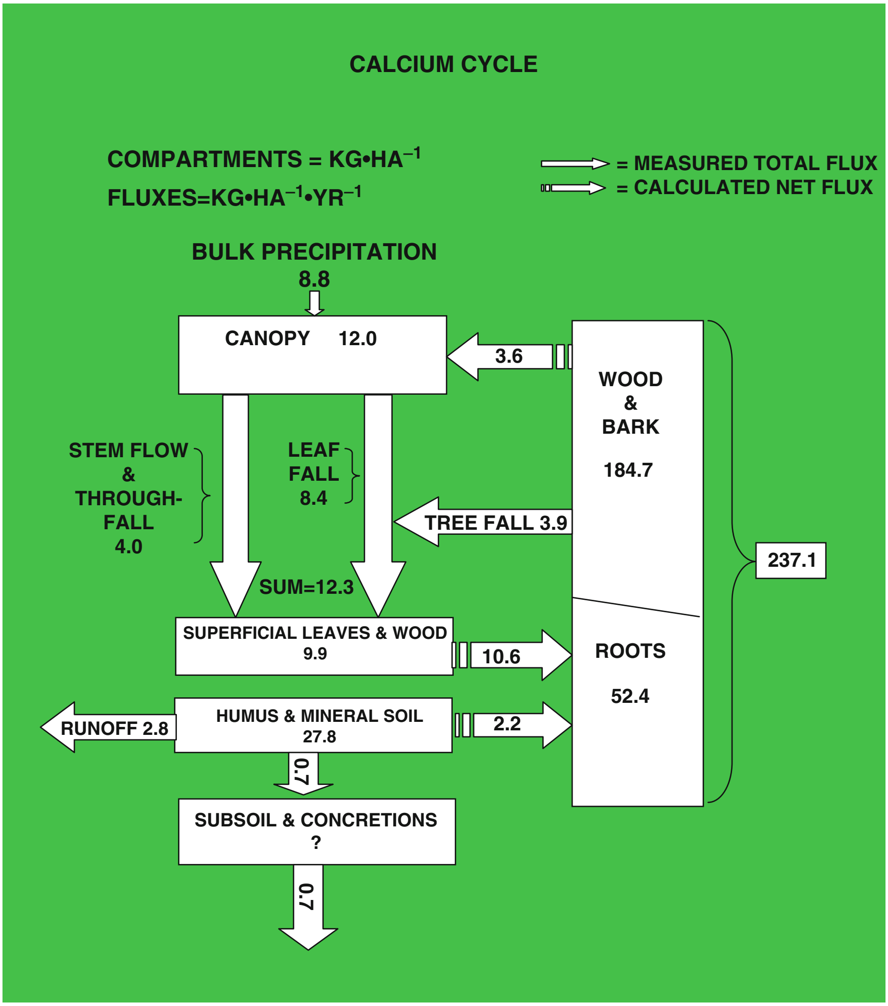

Fig. 1.10 Calcium cycle of a rain forest in the Amazon region of Venezuela

steady state. The system is neither increasing nor decreasing in biomass. The amount moving through the system, as determined by the amount entering the soil, is ten units. The amount recycled from the soil into the biomass is nine units, so the nutrient cycling efficiency is 90 %.

Figure 1.10 illustrates a concrete example of the efficiency of calcium cycle in a late successional rain forest in Venezuela (Jordan 1989). Calcium input into the forest floor is 16.3 kg/ha/year (sum of all inputs to the forest floor). Movement from forest floor to the trees is 12.8 kg/ha/year, but only 3.6 is recycled out of the wood, meaning that there is a 9.2 kg/ha/year gain in standing stock of

Box 1.18

I have been criticized because my values for the nutrient cycles in the final report of the 10-year ecosystem study (Fig. 1.10) were somewhat different than those in an earlier journal. The explanation is that ecosystem functions are not constant: they are always changing, depending on the weather, the insect populations, and other factors. Long term averages are often different than short-term averages.

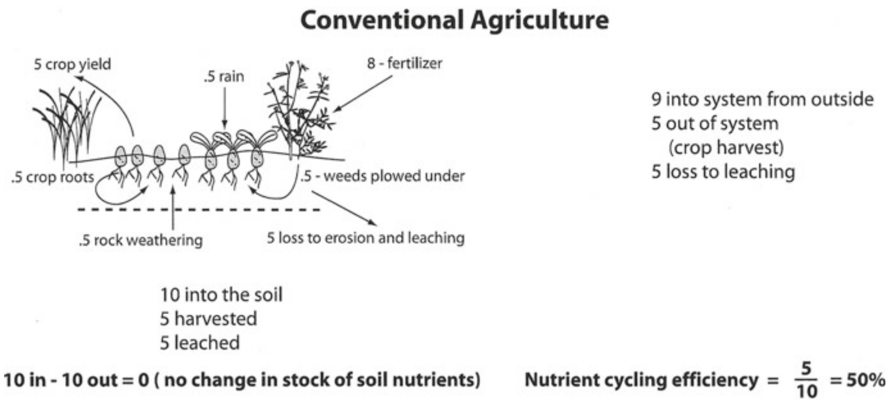

Fig. 1.11 Theoretical pattern of nutrient cycling efficiency in a conventional agricultural system

biomass. Calcium cycling efficiency then is 12.8/16.3 = 79 %. If the system had been perfectly tight (no loss through leaching), then cycling from the forest floor to the trees would be 15.2 kg/ha/year, and the nutrient cycling efficiency would be 100 % (Box 1.18).

Figure 1.11 is a theoretical example of nutrient cycling in conventional agriculture. Nutrient cycling efficiency is low, because most of the soil organic matter, a factor critical in nutrient retention and cycling has been oxidized (destroyed) by plowing. With low levels of soil organic matter, leaching losses are high. To keep the system stable, the nutrients lost through harvest of crops plus nutrients lost through leaching must be replaced by nutrient subsidies in the form of fertilizer from outside the system.

Figure 1.12 shows changes in nutrient cycling efficiency when conventional agriculture is replaced by a system in which soil organic matter is increased through addition of compost, manure, or mulch. The recycling efficiency increases the first year the system changes, and it increases again the second year. It takes a number of years to build up soil organic matter, but eventually cycling can reach the efficiency of natural ecosystems.

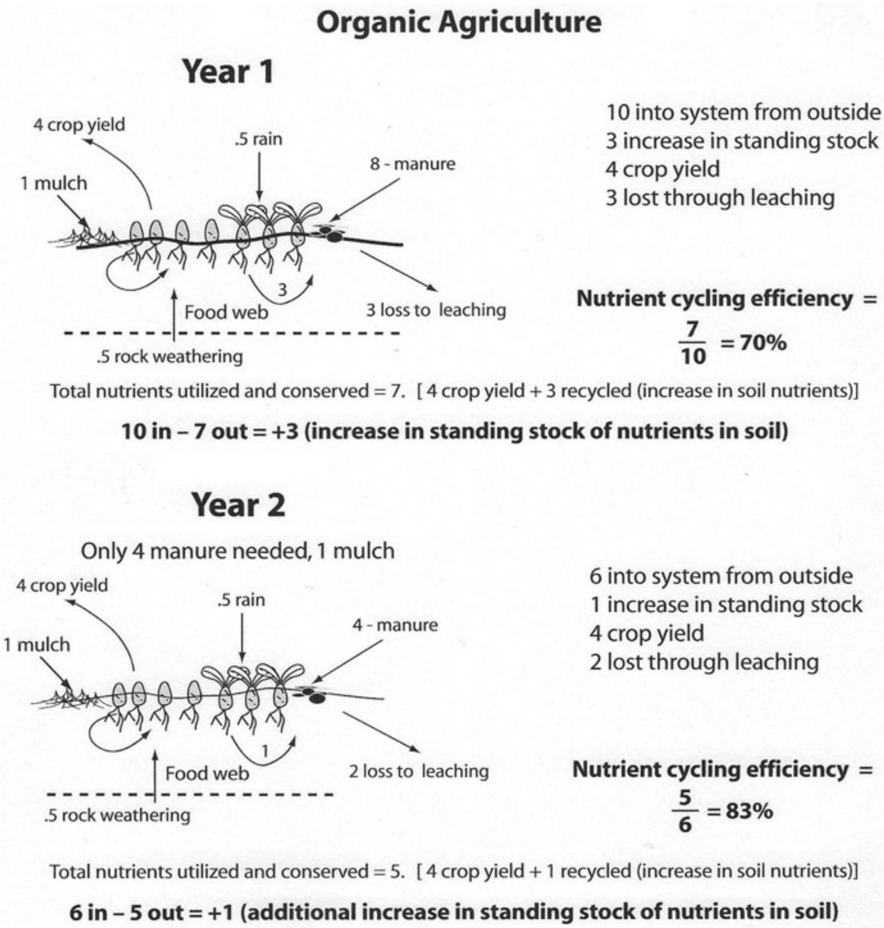

Fig. 1.12 Theoretical pattern of nutrient cycling efficiency in a 1-year and 2-year old organic agricultural system. Efficiency increases with time

1.11.4 Diversity and Stability

Natural systems often evolve toward diversity, whereas management of agricultural systems by humans is toward simplification. Diversity is a key ingredient of stability in ecological systems. An explanation can begin with an analogy to more familiar physical systems. Engineers know that to ensure the reliability of a system, built-in redundancy is required. For example, most jet airplanes have several independent hydraulic systems because aircraft control is dependent on a functioning hydraulic system. If one system fails, backups remain and the plane lands safely. Often each hydraulic system will be different in order to ensure that a problem that causes one to fail will not incapacitate the others. Redundancy and diversity of structure and function in a aircraft system are related to the reliability of aircraft performance.

Box 1.19

For this reason, it might have been wiser for Congress in 1973 to pass an "Endangered Ecosystem Act" rather than the "Endangered Species Act" that finally was approved.

There has been confusion regarding the relationship between diversity and stability in ecological systems. Some population biologists have argued that in nature, there is little or no relation between complexity and stability (May 1972, 1973a, b; Pimm 1982). Complex food chains, they maintain, are as likely to be unstable, or perhaps more unstable than simple food chains. Their studies have been used to rebut the thesis that complex agroecosystems are more stable than simple crop monocultures, and that diversity does not result in stability.

In fact, the studies do not contradict the hypothesis that complex ecosystems are more stable than simple systems. The analysis of Pimm, May, and other population biologists focus on species or populations that may go extinct following a perturbation to the system. In contrast, the resource manager or engineer is more concerned with whether the whole system continues to function despite a malfunction of one of its parts. From the point of view of resource management, there is more interest in the stability of the system output than of the system components per se (Box 1.19). It is analogous to the plane, where the pilot is not particularly worried about one hydraulic system, but only about whether has enough hydraulic systems to get him home should one or two the systems fail. The reliability of a particular hydraulic system is not greater in airplanes with three systems than in those with one system. However, the reliability of airplanes with three hydraulic systems is greater than the reliability of airplanes with only one.

Because of redundancy, more complex and diverse ecological systems are often more stable (unchanging over long periods of time) energetically than simple systems. Contributing to the relative stability of energy flow and nutrient cycling within ecosystems is the dynamic of individual populations. Populations of herbivores, predators, and omnivores can appear, grow, shrink and become extinct. As conditions vary, one population will replace another. Ecosystems with many populations have greater stability of energy flow and nutrient cycling than ecosystems with low population diversity. As one population declines, its function within the ecosystem switches to another species or population of the same functional group. The greater the diversity of species within the ecosystem, the more alternative pathways for energy flow and nutrient cycling and the greater the opportunity for switching from one pathway to another. Replacement of one species with another that performs a similar functional task is the reason that stable ecosystems are resistant to perturbations. Duffy et al. (2007) have shown that diversity within a trophic level (horizontal diversity) interacts with vertical diversity (food chain length and omnivory) to affect overall ecosystem stability. Moffat (1996) in her review of the subject, summed it up as follows: “Biodiversity is a boon to ecosystems, not species.”

1.11.5 Succession

Succession is the sequence of plant and animal communities that occupy a site following disturbance. The ability of succession to replace the original structure and function of an ecosystem can be termed resilience.

1.11.5.1 Succession in the Piedmont

The Piedmont region of the Appalachian Mountains extends from Alabama all the way to New Jersey, and lies between the mountains on one side and the coastal plain on the other. The region originally was in forest, but during the 1800s, it was almost all cleared for agriculture. Then in the 1930s, when the boll weevil and the Great Depression wiped out farming, much of the land in the South was abandoned. A series of plant communities began to occupy the deserted farm lands. Because the soils throughout the Piedmont are similar – red clay – the succession of plant communities throughout the range has been very similar (Keever 1950; Bard 1952).

The first year after agriculture is abandoned, a site may be occupied by annuals such as ragweed and crab grass, and the next few years by perennial herbs like sumac and goldenrod. The exact composition depends on the time that the site was abandoned and the proximity to seed sources. But after that, the sequence becomes quite predictable (Fig. 1.13). Conifers occur first. In the South, Loblolly pine is dominant, and often occurs in pure stands, although black locust occasionally is important. However if there is fire, grasses such as bluestem and broom sedge occur, and become dominant along with perennial shrubs after repeated burnings. If there is no fire or other disturbance, hardwoods, mainly oaks and hickories begin to become established.

Pines are often the first trees to colonize an abandoned field, because ectomycorrhizal fungi on the roots of pines conveys an advantage on soils poor in available phosphorus. This type of fungi may have the ability to solubilize phosphorus bound in clay soils. The evergreen nature of conifers also conveys an advantage on nutrient poor soils, because leaves do not have to be replaced every year, but as the soil organic matter and nutrient content gradually build up , pines lose this advantage. Eventually, pines are replaced by hardwoods, because pines cannot grow in the shade of the hardwoods, and pine seeds are unable to penetrate the thick layer of pine needles, whereas the larger acorns of oaks can send down roots to the mineral soil to obtain moisture.

If no disturbance occurs to the oak forest, a community of magnolia and beech trees will replace the oaks, because of the greater shade tolerance of the magnolia and beech. However, when ground fires occur, the oak community is better able to resist than beech and magnolia, because of its thicker bark, and ability to resprout vigorously.

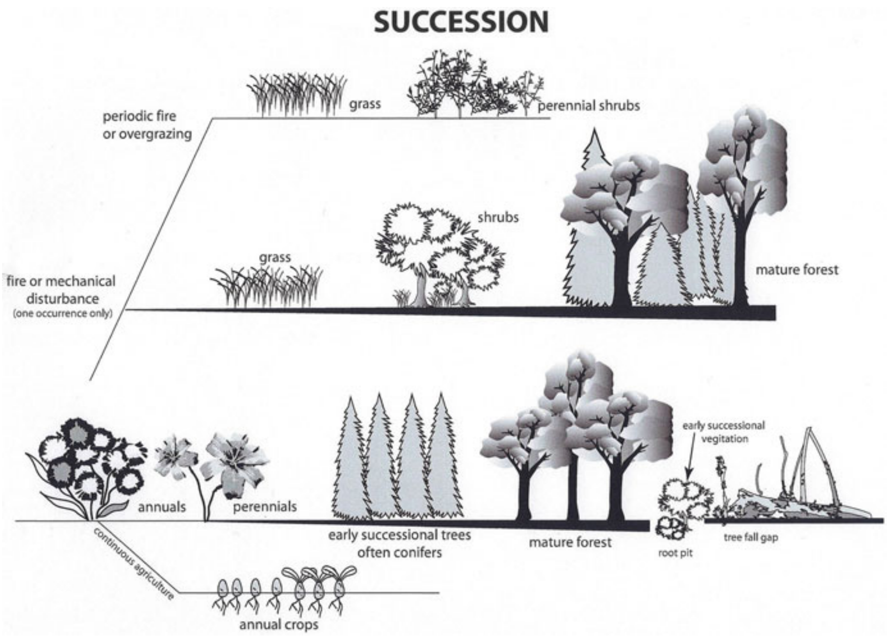

Fig. 1.13 Successional series in the Southeastern Piedmont following abandonment of agricultural fields when, from the *top* down: there is continual grazing and/or annual fires; there is a single disturbance that kills colonizing pines; the community is undisturbed; the field is returned to agriculture

1.11.6 Productivity

Productivity is a measure of the rate at which energy is captured by an ecosystem and converted to biomass. It represents conversion of radiant energy into chemical energy through the process of photosynthesis. Gross primary productivity is the total energy captured by the sun per unit time by all the plants in an ecosystem. Some of this energy is respired off, and the rest is converted into plant biomass. This biomass (or its energy equivalent) is called net primary productivity.

In agricultural systems, production of crops is called yield. Yield is not the total biomass produced during a growing season, but consists only of the proportion of the total net primary production that has market value. In a wheat system, it would be the bushels of grain per acre. It would not include the straw left after threshing. In the energy efficiency equation, output of grain divided by input of subsidies is equal to EROI, or energy returned on energy invested.

$$EROI = \frac{EG}{EI}$$

Yield would be the output, or EG. Energy input, EI would be the energy subsidies – the fertilizers, pesticides, diesel fuel etc. but not the solar energy. EROI is the

Box 1.20

Net primary productivity is one of the easiest properties of ecological systems to measure. One of the goals of the International Biological Program (I.B.P.) in the 1960s and 1970s was to estimate existing and potential plant production in the major climatic regions of the world (National Academy of Science 1968). Even before this goal was proposed for the I.B.P., ecologists realized the importance of determining the productivity of natural ecosystems, and consequently there had already been many studies of primary production.

measure of energy use efficiency. If wheat straw, sometimes used as animal bedding is included in EG, EROI would increase (Box 1.20).

1.11.7 Respiration and Decomposition

While productivity is the rate at which energy is captured by an ecosystem, respiration is the rate at which it is lost. Respiration is the release of energy from carbohydrates from all living organisms in an ecosystem. In animals, the process is called breathing. When the release of energy is by underground organisms, it is called decomposition. In natural ecosystems that are stable, respiration and decomposition of organic matter are balanced by productivity of organic matter. The ecosystem structure remains intact and its functions are stable. Most agricultural systems are unstable because cultivating destroys soil organic matter, and harvest removes nutrients.

1.11.8 Pollution Discharge

The rate at which an ecosystem rids itself of a pollutant is a property of the entire ecosystem.

For example, a river could be polluted as a result of sewage discharge. The ability of an ecosystem to rid itself of toxic substances is an ecosystem property. In theory, a polluted ecosystem is never completely clean. What scientists do is measure the length of time that it takes for half of the pollution to disappear. That is called the environmental half life. The reason that a pollutant never completely disappears is that after half of the pollution disappears, it takes an equal amount of time for half of the remaining pollution to be cleansed, and so on. Theoretically it is a never-ending sequence. The decomposition constant of a substance is used to determine the amount of material that is left in a system after an interval of time (Olson 1963). The constant can be used to predict when the amount of pollutant has declined to a level considered “safe”.

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Chapter 2
A History of Unsustainability in Agriculture

Abstract Throughout history, farmers have sought to maximize yield, because growing bumper crops gives them a competitive advantage over their neighbors. Nations have sought to maximize agricultural yield, because it gives them an economic advantage in the world marketplace. The history of agriculture is the history of how producers, from farmers to nations, have maximized agricultural yields through maximizing energy subsidies to farmers' fields and to nations' farmers. But maximizing yield always had a downside. Early agriculturalists in Mesopotamia subsidized their crops with irrigation. As populations grew, more crops were needed until excess irrigation resulted in salinization of the region's soil. The drive for more crop production in Greece and Rome resulted in deforestation that stripped the land of its ability to prevent erosion. Over-exploitation of the land to increase yield in Medieval Europe instead led to crop declines. The Mayan civilization declined, in part, because the demands they placed upon their environment grew beyond the carrying capacity of the land. For the first 9,700 years of agriculture, the use of energy subsidies including draft animals, slaves, and peasant farmers increased gradually, and cultures were able to adapt to problems caused by the subsidies. But with the advent of the industrial revolution, the pace of energy subsidies increased, and by the time the "Green Revolution" (industrial agriculture) appeared in the mid twentieth century, problems of energy pollution and energy scarcity have been increasing at an increasingly rapid rate.

Keywords History of agricultural yield • Agricultural history and unsustainability • Energy subsidies in agriculture • Energy subsidies and unsustainability in agriculture • The green revolution and unsustainability • Energy subsidies and the green revolution

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2.1 Pre-History

Twenty thousand years ago, humans in all parts of the world that they inhabited were foragers and hunters, whose most advanced technique was to attach themselves to a moving herd of animals. Before 10,000 B.C E., nomadic peoples followed the migration of wild herds, but sheep and goats have no natural migrations and so they were the first to be domesticated. When humans domesticated them, they took on the responsibility of nature: the nomad must lead the herd. This was the first energy subsidy in agriculture. Instead of expending energy to find forage and water on their own, the sheep and goats depended upon humans to lead them.

By 10,000 years ago, that had changed, and humans had begun in some places to domesticate animals and to cultivate plants. Domestication and cultivation were the changes in human history that allowed civilization to emerge. Now it became possible for humans to settle. Tribes were the social unit. Some tribes followed the nomadic tradition, while others became villagers. It was in the villages that civilization grew. Agricultural development could never have occurred while tribes were on the move, because the implements of civilization are difficult to store and carry. It was the nomadic tribes, however, that maintained the soil-regenerating service of animal migrations.

2.2 Mesopotamia

At the end of the Ice Age, a precursor of modern wheat appeared in the Fertile Crescent of the Middle East. But for wheat to become a continuous source of nutrition for humans, fertile soil was needed. And the silt deposited by floods of the Tigris, Euphrates, and Nile Rivers was the source of needed nutrients. The Fertile Crescent has been called "The Cradle of Civilization", because the dependable source of food enabled Man to engage in activities other than farming (Bronowski 1973). The yearly enrichment of soils through silt deposition was an energy subsidy that still is used by agriculturalists in some regions of the world (Box 2.1).

Draft animals were one of the energy subsidies that allowed the villages of the Fertile Crescent to grow. In order to cultivate wheat, it is necessary to plow, to rid the fields of weeds, and to open up furrows in the soil where the seeds can germinate. The first draft animals were donkeys and oxen, which pulled a wedge-like implement attached to a stick that scratched the soil surface to create furrows. The bounty from this agricultural subsidy allowed city-states such as Sumer to emerge between the Tigris and Euphrates Rivers. These city-states were militaristic, hierarchical societies. In the early dynastic period, the major city-states had a food surplus that enabled them to build their bureaucracies and armies to extend their influence. They maintained this surplus, despite the region's hot, dry climate, because of two other important subsidies: water storage and irrigation. Based on the detailed administrative record that they kept in their temples, we now know that environmental problems contributed to the ultimate collapse of those societies. Records of the declining

Box 2.1

The upper portion of the Amazon River above Manaus is called the Solimoes. In the 1980s, when I was studying agriculture in the region, a Brazilian student took me to visit a site of "varzea" agriculture on one of the tributaries of the Solimoes. A varzea is a layer of silt deposition carried down from erosion in the Andes, and deposited along banks of rivers as the waters recede during the end of the rainy season. The silt is rich in nutrients, and the bank that is formed by its deposition is completely weed free, because weeds that occurred when the water began to rise were killed by the flood. The combination of rich soil, water, and lack of weeds is an ideal combination for agriculture. All the farmer needs to do is drop the seed in the soil and then wait. While weeds do eventually appear, by the time that happens, the crop is well established and can withstand the competition. The yearly cycle of flooding presents two services of nature: restoring soil fertility, and killing of weeds.

amount of wheat cultivation and its replacement by the more salt-tolerant barley indicate that over the centuries, irrigation resulted in salinization of the region's soil. Because of the hot, dry climate, evaporation from the soil surface was high. The upward movement of the water from depth between periods of irrigation carried dissolved salts to the surface where they accumulated and damaged the crops. Between 3500 and 2500 B.C.E., wheat fell from 50 % of the crop to 15 %.

In about 2200 B.C.E., a marked increase in aridity and wind circulation subsequent to a volcanic eruption induced severe degradation of land-use conditions in Subir, immediately north of Sumer (Weiss et al. 1993). As land in Subir was abandoned, populations migrated southward at the same time that southern irrigation agriculture was suffering from the reduced flow the Euphrates. The growing population of Sumer necessitated cultivation of new areas. But the amount of new land that could be cultivated was limited, even with the more extensive and complex irrigation works that were becoming common at the time. Consequently, the size of the bureaucracy and the army that could be fed and maintained fell rapidly, making the state vulnerable to external conquest. The decline and fall of Sumer closely followed the decline of its agricultural base (Ponting 1990). Even today, governmental bureaucracies and armies are energy sinks that divert the energy available to a nation away from more productive uses. It has yet to be shown however, how a growing nation can avoid these sinks.

2.3 The Mediterranean

In the millennia before Christ, the natural vegetation of the Mediterranean basin was a mixed evergreen and deciduous forest of oak, beech, pine, and cedar. Bit by bit, the forest was cleared to provide land for agriculture and wood for cooking, heating, and construction. Sheep, cattle, and goats as well as fire suppressed regeneration, and gradually the region was transformed into scrubland. Some of the first areas to suffer deforestation were the hills of Lebanon and Syria. The natural climax forests there were particularly rich in cedars; the cedars of Lebanon were famous throughout the ancient Near East for their height and stature. In Greece, the first signs of widespread environmental problems appeared in about 650 B.C.E. as the population grew and cities expanded. Although the Greeks were well aware of techniques for soil conservation, the pressure from a continually rising population proved too great. The hills of Attica were stripped bare of trees within a couple of generations. The only tree that would grow on the badly eroded land was olive because it had roots strong enough to penetrate the underlying limestone rock. The Greeks tried to replace the erosion-prevention services of the natural forests with manuring and terracing, but these subsidies weren't enough to compensate for the destructive power of a growing population.

The overgrazing and over intensive cultivation that devastated Greece would be repeated a few centuries later in Rome. In 300 B.C.E., the land comprising modern Italy and Sicily was still well forested, but the increasing demand for land and timber resulted in rapid clearing. The growth of the Roman empire increased the pressure on the environment in other areas of the Mediterranean. Many of the empire's provinces were turned into granaries to feed the population of Rome. North Africa contains many Roman remains such as the great city of Leptis Magna in what once was a highly productive agricultural province. The North African provinces declined through a gradual process of increasing overexploitation of resources and consequent environmental deterioration. As vegetative cover disappeared, the energy it supplied to prevent soil erosion disappeared, and the desert slowly encroached. The process intensified after the fall of Rome, when Berbers and other tribes moved into the cultivated areas with large flocks of grazing animals (Ponting 1990). The decline of agriculture in these civilizations resulted from prodigal use of energy, that is, energy taken from the soil in terms of yield exceeded energy returned in terms of fertility.

2.4 The Middle Ages and Medieval Europe

During the middle ages, the main economic units were the villages and manors. These were self-contained economic units which consumed most of the food that was raised. There were basically two levels of people in this society-the peasant and the lord or priest. The peasants or serfs raised the food. They were the source of agricultural energy. They could not leave the village, sell an ox, or marry without the lord of the manor's permission. The lords required taxes from the serfs in the form of food or labor.

The serfs lived in villages surrounded by several large open fields, with each field containing a different crop as part of a three-field crop rotation. The fields were subdivided into long, narrow strips. Under their commoners' rights, each villager was allocated a set number of strips in each field. The strips were generally allocated by lot in a public meeting at the start of the year. The land in north-western Europe was particularly well suited to the very heavy plows that were used to cut through the dense clay, common in the region. Oxen were usually used to pull the plows. However, the plows differed little from those of the Roman times. They opened a furrow simply by scratching the surface, much as early farmers did with a stick.

In addition to the strips, there were large commonly owned meadows for pasture, where villagers could graze their livestock throughout the year. It was this practice that inspired Hardin (1968) to write his controversial "Tragedy of the Commons". The theme was that commonly owned land will be over-exploited. If Edwin, a villager in Medieval England, sees that Anselm is grazing more of his cattle on the commons than he is, Edwin will increase his herd to match or surpass that of Anselm. Anselm, not to be outdone, then increases his herd. Soon Gamel, Leofwin, and Umfrey join the race until the commons is overgrazed and destroyed through lack of grass to hold the soil in place. Critics of the theory argue that there are many examples of commonly owned resources that are not over-exploited, because of social control. However, social control only works where everybody knows everybody else, and social pressure can be applied.

2.5 The Mayan Civilization

By the time the Spanish Conquistadors arrived in what is now Central America, most of the large Mayan sites had been all but abandoned for hundreds of years. Most of their cities had fallen into ruin and were being overtaken by jungle. The Mayan people had splintered into small villages and towns, losing the complex social strata and rituals that supported this great civilization at its apex. The causes for the Maya's decline are numerous, but one of the most important is that the demands they placed upon their environment grew beyond the carrying capacity of the land. At it's peak, there were about 15 million people occupying the Mayan world. Over-population of Mayan metropolises are suspected to have gone beyond levels that the Mayan agriculture was able to support, resulting in social unrest and revolution. Archeological studies have shown evidence of severe droughts, deforestation, and a decline in large game animals that began around 800 A.D., coinciding with a sharp drop in new construction. Human bones found from this time show signs of severe malnutrition, which would have been a driving factor behind raids by Toltec nation. While Maya civilization did go through a brief renaissance after this period, ongoing environmental constraints played a large role in their eventual decline (Trupp 2012).

2.6 The Industrial Revolution – Energy Intensification

The Industrial Revolution was a period from 1750 to 1850 when changes in manufacturing, mining, transportation, and technology had a profound effect on the social, economic and cultural conditions of the times. It began in Great Britain where an economy based on machine-based energy replaced a manual labor and draft-animal–based economy. It started with the mechanization of the textile industries, the development of iron-making techniques and the increased use of refined coal. Trade expansion was enabled by the introduction of canals, improved roads and railways.

Romanticism was an artistic, literary, and intellectual movement that originated in Europe toward the end of the eighteenth century and in most areas was at its peak during the industrial revolution. It was partly a reaction to the pollution and environmental degradation caused by the Industrial Revolution, and also a revolt against the scientific rationalization of nature. Romanticism was embodied most strongly in the visual arts, music, and literature.

2.6.1 Plows

During the Middle Ages, farmers in many parts of the world gradually converted a modest proportion of the world's forests into farmland or pasture, but the fertile soils of the world's grasslands were little affected. By the middle of the seventeenth century, needs for food production in Europe increased as populations recovered after the plagues of the thirteenth and fourteenth centuries and the Black Death. Landowners began to take an interest in cultivation. Preparation of a good seedbed was still the objective, and fineness of the soil surface was seen as a prerequisite. The advent of stronger and sharper plowshares enabled farmers to cultivate the sod of the Eurasian steppe, the North American prairies, and the South American pampas (McNeill and Winiwarter 2004). Plows enabled a more intense application of energy to the soil

Different plows were developed for effective tilling of different soils (Warkentin 2008). Nevertheless, the basic effect of plowing was to cut a strip in the soil. Not until the early to mid nineteenth century did a major change in land cultivation occur: the perfection of the moldboard plow. Instead of merely cutting the soil, the moldboard plow with its curved blade actually turned over the soil, allowing a whole field to be ready for seeding, and burying weeds under the inverted topsoil (Figs. 2.1 and 2.2). The large plows made for cutting the tough American prairie soil were called "grasshopper plows" (Bellis 2012). The energy subsidy of these plows destroyed perennial grasslands, the source of energy that stabilized soil. In 1837, John Deere developed and marketed the world's first self-polishing cast steel plow. Though the blade was made of steel, it was still called a "moldboard". In the United States, the result of this agricultural advance was the devastating whirlwind of dust stirred up by the drought and winds of the 1930s. John Steinbeck's famous 1939 novel, "The Grapes of Wrath", portrayed the plight of the families who lost their land during the "Dust Bowl" of mid-America. It brought attention of the nation to the problem of soil erosion.

Fig. 2.1 Moldboard sulky plow pulled by a team of draft horses in Nacoochee Valley Farm, Sautee, Georgia

Fig. 2.2 Close-up of a moldboard plow, moving right to left. Note the curved steel blade of the plow which actually inverts the soil. Turning over the topsoil makes it a good seed bed, and buries the weeds

2.6.2 Dams and Levees – Formations Used to Store and Divert Energy

Since agriculture first evolved in the Fertile Crescent, the yearly rise and fall of the Nile River provided needed nutrients for the early farmers that lived along its banks. As the river fell during the dry season, silt rich in nutrients was deposited in the farmer's fields. This service ended with the construction of the Aswan dam in Egypt. Farmers wanted a constant and reliable source of irrigation water, but yearly fluctuations of rain in the headwaters made water supplies unpredictable. The solution was a mega-dam. The pool behind the Aswan was large enough to dampen out yearly fluctuations in water supply. However, the annual replenishment of soil fertility from silt deposition was lost. Instead, the silt was deposited behind the dam, where it became a liability. The dam also had great impact on the fertility of the coastal waters. The fertilizing effect of the inflow of the nutrient-rich water during the flood season once resulted in exceptionally dense blooms of phytoplankton off the Nile Delta. This "Nile bloom" provided sustenance to sardines and other pelagic fishes. It also constituted a large source of detrital material, the products of organic decay, which forms a vital source of food for commercially valuable organisms such as shrimp (El-Sayed and van Dijken 1995).

Dams in the U.S. Before the twentieth century, streams and small rivers often were used for hydropower to turn mills that ground grain, and in Eastern U.S., to run cotton spinning machinery in mills (Walter and Merritts 2008). Usually these mills were built near rapids or falls, where a steep drop in elevation provided potential power. Water was diverted into a millrace that ran alongside the mill and turned a water wheel which powered the cotton spinning machinery. In the late nineteenth century, much bigger dams were built to power turbines that produced electricity. These had a great impact on fisheries. In New England, dams on the Connecticut River blocked the migrations of shad, lamprey, salmon, blueback herring and alewives, and decimated their populations. The dams also impacted agrarian users who relied on the services of free-flowing rivers for seasonal flooding that maintained the fertility of meadow lands.

While hydroelectric dams provided cheap electricity and irrigation water for agriculture in the West, they had a devastating effect on the populations of commercially important salmon. Big dams on the Columbia River such as The Dalles and the Grand Coulee blocked salmon runs and endangered the fishing industry. "Fish ladders" were installed to provide a way for fish to bypass the dams, but they have been minimally effective.

Levees. For thousands of years, periodic flooding along the Mississippi River deposited rich layers of silt on the floodplain. During the colonial era, farmers who recognized this good quality soil established their farms in the floodplain. Later, levees were built along the River to benefit navigation, so that riverboats and barges would not run aground due to the constantly shifting sand and silt bars. Farmers on the dry side of the levees approved of them, because they protected their crops from the damages of flooding. But when levees are built along rivers, as they have been along the Mississippi River, Nature can no longer do her work. The good soil is flushed down into the Gulf of Mexico where the fertilizer-derived nitrogen that it carries causes hypoxia and fish kills. The farmers that settle on a flood plain protected by levees and dikes have the advantage of thousands of years of accumulation of good soil, but the chance they take is that if they cultivate fields in the floodplain, they will get flooded when the levees are breached. When that happens, they ask the government to bail them out (Kesling 2012).

2.7 The Agricultural Revolution in North America

Except where specifically noted, source for this section was Jordan (1998).

2.7.1 The Nineteenth Century

Before the early nineteenth century, most American farmers were limited by labor. Slaves, hired hands, and draft animals were the only subsidies. Things began to change with the emergence of the Industrial Revolution and the market economy in the 1800s. Mechanical implements such as plows, tractors, cultivators, and the cotton gin revolutionized agriculture. Steam-powered machinery enabled farmers to cultivate their fields much faster than was possible with animal traction.

Taking the Plains. At one time, the great plains and the bison that grazed upon them were a sustainable resource for native American peoples. Beginning in 1832, there began a series of technological innovations that, in conjunction with the introduction of cattle to the western ranges, changed the Plains ecosystems from a state of sustainability to one of dependence upon subsidy. One crucial technological innovation was well drilling, which replaced digging, and allowed tapping of the deep water tables. Another was the self-regulating wind pump, commonly called the windmill. It was capable of reliably drawing water up from the deep wells and supplied a non-supervised means of regulating flow. A third innovation was barbed wire, invented in 1873. It was the first means of fencing that effectively controlled cattle movement and could be easily erected in extensive grasslands. It was this combination of well drilling, windmills, and barbed wire that made it possible for the land to be fenced into small areas and for the stockmen to transform ranges into pastures. Thus began the transition from sustainability dependent upon regulation by natural cycles to unsustainability dependent upon technology.

Cattle. In the 1500s, the Spanish began to bring cattle to the New World, some to the East Coast of North America, and some to Mexico. These cattle were hardy animals, ancient stock from the plains of Andalusia. Many escaped or were abandoned into the forests and fields of sixteenth century America. The cattle bred without human interference in the brushy wooded terrain of the Gulf Coast. They developed natural resistance to disease, and were able to forage in the palmetto underbrush of the pine forests. In Florida and Georgia, they were (and still are) called "Piney Woods Cattle". In Texas, the Spanish cattle were the progenitors of the Texas Longhorn. In the late 1800s, these tough and adaptable longhorns were crossed with or replaced by heavier, short-horned animals. The end result was an animal that could efficiently transform grass into meat, but needed pampering, clinical care, and defense against predators. The process of breeding out sustainability was further accelerated with the advent of confined animal feeding operations, (so called CAFOs) where the cattle are kept in pens and fed grain delivered to them in troughs.

2.7.2 Subsidies

Accompanying the introduction of mechanized resource extraction was a change in the rural economy. Mechanized agriculture allowed the farmer to become more efficient, when efficiency is defined as yield per unit time of farmer effort. However, mechanization was economically feasible for the individual farmer only through specialization, so the predominant strategy was to replace a variety of subsistence crops with a single commodity crop such as corn or wheat.

Meanwhile, the flood of immigrants to cities in eastern United States created a sharply increasing demand for food and fiber. To help farmers and ranchers supply the needs of a growing country, state and federal governments established agricultural assistance programs. The Federal Government gave ranchers low-cost grazing rights on public lands. The Homestead Act, which gave an applicant ownership at no cost of farmland called a "homestead" – typically 160 acres of undeveloped federal land west of the Mississippi River – encouraged many new farmers. The system of railroads that integrated farms and ranches into the national market was encouraged by grants of free land to the railroad companies. The killing of native American Indians by the U.S. Army was the essential subsidy that allowed development to proceed with minimal interference. The killing of bison herds by bounty hunters allowed cattle and sheep to take over the range. In 1862, the Department of Agriculture was established, and its primary mission was helping to increase farm production. In the same year, the Morrill Act was passed to establish land grant agricultural colleges. Their missions were: to educate young people who were interested in agriculture; to research ways of increasing crop production; and to disseminate new information to farms of the country through extension services (Smith 1971).

For the most part, the programs were deemed successful. The growing population of America was supplied with food and fiber at a price so low that the economy developed far beyond provision for mere subsistence. As the market economy grew, economies of scale gave the biggest advantage to the largest operators. Since big farms could better utilize "modern" methods of increasing production, much of the government effort went toward assisting big farms in getting bigger, as well as increasing the scale of ranching operations. As the economic importance of farmers

Box 2.2

Because competition drives down the prices for farm goods, in 1985 through a provision of the Farm Bill, the U.S. Dept. of Agriculture added new provisions to existing policies to pay farmers not to grow certain crops, so that limiting the supply of these crops would keep prices high enough to keep farmers from going out of business. Spring Valley Ecofarm was grandfathered into this program because the previous owner had raised wheat and sorghum, two commodities that were included in this program.

grew, so did their political influence. The "farm block" became an important political influence in the mid-twentieth century. Farm states elected representatives who supported existing subsidies and fought for new ones. While the public benefitted from these policies, the result was that they did not pay for the true cost of food.

Subsidies for agriculture and ranching – when first introduced – were a good thing. They enabled both the producers in the country and the consumers in the city to achieve a standard of living far higher than their ancestors had ever thought possible. The American Dream was based upon the exploitation of North America's resources – its rich soils and productive ecosystems. But the individual entrepreneurs did not develop these resources on their own. It was government subsidies that made development possible and brought great riches to those who most aggressively took advantage of the subsidies. And when supplies outstripped demand and prices for commodities dropped, the government instituted a program to keep prices up by limiting supply – paying farmers not to grow crops (Box 2.2).

But there was a serious flaw with the subsidy system. Subsidies encouraged maximizing short-term yield, an inefficient use of the energetic value of the resources. Farmers and ranchers mined the soil and loggers mined the forests – that is, they extracted resources in the cheapest way possible, with little or no thought for replacement or sustainability. In the Midwestern prairies, this involved stripping the ground of its cover to plant annual grains; in the forest, clear cutting and burning without replanting; and on the range, overgrazing until the grass disappeared. Few saw anything wrong with this system. Low prices were one of the things that made America great, and competition that kept them low was applauded. There were, however, some who complained. At the beginning of the twentieth century, groups such as the Sierra Club organized and began to protest against the destruction of Americas' forests, but they had little effect on a national level. It took the dust bowl of the 1930s to jolt Americans into the realization that America's resources were not endless. As a result, the Federal Government established the Soil Conservation service in 1935, and new methods such as contour cultivation, windbreaks, and ground cover were encouraged and implemented, even though they often decreased short-term profit. Americans finally began to realize that sustainability had to be subsidized to be achieved, just as high yield had to subsidized to feed a growing America.

2.7.3 Concentrated Animal Feeding Operations

The production of animals by concentrating them together in feed lots is called a Concentrated Animal Feeding Operation (CAFO). The Environmental Protection Agency defines a CAFO as an animal feeding operation with 1,000 confined animals, or 300 or more where there is a direct pollution discharge into a body of water. In CAFOs, cattle are fed with grain grown elsewhere and transported to the CAFO site. CAFOs have been favored by the cattle industry because in the days of low cost energy, fattening animals in feed lots was cheaper than feeding them on grass. CAFOs were also attractive because:

- The production of animals by concentrating them in feed lots decreases the time required for animals to be ready for slaughter. Production is more time efficient.
- Land use efficiency increases because less land is required to raise an animal.
- CAFO cattle don't forage, so more of their energy intake is converted to meat instead of being spent by grazing.

Cattle, hogs, and poultry have been cheaper to produce in CAFOs than those raised in pastures, because of the low price of petroleum products. However, the economics may be changing due to the increasing cost of energy. Factory farming is energy inefficient. It takes more energy to raise a 500 lb steer in a feed lot than it does in an open pasture. In factory farming, energy is expended in growing grain, transporting it to the feed lot, giving it to the animals, and then disposing of the manure. In a pasture, the steer does all the work, and the manure fertilizes the pasture.

CAFOs have been criticized on grounds of environmental impact, health, and the ethics of animal treatments. By failing to internalize the external costs of downstream impacts on water quality, CAFOs cause local communities to bear the costs. CAFOs generally discharge considerable amounts of pollution that are not routinely monitored. While it is difficult to make an exact connection between CAFO pollution and health problems, there are a number of cases where communities exposed to increased levels of agricultural pollution show a number of common health problems (Dowding 2008). The increase in health care costs due to CAFO pollution affects property values, because people do not wish to live in communities plagued by pollution and health problems. Remediation of land contaminated by pollution is expensive, but mitigation costs are often passed on to the Environmental Protection Agency because of the difficulty or proving the CAFOs are solely responsible.

Pollution discharge from CAFO operations into streams and lakes causes an increase in nitrogen and phosphorus concentrations in the water, causing an increase in algae that consume oxygen. The result is anaerobic conditions that cause fish kills. Another way that CAFOs are detrimental is through the antibiotics given to animals to prevent disease outbreaks, common in congested environments. Because of increased exposure of animals to antibiotics, and of humans that eat the exposed animals, animal pathogens are becoming increasingly resistant to antibiotics.

2.8 The Green Revolution

The Green Revolution refers to a series of research, development, and technology transfer activities occurring in the decades after WWII that resulted in dramatic increases of agricultural production. It involved replacing hand labor with machine labor, the development of high-yielding varieties of cereal grains, expansion of irrigation infrastructure, and distribution of hybridized seeds, synthetic fertilizers, and pesticides to farmers.

2.8.1 Commercial Nitrogen Fixation

Fritz Haber was a professor in Karlsruhe Germany when he demonstrated in 1909, the feasibility of ammonia synthesis, which led to the process of taking nitrogen from the air and turning it into fertilizer. Carl Bosch, an engineer at BASF in Ludwigshafen, then overcame the engineering problems associated with the enormous energy required by the process. Commercial production started in 1913 (Schmidhuber 2012). Their Haber-Bosch process has often been called the most important invention of the twentieth century as it "detonated the population explosion," driving the world's population from 1.6 billion in 1900 to 6 billion in 2000 (Smil 1999).

The high temperatures and very high pressures needed to transform atmospheric nitrogen (N2) to ammonia (NH3) are energy intensive. About one percent of the world's annual energy supply is used to produce ammonia, most of which becomes nitrogen fertilizer (Ogburn 2009). A century after its invention, the process is still applied all over the world to produce 500 million tons of artificial fertilizer per year (Fryzuk 2004).

Agricultural production in the United States, as well as the world began to increase dramatically after World War II, owing in part to the increased availability of nitrogen fertilizers. Along with chemical fertilizers, agronomists developed pest and weed control chemicals, and more powerful machinery to cultivate large areas. To achieve that increase, hybrid grains were bred that responded to the subsidies. But while the new lines of crops were highly productive, they were also more susceptible to disease, insects, and competition from weeds. The response was a new type of energy-derived subsidy: pesticides and herbicides.

Box 2.3

The 50th anniversary of the publication of Carson's "Silent Spring" in 2012 spawned many books and papers citing the book as the start of the modern environmental movement. Her book concludes: "The control of nature is a phrase conceived in arrogance, born of the Neanderthal age of biology and philosophy, when it was supposed that nature exists for the convenience of man. The concepts and practices of applied entomology for the most part date from that Stone Age of science. It is our alarming misfortune that so primitive a science has armed itself with the most modern and terrible weapons, and that in turning them against the insects it has also turned them against the earth" (Carson 1962).

2.8.2 *Pesticides*

Potency and persistence of dichlorodiphenyltrichloroethane, better known as DDT, were qualities that made this insecticide attractive to farmers when it was first used in the late 1930s. What was not realized at first were the environmental hazards that it posed. Fat-soluble pesticides such as DDT are concentrated as they pass up the food chain. In the top trophic level of ecosystems, concentrations of DDT were concentrated up to 10^6 times, even in animals such as eagles that lived far from where DDT was sprayed (Harrison et al. 1970). Dead robins that fed on worms had up to 3 mg of DDT in their tissues. Accumulation of DDT in predatory birds resulted in thinning of egg shells with a resultant decrease in populations of bald eagles, falcons, and pelicans. Because of its persistence, DDT was transported from its initial site of application by both biotic and abiotic factors until almost no part of the earth's surface was free of it (Buckley 1986). Although many scientists in the 1950s were aware of the potential effects of DDT on agricultural systems, it was Rachel Carson's 1962 book "Silent Spring" that brought the problem to the attention of the general public. It was a highly controversial book, and even as late as 2000, some agronomists claimed that there is no evidence that pesticides are harmful to humans (Avery 2000) (Box 2.3).

Additional documented after-effects of these so-called "hard" insecticides include the resurgence of pests after treatment. When predator insects that feed upon herbivorous insects are killed by the pesticide, resurgence of the herbivores can be especially severe. Other effects include the elimination of economically beneficial insects such as honey bees (National Research Council 1989) and aesthetically pleasing insects such as butterflies (Longley and Sotherton 1997).

In the Rio Grande Valley of Texas, where cotton is an important crop, aerial spraying of malathion was initiated to vanquish the boll weevil. Scientists implicated the insecticide in the elimination of wasps and other beneficial insects that previously controlled other cotton pests, such as the armyworm. In 1995, many farmers suffered crop losses of hundreds of thousands of dollars, and in 1996, they voted by a margin of 3–1 to stop the program. Nevertheless, the Texas Dept. of Agriculture continued to assess farmers \$12–\$18 per acre for spraying (N.Y. Times 1996).

In the 1980s, a boll weevil eradication program was instituted by the U.S.D.A. in southern states to try to completely eliminate the boll weevil. Part of the program is to place pheromone (sexual attractant) traps around cotton fields to attract the beetles that lay eggs in the cotton bolls. Inspectors from the Dept. of Agriculture periodically inspect the traps and whenever an adult is found in a trap, the field is sprayed with malathion, whether the farmer likes it or not. Farmers who try to grow organic cotton lose their ability to claim "organically grown" when their fields are malathionized.

2.8.3 Herbicides

Herbicides are useful for farmers who want to build up soil organic matter by using conservation tillage. In conservation tillage, seeds are planted by a machine that injects them through a layer of cover crop residue. This type of planting eliminates the need for plowing and harrowing, practices which expose mineral soil and cause erosion. However, weed control is a problem. Plowing to control weeds would defeat the soil-enhancing goals of conservation tillage. As a result, many farmers who use conservation tillage use herbicides to control weeds.

While modern herbicides appear to readily degrade in the soil, the rate of degradation depends upon climate, and physical and chemical properties of the soil. When herbicides are incompletely degraded, residues can contaminate drinking water supplies and water used for irrigation. Herbicide residues have been detected in surface water (Thurman et al. 1992) and ground water (Burkart and Kolpin 1993). Herbicides in drinking water supplies cannot be effectively removed by conventional treatment, or even by carbon filtration systems. (National Research Council 1989). Evolution of resistance in weeds may be the more dangerous aspect of long-term use of herbicides. As a result of long-term exposure, some weed species are already resistant. At Spring Valley, pig weed (*Amaranth* spp.) and a type of thistle are already resistant. Fortunately, they seem to thrive only on bare soil, and when they grow in vigorous pastures, the grasses crowd them out.

Herbicides are not permitted to be used in agricultural fields where the crops are to be labeled "Organic". However, there is a possibility that herbicides can increase agricultural sustainability as compared to other types of weed control. It will depend on the relative energy costs. Plastic weed barriers are permitted in organic farming, but getting rid of them every year is energetically expensive. Even weeding with a hoe may be more energetically expensive than weed control with herbicide. Other traditional weed control practices such as allowing geese to graze along the rows once the crops begin to mature are energy-saving, but are impractical on a large scale (Box 2.4).

Box 2.4

There are certain instances, even on farms that aspire to be sustainable, when herbicides seem overwhelmingly preferable. Control of Chinese privet, in the bottomland forests of Spring Valley Ecofarm, is an example. Privet is, without a doubt, the most pernicious of all invasives in the South. Others, like kudzu and wisteria are easily controlled, and are pests only in abandoned land. Privet invades the understory of mature forests, and crowds out seedlings of the trees. It produces seeds profusely, that are spread far and wide by birds. When I bought Spring Valley Ecofarm in 1993, the understory of the tulip-poplar/ river birch forest was an impenetrable thicket of privet. Cutting by hand or with a chain saw does no good. Neither do the machines that suck it in and chip it up as it rolls along. The privet only resprouts more vigorously the next year. Only herbicides seem to offer some energetic savings.

2.8.4 Social Aspects of the Green Revolution

Considerable polarization has developed between those with positive, optimistic views about the Green Revolution and those with negative, pessimistic outlooks. The optimists have included biological and agricultural scientists involved with developing the new technologies. In the early days of the Green Revolution, some of them saw an enormous potential. They were fired with enthusiasm and faith, excited at the way in which the new dwarf wheat and rice shifted yield potentials to new high levels. Attention was concentrated on geographical areas that were well endowed with irrigation water and infrastructure. The spectacular increases of wheat production during the 1960s encouraged this optimism. As the Green Revolution spread to other crops, it was hailed as the key to banishing world hunger.

Those who took negative and pessimistic views included social scientists concerned about the political economy and about the question of who gained and who lost from the Green Revolution. Many studies showed that the new technologies were captured by the rural elites and benefited those in the more favored regions. The new high-yielding varieties of food grains, planted, fertilized, irrigated, and protected by pesticides, usually were found on the fields of the larger and more prosperous. farmers. As a result of the new technology, major social and economic consequences arose. They included an increase in the number and proportion of landless households, a growing concentration of land and assets in fewer hands, and a widening disparity between the rich and poor households, In their negative assessments, some social scientists believed the Green Revolution had sharpened social tension, and some spoke of it turning red (Chambers 1984). While both the optimists and pessimists have debatable points, what is clear is that the Green Revolution has made us clearly dependent upon fossil fuel subsidies for feeding ourselves and the world, and thus has made agriculture less sustainable. The Green Revolution enabled crops to be produced more efficiently, when efficiency is defined as the amount of time spent by a farmer to produce 100 bushels of corn. However, when efficiency is defined as the amount of energy required to produce 100 bushels of corn, the Green Revolution has *decreased* farm efficiency. It requires more energy today to produce 100 bushels of corn than it did before the Green Revolution.

2.9 The Second Green Revolution

Since 18 May, 1994, when the U.S. Food and Drug Administration approved the first genetically modified organism for commercial sale, genetic engineering has been hailed as a solution to many of the problems of agriculture (Thomashow and Mooney 1994). It has been claimed that the increases in crop production brought about by genetic engineering can help relieve problems faced by farmers by decreasing the losses caused by pests, disease, weeds, and other stressors (Guerinot 2000).

From the point of view of an individual farmer, genetically engineered crops might seem to be very desirable. During the Ceres Forum on Environmental Benefits and Sustainable Agriculture through Biotechnology at Georgetown University (Doyle 1999), several farmers testified that planting genetically modified plants increased their income because of increased production and fewer losses to pests and disease. The problem is, of course, that if all farmers adopt genetically altered crops, there will be an oversupply, resulting in a decrease of prices that cancel out the economic gains reached through genetically altered crops. It is an interesting variation on the tragedy of the commons. If one farmer exploits the commons (the commons being a restricted market) by producing more than his or her fair share (a fair share being that amount that could be produced without genetically altered crops,), then the farmer will achieve an "unfair" advantage. This famer will profit at the expense of all other farmers. Of course, if *all* farmers planted genetically modified crops, then all would have an equal advantage, and everyone would again receive a fair share, which economically would be about what it was before they planted the genetically modified crops.

Insect Resistance. Besides increased production, another reason given for using genetically engineered crops is that such crops benefit the environment by reducing the need for pesticides that kill beneficial organisms (Hardy 1994). To protect a crop species from insect herbivores, transgenic varieties can be created that contain insecticidal proteins of the bacterium *Bacillus thuringiensis* (Bt), which are effective for controlling many insect pest species but do not harm predatory insects or mammals (Oppert et al. 1997). A problem, however, is that evolution in insect pests of resistance to the insecticide is virtually inevitable where large areas are planted to transgenic crops. To slow down the rate of evolution of resistance to insecticides, "refuges" are sometimes established, in which farmers plant non-transgenic plants (McGaughey and Whalon 1992). The idea is that if part of a field contains nontransgenic plants, the trait for nonresistance will be maintained in the target population of insects. However, the refuge idea depends upon the resistance being recessive and mating being random, not always true (Huang et al. 1999).

Herbicide Resistance. Geneticists also have engineered crops to be herbicide resistant, so that herbicides can be used to control weeds that appear amongst a growing crop. However, weeds can quickly evolve resistance to herbicides (Powles et al. 1997), and there can be transgene escape into weedy relatives, even in a species considered to be almost completely selfing (Bergelson et al. 1998).

2.9.1 Thermodynamic Considerations

Greenstone (2001) has criticized those who oppose genetically altered crops by saying, “They want the free lunch, to have a Green World where humankind lives lightly off the bounty of benign and unmanipulated nature” He has a point, but proponents of genetically engineered crops also claim a free lunch. They claim that it is possible to get increased yield, but at the same time, get plants that are insect protected, stress tolerant, herbicide resistant, and perennial (Horsch 2001). This claim raises the question of energy tradeoffs in transgenic plants, Can genetically engineered plants actually increase food production, and at the same time repel pests, resist herbicides, and compete with weeds for water and nutrients? Thermodynamic considerations suggest that they cannot.

There is only so much solar energy that reaches an acre of field every year. Some of that energy is captured through photosynthesis and converted to carbohydrates, which are then transformed and used for growth and metabolic processes of the plants. The ability of plants to capture and fix the energy is inherently limited by the physics of intercepting photons and capturing carbon dioxide, the biochemistry of photosynthesis, and the physiology of nutrient uptake and utilization (Federoff and Cohen 1999). What plant breeding does is change how the captured energy is used. When crop plants were domesticated, certain traits such as ability to compete for nutrients and ability to resist pests, were traded for other qualities, such as high production, especially production of grain. The farmer took over the functions of plant nutrition and pest control using machinery and agrochemicals. What plant breeding has not done is increase the amount of energy captured through photosynthesis. In certain cases, breeding changed the structure or architecture of species such as rice plants so that plants could take better advantage of environmental conditions in the farmer’s field or paddy. By decreasing stem length, rice could be made more productive under certain management regimes (Conway 1997). However, such changes do not mean that scientists have overcome the first law of thermodynamics – Matter and energy cannot be created, only transformed. Traits such as herbicide resistance and pest resistance, achieved through genetic engineering, have a thermodynamic cost. Purrington and Bergelson (1999) found that seed production in herbicide resistant *Arabidopsis thaliana* was lower than in non-resistant varieties. Fineblum and Rauscher (1995) showed that there was a tradeoff between resistance and tolerance to herbivore damage in morning glory. Recently, Powell et al. (2012) have inadvertently confirmed the biological implications of the First Law of Thermodynamics in their study of tomato genetics. For decades, plant breeders in the tomato industry have selected varieties that are uniformly light green

Box 2.5

Advocates genetic engineering like to focus on the increase in yield resulting from the use of engineered crops. For example, Ridley (2012) wrote "The most obvious benefit is yield increase. In 2010, a Monsanto funded report estimated that the world's corn crop was 31 million tons larger and the soybean crop 14 million tons larger than it would have been without the use of biotech crops." What never is mentioned in such reports is the huge energy cost required to achieve this yield. Without nitrogen fertilizers supplied in prodigious amounts, such yields are not possible. Ogburn's (2009) report that one percent of the world's annual energy consumption is used to manufacture nitrogen fertilizer highlights the unsustainability of biotech agriculture highly dependent on fossil fuel energy.

Also never mentioned is that the problem of hunger is not caused by lack of genetic engineering to produce more food. The undernourished and the food-insecure persons are in these conditions because they are poor in terms of income to purchase food, particularly biotech food that is dependent on huge energy resources.

before they ripen, in order to produce tomatoes that can be harvested at the same time. Powell's research has shown that this characteristic is accompanied by an unintended reduction in sugars that compromises the flavor of the fresh fruit and its desirability for processing.

As crop plants are modified to be more weed and pest resistant, they become more and more like their wild ancestors. Conway and Sechler (2000) pointed out that the technology of the first Green Revolution allowed plants to channel more photosynthate into grain production, dramatically increasing yields, but diminished other useful traits such as vigorous deep roots, insect resistance, and ability to compete with weeds. Unless the first law of thermodynamics can be repealed, the second Green Revolution – breeding genetically modified crops that have deep roots, insect resistance, and high competitive ability – will merely reverse the changes of the first revolution (Box 2.5).

2.9.2 Sustainability of Green Revolutions

Everyone agrees that agriculture must become more sustainable. However, there is sharp disagreement as to how to do it (Kiers et al. 2008; Stokstad 2008). One side of the debate is that Green Revolutions (industrial agriculture based on inorganic fertilizers, pesticides, and genetically modified crops) are necessary to sustain the growing populations necessary for an expanding economy (Borlaug 2007; Pennisi 2008; Brown and Funk 2008). Yields must be increased, and increases can be obtained only through more intensive application of inorganic nitrogen and

Box 2.6

The difference between yield (gross income) and sustainability (net income) often is not clarified in debates about green revolutions.

Yield.
Yield is the amount of grain, fruit, vegetable, or animal produced per year per unit area (per acre for farmers, per hectare for scientists). Yield is comparable to ***gross*** income for a business. In a business, it is the total amount of money taken in. Businesses, no matter how large their gross income, can still go bankrupt if their expenses are even larger. Likewise for farms, no matter how large their yield (in energy production and in dollars), they can still be unsustainable if their energy costs are even larger. Yield alone does not confer sustainability.

Sustainability.
Sustainability is a measure of the amount of yield per unit input. For economists, yield and input are in terms of dollars. For ecologists, they are in terms of energy. Sustainability is comparable to ***net*** income for a business. It is the gross income minus expenses to produce that gross. For a business to be viable, the difference has to be positive. For agriculture to be sustainable, yield minus input must be positive.

other nutrients, increased irrigation, greater application of petroleum-based chemicals to control insect pests and weeds, and through the use of genetically modified crops that are programmed to take advantage of these subsidies (Jauhar and Khush 2003) (Box 2.6).

Opponents of industrial agriculture argue that it is unsustainable for a number of reasons:

- It is highly dependent upon petroleum to synthesize the fertilizers, pesticides, and herbicides, and for fuel for the airplanes, trucks, and tractors that deliver and spread these compounds. Because petroleum supply is erratic and limited (Kerr 2008), agriculture based on these compounds is unsustainable. As the price of petroleum increases, prices for agricultural chemicals will increase (Tyner and Taheripour 2008). As prices increase, less fertilizer will be used, resulting in greater soil degradation and declining yield of agriculture (Scherr 2003).
- Use of genetically modified crops can increase yield (Le 2005). However increasing yield requires an energy tradeoff against ability to resist pests, and compete with weeds for nutrients and water. Genetic engineering does not increase the photosynthetic energy available to plants. It just redirects it (Jordan 2002).
- Use of genetically modified crops can put the farmer under the control of international corporations that own patents on the crops. As use of these crops spreads, the world's food supply becomes increasingly dependent on the economic goals of a handful of corporations and not on the needs and desires of consumers (Then 2000).

Box 2.7

The name "green revolution" is misleading, because it implies agriculture in harmony with nature. Instead, it means agriculture in a war with nature. It is a war that is still going on, with the energy subsidies of the green revolution giving it temporary advantages, but with nature fighting back at periodic intervals.

- The simple, vertically integrated economic food chain common in industrial agriculture can be highly susceptible to disturbances (Striffler 2005). For example, terrorists can disrupt the world's food supply by introducing pathogens and other biological weapons into a few key links in the food chain (Parker 2002; FAO 2008).
- Industrial agriculture is leading to a depletion of water resources. Irrigation in central Georgia has increased from 5 % of the acreage 31 years ago to 60 % today (Crenshaw 2012).
- Prevalence of monocultures in industrial food production systems leads to loss of genetic diversity (Soule and Piper 1992). Low genetic diversity increases the risk of disease or insect outbreak (Real 1996).
- Inorganic nitrogen leached from fertilizers spread on agricultural fields enters waterways and causes hypoxia that results in kills of fish, crustaceans and other marine life (Rabalais et al. 2002; Diaz and Rosenberg 2008).
- Nitrogen volatilized from fertilizers enters the troposphere and poses direct health threats to humans and causes substantial losses in agricultural production (Galloway et al. 2008).
- Animal waste lagoons and sprayfields near aquatic environments can significantly degrade water quality and endanger health (Mallin 2000).
- Overuse of antibiotics in the livestock industry has resulted in increasing resistance of pathogens (Mlot 2000).
- Increasing resistance of weeds to a single type of herbicide is resulting in the need for an expensive series of herbicides (Service 2007).
- Use of pesticides kills beneficial insects that can help control pest species (Soule and Piper 1992).
- Plowing and other methods of tillage that disrupt the structure of the soil result in erosion that is destroying croplands (McNeill and Winiwarter 2004) (Box 2.7).

2.9.3 A Tale of Two Botanies

Amory Lovins is considered by many to be the world's leading authority on energy issues, and how they relate to economic, environmental, developmental, and security concerns. In 1999, the International Union of Biological Sciences held its 16th International Botanical Congress in St. Louis. Appalled by the state of agriculture and the rapidly spreading use of biologically uninformed genetic modification in agriculture, Lovins (1999) wrote an article for the St. Louis Post Dispatch called "A Tale of Two Botanies" , in which he said "In the name of feeding a growing human population, the process of biological evolution is being transformed. A St. Louis firm is practicing a completely different kind of botany which, in the Cartesian tradition of reducing complex wholes to simple parts, strives to alter isolated genes while disregarding the interactive totality of ecosystems. Seeking what Sir Francis Bacon called the enlarging of the bounds of Human Empire, to the effecting of all things possible, its ambition is to replace nature's wisdom with people's cleverness; to treat nature not as a model and mentor, but as a set of limits to be evaded when inconvenient; not to study nature but to restructure it."

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Chapter 3
Political and Economic Challenges to Creating a Sustainable Agriculture

Abstract There are many barriers that stand in the way of established conventional farmers who want to adopt sustainable techniques, and young people who want to become sustainable farmers. For established farmers, barriers include:

- Concerns about transition costs
- Termination of government subsidies
- Lack of tariffs that protect production
- Lack of knowledge about sustainable techniques
- Need to break ties with conventional farmers
- Loss of investment in conventional equipment
- Need to increase labor force
- Family is risk-averse

For young people who want to farm sustainably, barriers include:

- Regulations that are designed for industrial farmers
- Price of Land
- Leasing land is risky – improvements might increase lease payments.
- Marketing. Raising produce leaves little time for marketing
- Competition from other young organic growers
- Getting a loan
- Help from Colleges of Agriculture has limited applicability. Very little local research
- Need for specialization to develop a niche market

Barriers that affect both types of farmers include:

- Vested interests that support industrial agriculture
- Reductionistic science that does not answer sustainability questions
- Misdirected government policies that subsidize unsustainable farming
- Failure of the economic system to recognize environmental services
- The law of supply and demand
- The discount rate discourages farmers from investing in sustainability

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- The abundance of resources encourages people to waste them
- Attitude that nature needs to be conquered

Keywords Barriers to sustainable agriculture • Challenges for sustainable agriculture • Agricultural tariffs • Agricultural subsidies • Economics and sustainable agriculture

3.1 Introduction

The history of agriculture has shown that energy in agricultural systems has been used inefficiently and unsustainably. It might seem that those concerned with agriculture, from farmers to tribal chiefs to kings and governments might have learned something about increasing efficiency during several thousand years of experience. Perhaps they did. However, their survival depended upon economic growth, which in turn depended on using energy to maximize power, not efficiency. Maximizing power was the key to winning the competition for land, resources, and women. In maximizing power, a certain amount of energy input is wasted (Odum and Pinkerton 1955). It was this waste of power that caused agriculture to become unsustainable.

Today, many farmers understand that energy intensive agriculture is the cause of unsustainability. Despite the advantages of techniques for making agriculture more sustainable, there are powerful social, economic and political barriers that a farmer faces in order to accomplish a transition to ecologically sustainable agriculture. To illustrate, let's consider two farmers, Caleb and Nate, fictional composites of many real life farmers on two opposing ends of an economic and cultural spectrum.

3.2 Dilemmas of Two Farmers

Caleb. Caleb is 55 years old, and farms cotton on 2,000 acres that he inherited from his parents in South Georgia. He would like to pass the farm down to his children, but is concerned with the future of conventionally farmed monocultures. He sees many problems – unstable markets, increased foreign competition, increasing weed resistance to herbicides, water scarcity for irrigation, pollution due to overuse of industrial fertilizers, increasing costs of fertilizers and diesel fuel, loss of young people from the community as they see little future in agriculture, a feeling of sadness due to destruction by herbicides of native plants that used to provide cover for the quail he loves to hunt, erosion due to what he perceives as increasing severity of storms. He realizes that converting his annually plowed cotton fields to perennial pasture land would alleviate many of his concerns. Caleb has heard that there is a niche market for grass fed beef, that will bring a higher market price than grain fed beef raised in feedlots. But he worries about barriers that prevent him from switching.

Some of those barriers include:

- General economic concerns. – unsure of market, unsure of transition costs.
- Subsidies. Caleb is receiving substantial subsidy from the government, to encourage him to compete against foreign cotton growers who produce at a lower price because of lower wages. If he switched, he would lose these subsidies.
- Tariffs. Although Caleb is a staunch believer in the free market, he favors tariffs. He is worried that if he switches to beef, the lack of a tariff on foreign beef would depress the price that he could get for his cattle.
- Ability to access information on sustainable agriculture is limited.
- Cultural barriers. Caleb is afraid that other farmers in his church would ridicule him for being an "environmentalist".
- Investment. Caleb has invested a lot of cash in equipment specialized for cotton farming. The cotton harvester alone cost him $500,000. He could only sell it at a big loss.
- Labor. Caleb's cotton farm is highly mechanized, and he runs the whole operation from planting through harvesting with only the help from his two sons. Sustainable agriculture is labor intensive, and Caleb would have to hire a crew, and then pay them health benefits, social security, and other benefits.
- Family is risk-averse.

Nate. Nate is 23 years old and a recent University graduate, where he majored in Agricultural Business. He grew up in the suburbs of Atlanta, but his uncle had a small farm in a valley of North Georgia where he spent summers helping with feeding the chickens and learning how to slaughter, clean, and smoke a pig. Nate was disappointed in his major, because of its single minded focus on increasing yield and profitability. He happened to take an ecology course as an elective, and learned about organic farming and sustainability. He decided that after graduation, he would do an internship on an organic farm, and then strike out on his own.

Some of the barriers that prevent Nate from being successful include:

- Regulations. Nate wants to raise free ranging pigs. However he would have to bring the pigs to a USDA approved slaughterhouse, but they are few and far between. He also would like to raise poultry for eggs, but to do that, he needs a "Candler's License".
- Price of Land. Nate needs to have a farm close to a major population center where there would be a good market, but the only land within the price range for farmers is far from metropolitan areas.
- Problems with Leasing land. Nate is wary of leasing land, because he sees himself working hard to improve the land, only to have his lease payments increased.
- Marketing. Raising produce is a full time job, and leaves little time for going to farmer's markets, or organizing a "Community Supported Agriculture".
- Competition from other young organic growers, already in the marketplace.
- Getting a loan. Much of the general public still equates organic farming with subsistence agriculture as practiced before WWII.
- Help from Colleges of Agriculture, and from the web, has limited applicability. Very little local research.
- Need for specialization.

3.3 The Large Scale Commodity Farmer

Let's first look at the barriers that concern Caleb.

3.3.1 Subsidies

In the U.S., a subsidy farm bill was passed during the Great Depression, to keep small farmers afloat and ensure a food supply for Americans (Howard 2008). Subsidies, however, outlive their usefulness, when their goal has been accomplished. Feeding this nation is no longer a problem. The problem has been solved. There is plenty of food. According to a new report from the Natural Resources Defense Council (NRDC 2012), 40 % of food in the United States is wasted. The average American throws away 33 lb of food every month. It costs $750 million just to dispose of all the wasted food, and food waste accounts for about 4 % of total U.S. oil consumption. Nevertheless, subsidies to producers of corn, wheat, rice, soybeans and cotton have continued, because of the well organized lobby of the small segment of the population that benefits from the subsidies. These subsidies are distortions to the free market. Subsidies hide the real cost of agricultural production, and make profitability more difficult for farmers using more ecologically sustainable methods. The difficulty in changing this system lies in the effectiveness of the lobbying efforts of industrial agricultural corporations. Their control over production and marketing of farm chemicals, and genetically modified crops has been an important factor in the evolution of the industrialized bio-tech vertical system, and they resist efforts to change (Striffler 2005; Pollan 2006) (Box 3.1).

3.3.1.1 Is a Completely Free Market the Answer?

The effect of farm bills has been to promote huge industrial monocultures that can exist only with massive inputs of synthetic chemicals (Anon 2008a). The federal government spends billions subsidizing mega farms. Opponents of the farm subsidy system have found an unlikely ally in Dennis Avery, author of a book called "Saving the Planet with Pesticides and Plastic" (Avery 2000). He complained (in the year 2000), about Congress's gift of $6 billion in cash to farmers to aid them because of low world farm prices. "*What Congress didn't*

Box 3.1

In Chap. 1, subsidies were described in terms of energy. Here subsidies are described in terms of dollars. From the farmer's point of view, they are the same thing, because farmers use dollars to buy energy.

Box 3.2

When the "Freedom to Farm" act (the Federal Agriculture Improvement and Reform Act of 1996) was passed in 1996, many of the restrictions and production quotas were reduced or eliminated. Although farmers thought that this bill would give them the freedom to produce more and thus profit more, in reality it gave them freedom to produce more and profit less (Knutson et al. 1998). It's the law of supply and demand.

give", he said, *"was free trade in farm products, which is the only real solution to the farm price problem. Free trade would raise the world market's farm prices by about 25 to 35 percent. Free trade would allow export farmers to sell all the output they could cost-effectively produce at the higher prices. This would be worth perhaps $50 to $60 billion per year every year for as far as we can foresee."* Avery's complaint was that trade barriers by countries outside the U.S. reduced the amount of farm products that American farmers could sell abroad, resulting in a lower demand and a lower price, and that Congress does nothing about these barriers. Thirteen years later, things hadn't changed. The Wall Street Journal was still making the same complaint, and urging the end of regulatory barriers on both sides of the Atlantic (Wall Street Journal 2013).

Could free trade solve the problem of agricultural sustainability? Clearly, there is a sustainability problem in agriculture, but the problem might not be solved by free market economics. Why not? Because of the competition to produce food at the lowest possible price drives farmers to use practices that counteract sustainability (Box 3.2). There must be an incentive to use sustainable management techniques, and a completely free market encourages farmers to take short cuts by "externalizing" environmental costs (Box 3.3).

3.3.2 Tariffs

Tariffs are an instrument of government policy to protect the farmers of a country from "unfair" competition from farmers in another country. For example, Brazil has threatened to impose a 100 % tariff on North American cotton, because of the subsidies than American cotton farmers receive (BBC News 2012). Those subsidies enable farmers to sell their cotton abroad at below-market prices. But do Brazilian cotton farmers use unsustainable practices such as spraying with toxic pesticides, while American farmers use integrated pest management techniques? If that is the case, then our subsidies are justified because the Brazilians are being "unfair". On the other hand, if tariffs protect American cotton farmers from competition by Egyptian farmers that raise their crop along the banks of the Nile where cotton is better adapted, then the tariffs are undesirable from the viewpoint of sustainability (Box 3.4).

Box 3.3

There are incentives for farmers to grow crops sustainably: – it is willingness of consumers to pay a higher price for foods labeled "organic". (Although "organic" does not necessarily mean "sustainable.") Sustainability practices are being encouraged by the U.S. Dept. of Agriculture, through programs of Natural Resource Conservation Service, and through grants from the Sustainable Agriculture, Research and Education Program. The National Institute of Food and Agriculture established by the Farm Bill of 2008 may help promote agriculture that is less dependent on petroleum-derived chemicals (Kelhart 2008).

Box 3.4

Tariffs are the flip side of subsidies. Subsidies give local growers an advantage over foreign producers. Tariffs protect local growers from the advantages that foreign competitors may have.

3.3.3 Cultural/Mindset

Part of the resistance to sustainable agriculture in the U.S. results from a wrongful belief that it is equivalent to the agriculture prevalent in the U.S. at the time of the great depression and the dust bowl. The biggest difference now is the use of conservation tillage in sustainable agriculture.

Conservation tillage looks different from conventional-tillage, and it takes some getting used to. In the lobby of Conner Hall, the location of the Dean of the College of Agriculture at the University of Georgia, there is a mural commemorating a Georgia farmer cultivating row crops. The most striking thing about the picture is that the rows are "clean", that is, there is no residue that looks like debris. The field is pure red clay soil. That is what Georgia farmers are used to. Fields that are planted using conservation tillage do not look like that. The residue of cover crop that covers the soil looks, to the untutored eye, as being "dirty" .

The smell of fresh-turned earth is another factor. In a presentation about conversion to sustainable agriculture through the use of conservation tillage, Andy Page, district conservationist from Perry, Georgia said: *"The biggest obstacle to using conservation-tillage is the mindset of growers. A lot of old-timers like to smell that sweet smell you get whenever you turn the soil."* (Hollis 2012) (Box 3.5).

Box 3.5

Many people believe that farming , as practiced in the past, is a way of life that epitomizes American values.

3.3.4 Social

The trend away from smaller family farms to larger corporate owned farms has resulted in economic stagnation of many rural areas. The mechanistic and simplistic approach of industrial agriculture requires fewer farmers and farm workers, and often less skilled workers. While the change in agriculture from labor intensive to energy intensive began with the availability of tractors, the big change occurred after WWII with the "Green Revolution". There was little opportunity for most of the young people in farm towns. The migration of young people from farming communities left much of the countryside without a population base and economic infrastructure that is essential to establishing agriculture in a more sustainable mode. The social and economic survival of farm communities hinges on the willingness of residents to participate in, and to lead community organizations, -farm, religious, civic, youth, and professional (Goreham et al. 1999).

3.3.5 Transition Costs

An immediate and complete change from industrial to sustainable agriculture is often not practical. A conversion period from conventional to organic almost invariably leads to a temporary decline in yields (Pimentel et al. 2005). For fields in transition from conventional to organic, it may take a number of years for levels of production to regain their previous output, because of the time required to build up a healthy topsoil (Jacobsen 2008). In the case of Caleb, it would take several years to build up enough soil organic matter in a pasture to graze a herd of sustainable cattle. To soften the short-term economic sacrifice, farmers highly invested in industrial agriculture but interested in changing to organic techniques could convert just a portion of their land each year.

3.3.6 Lack of Evidence

The resistance to techniques of sustainable agriculture is due in part to the lack of on-farm trials and demonstrations. Farmers "want to see it work prior to adopting the practice. Farmers lack good tests of what practices will work best on their farm. There are not enough on-farm trials – the time that research is done is years before any on farm trials and demos are initiated. Further, sometimes the research stays in the science publications and is not put into the farmers hands." Fazio et al. (2010).

3.3.7 Risk Aversion

Switching from conventional agriculture to sustainable agriculture is almost like changing careers when you are in your 50s. It's a risk. Why give up something that you have got for something you know little about, when it may not pan out? That's what Caleb's family might ask.

3.4 The Small Scale Organic Farmer

Now Let's look at the barriers that face Nate.

3.4.1 Regulations

Government regulations on the processing and selling of food were promoted to protect public health from lack of sanitation in the food processing industry. The release of Upton Sinclair's 1906 book "The Jungle" about unsanitary conditions in the meat packing industry caused a public outcry that resulted in regulations governing not only meat packing, but other food processing industries as well (Adler 2012). The regulations devised to protect consumers were well intentioned, but an unanticipated outcome has been to limit competition. Regulations have instead benefited more the behemoth food processing industries and contributed to the consolidation of the food industry in the hands of very few corporations who then form "vertically integrated food systems" in which they can dictate every aspect of a farming operation. Because of their size, they can afford specialized personnel to deal with regulations, but regulations restrict potential small scale farmers from entering the field.

3.4.1.1 How USDA Regulations Hurt Small Sustainable Farmers

There is a U.S. Dept. of Agriculture regulation that all beef and pork sold to the public must be slaughtered in a USDA approved and inspected abattoir. This is a sensible regulation, considering the potential for contamination and disease-causing bacteria that could spread when hundreds of animals are butchered in a confined slaughter house. The danger is especially high when animals are raised in a Concentrated Animal Feeding Operation. However, the rule also applies to small farms and traditional farms, where hogs are slaughtered as they have been for hundreds of years.

At Spring Valley Ecofarm we have a passel of about 20 hogs that graze in a secondary forest surrounded only by electric fence. Occasionally in the summer we move them to a corn field, where they graze happily among the stalks and weeds. This is a humane way to raise animals, and it is also sustainable in that it is energy efficient. Fuels are not spent manufacturing pig feed, nor in transporting it from the factory to the farm. And the pig manure fertilizes the soil, so fewer nutrients are needed next year for the corn. We also slaughter the hogs right here on the farm, and either cure them, then smoke them in our 1917 pig smokehouse, or freeze the meat for later consumption. Our problem is that we cannot sell the smoked or frozen meat to local restaurants, even though there is a big demand for "pastured pigs". The nearest USDA approved slaughter house is a 2-hour drive away, and the fuel and time involved for just a few pigs would make the effort a money-losing operation.

For years, Joel Salatin of Polyface farms in the Shenandoah Valley of Virginia has been on a crusade to change the regulations to a common sense standard so that small and beginning organic farmers have an opportunity to raise and sell beef, hogs, and poultry that are raised sustainably. No luck so far, but this could be an issue for non-profit organizations dedicated to helping small organic farmers. In some regions of the country, entrepreneurs have found a way to avoid the problem of hauling their livestock to distant slaughterhouses. In the Pacific Northwest and the Northeast, there are a few mobile "red meat" slaughterhouses – 53-foot tractor-trailers with a federal inspector on board. Farmers with livestock to be slaughtered and packaged can contact the mobile slaughterhouse to find out when it is scheduled to be in their area (Weigl 2010).

Egg producers also face a regulatory problem. Egg producers in Georgia who want to sell their eggs at a farmers' market or to individuals are now required to have and Egg Candling Certificate. The term candling is used because candles were first used as the light source to observe the inside of eggs. The Georgia egg Law requires an individual to demonstrate to the satisfaction of the Food Safety Division of the Georgia Department of Agriculture, the capability and qualifications as an egg candler and grader in order to receive the Egg Candling Certificate (Anon 2008b). Does this law protect the public, or the industrial chicken producers?.

Selling birds for meat poses a similar problem. For years, farmers have followed the federal law that allows them to slaughter up to 1,000 birds a year on their farm if they didn't have a building for slaughtering on their property. In North Carolina, several entrepreneurs have built mobile chicken slaughterhouses, that enable them to service farmers over a wide area. However, such slaughterhouses are not the same as a abattoir with a federal USDA inspector aboard, and some restaurants and farmer's markets will not sell poultry that is not USDA certified.

3.4.2 Financing

While a lawyer has to pass a bar exam in order to practice law, and a beautician must be licensed in many states to be a hairdresser, anyone who feels like it can be a

Box 3.6

Organizations such as Land for Good (Landforgood 2009) have begun to address this problem by facilitating information exchange between landowners with idle land and potential organic farmers who are looking for land to cultivate.

farmer, or at least try to be one. There are no entrance barriers nor regulations to starting a farm (other than zoning regulations near towns and cities). Farming appeals to people that like to be independent. The idea of farming inspires young people who don't want to become a pawn on a corporate ladder. It seems romantic, up at daylight to help a cow give birth, and so on. And organic farming might seem a way to get into agriculture, because initial investment is small. Or so many think.

No one would think of trying to start a business to support a family accustomed to middle class living with an investment of a few thousand dollars. . The hard truth is that if you want to start a farm that will net you $50,000 a year, you need to start with an investment of half a million. Few banks are willing to lend half a million to an inexperienced young farmer. But perhaps by working a few years as an intern or hired hand, a young person can save up 10,000 or 20,000 dollars. The first problem he or she will encounter is access to land.

3.4.3 Access to Land

There are significant numbers of urbanites like Nate who aspire to become organic farmers, but lack the access to the land and capital necessary to begin. Good farmland in the South may go for as little as $4,000 per acre, but a reliable source of water will add to the price. Such land however, is usually distant from urban centers with farmer's markets, where organic produce can be sold. Ideally, the farm should be close to metropolitan areas, where there are vibrant farmer's markets and organic restaurants. The closer a farm to such centers, the higher the price for land.

An option for those who can't afford to buy is to lease land. However, this is not a good option for farmers who want to build a sustainable farm. All the time, effort, and expense to build up the soil organic matter could be wasted if the landlord cancels the lease (Box 3.6).

3.4.4 Competition

The problem of price competition is, and always has been, the bane of the independent farmer. The only way Nate can sell his tomatoes at the farmer's market is to offer a price that is lower than that of the farmer in the next booth. And that will start

Box 3.7

It is as challenging for a farmer to master the production of two different types of crops as it is for a musician to master two different types of instruments – the violin and the trumpet for example, or even the violin and the cello.

a price war. Vertically integrated agribusinesses that control food supply from field production to consumer delivery are insulated from this problem, because of their power to control prices at all levels.

3.4.4.1 Specialization and Quality Control

One way for small farmers to avoid the problem of price competition is to develop a highly specialized niche market. The trick is to choose something that is not common, and also that is highly specialized. A farmer that I met in North Georgia had chosen micro-greens as a niche specialty. Microgreens are the very young shoots of vegetables such as arugula that are popular for salads in upscale restaurants. The problem with microgreens is that they are relatively easy to grow, and no sooner had he developed a market, than a neighbor began competing to get a share of this lucrative enterprise. In contrast, Nolan Kennedy, of Covenant Valley Farms near Athens Georgia produces a type of honey that not only is uncommon, but also requires a lot of effort and skill. Kennedy goes to the effort of moving his hives to the mountains of Northeast Georgia when the sourwood trees are in bloom. He says their sourwood honey is viewed as the premium honey in the Southeast and one of the best in the world.

Specialization is necessary in order to produce the quality of produce that consumers demand. Consumers demand "perfect" products such as blemish-free applies. Farmers cannot compete in the marketplace if they offer sustainably produced but blemished apples, because consumers will not buy them. Quality control is a necessity for small farmers. But a single farmer cannot know all there is to know about optimizing quantity and quality of a wide variety of vegetables, grains, fruits, poultry, and livestock (Box 3.7). So to compete in the market, he must specialize. But specialization defeats the very tenant of sustainability. Sustainability demands diversity, not only to ensure efficiency of nutrient cycling and energy use, but also to buffer economic changes in the market (Box 3.8).

Raising crops and animals on the same farm is energy efficient and sustainable ecologically. However, increasing specialization of farm products demands that the farmer concentrate on one type of crop. The farmer who specializes can produce more economically than the farmer who is a generalist. ***A basic problem of agricultural sustainability is the conflict between the ecological efficiency of a generalist farmer, and the economic efficiency of a specialist.***

Box 3.8

Specialization in grain crops often is not feasible for new farmers, because corn, wheat and soybeans must be grown on a large scale for the farm to be profitable. Farmland is often too expensive for new farmers to specialize in grains.

3.4.5 Marketing

It is extremely difficult for a small, beginning organic farmer to devote sufficient time to marketing, when the day to day requirements of managing the farm takes up most of his or her time. There are several approaches taken by small organic growers to deal with this problem.

- Athens Locally Grown is a website-based "clearing house" for producers and consumers of organic products. Before each weekend, they inform Locally Grown of their produce that is ready to harvest. Each Sunday evening, a list of available products is sent by e-mail to everyone with an account. Customers must place their order for the week any time after that email goes out, but no later than Tuesday at 8:00 p.m. Orders are placed on the Locally Grown website. Growers receive their orders that same night and harvest on Wednesday and Thursday. Locally Grown maintains quality control, and standardizes prices.
- Community Supported Agriculture is a system used by many small farmers to sell their products. At the beginning of each growing system, the growers sell "shares" to members of the local community who want fresh food and want to support environmentally benign agriculture. Then throughout the season, weekly dividends are given to shareholders, the dividends being whatever is ripe that particular week.
- Food Hubs are a type of farmers' cooperative that serves small scale producers who find that they have too much produce for a farmer's market, but not enough to meet the needs of restaurants, schools, or grocery stores. Food hubs pull together five or more small and medium sized farms so they can pool their products to fill large orders. As of 2012, there are eight in Georgia, seven private businesses, and one farmers' cooperative (Georgia News 2012).
- Branding a product with a label that identifies the source-farm is an approach that allows buyers in a competitive marketplace to recognize a product that they know has higher quality.

3.4.6 Information

Farmers are frequently resistant to change because of lack of information about sustainable agriculture. In a survey of farmers in South Georgia, Ellis and Gaskin (2008) found that conventional fruit and vegetable farmers expressed significant interests in a wide array of sustainable agriculture practices, and expressed a willingness to consider adoption, especially if market data demonstrates increased economic opportunities. However, they reported that only 30 % of respondents agreed that clear/reliable information about sustainable agriculture is readily available, and there still appears to be widespread confusion regarding how sustainable agriculture is defined. Many respondents indicated that they rely on extension agents for sustainable agriculture information. Because extension agents often do not feel that adequate research is available to support recommendations for sustainable agriculture (particularly for small-scale farms) there appears to be an information gap between information demands and information availability.

Nate doesn't have to worry about getting information on how to grow vegetables, control insects, and fight disease. His problem is which information to use. There are dozens, if not more companies that sell products for organic farming, along with instructions on how to use them. Almost every State College of Agriculture has web pages that help farmers identify insect and disease problems common to that state. But these recommendations are sometimes too general to apply to local situations. Land grant universities and the Extension system, the traditional entities for the dissemination of innovation information, still lack capacity to tailor recommendations to the particular needs of an individual small-scale beginning farmer. Resource limited farmers often need to solve problems by substituting locally adapted innovations in place of more capital intensive solutions commonly utilized in conventional agriculture.

Local food system communities have largely assumed the responsibility for developing innovative solutions to production and marketing challenges. Local food systems are being posited as a new organizing paradigm for addressing problems of small scale producers by examining relationships that span the environment, the economy and the culture. A community of producers in Rabun and Habersham Counties in North Georgia is representative of an emerging local food system in a rural agricultural region (Ellis 2012).

3.5 Some Intractable Barriers

The barriers faced by Caleb and Nate are not intractable. Regulations can be changed, and exemptions granted. Subsidies can be eliminated. Mobile slaughter houses can be built.

However, there are several some barriers that steadfastly resist change.

3.5.1 Vested Interests

Vested interests include the existing infrastructure that supports industrial agriculture. This includes factories that manufacture agricultural machinery and chemicals,

Box 3.9

Industrialized meat production is an example of vested interests, and the type of response offered to criticism. For years, the public health community has warned about the risks of intensive livestock confinement. The American Public Health Association has, for years, called for a moratorium on concentrated animal feeding operations. The Pew Commission on Industrial Farm Animal Production (Pew Commission 2013) concluded that industrialized animal agriculture posed "unacceptable" risks to public health. A key recommendation was the phasing out of extreme confinement practices such as gestation crates, which "induce high levels of stress in the animals and threaten their health, which in turn may threaten human health."

In response, the pork industry appeared more interested in changing the name of swine flu than in changing the practices that are exacerbating it. An editorial in one leading U.S. agribusiness publication responded this way: "FAO [Food and Agriculture Organization of the United Nations] claims to use scientists to generate its reports, but I wonder if those scientists don't resemble a bearded man living in a cave in Pakistan who wants the U.S. on its knees."

(CNN News 2012).

the railroads and ships that transport agricultural products, the businesses that process the food, the supermarkets that deliver the food to the consumer, and the trucks that deliver the food to the markets. This infrastructure has a tremendous economic value, and cannot just be discarded. The businessmen that profit from this infrastructure have tremendous political pull that prevents change and innovation (Box 3.9).

3.5.2 Reductionistic Science

Much of mainstream science fails to answer questions about sustainability because it is too focused on reductionism. Science that devotes all its energy to rearranging DNA cannot help agriculture that is impacted by ecological, social, cultural, economic, and political factors. More on this is in Chap. 8.

3.5.3 Misdirected Government Policies

Policies that subsidize gross production (total yield) instead of net production (yield minus costs of production) are the opposite of sustainable policies. Subsidizing biofuels to increase energy output of a nation makes no sense if the energy costs of producing the biofuel are greater than the energy gained through the its use.

Box 3.10

How do we incorporate the services of nature into the economic system? Externalities such as pollution from a CAFO must now be internalized by industry accountants. If economists can do this, they can go further and recognize the services of nature. If economists were to devote the same amount of effort to this challenge as they do to increasing gross economic output, then maybe the services of nature would be given a place in our economy.

3.5.4 Failure of the Economic System

An economic system that fails to recognize the value of natural capital that can help ensure sustainability is a failed economic system. When an economic system puts no value on services of nature, those services will be wasted or destroyed (Box 3.10).

3.5.5 The Law of Supply and Demand

Family farms are in a no-win situation. The only way small farms can increase their income is to increase production. But increased production results in a greater supply, which drives prices down.

3.5.6 A Short-Term Economic Horizon

Why is the economic horizon – the horizon beyond which people and businesses consider that investments must be recovered – so short?

- The Discount Rate. People value something in the present much more than they do in the future. They know that they may die tomorrow, or that banks may go broke, or that promises for the future will not be fulfilled. Therefore, use it up now.
- Some farmers are undercapitalized. Sustainable farming requires an investment that will sustain production over the long term.
- Agriculture is a very competitive occupation. Like any business, it is important to get big fast, and to commandeer resources before others have the chance. The quickest way to get big fast is to exploit resources, not steward them. In terms of systems analysis, short-term success is dependent more on maximizing power than on using energy efficiently (Box 3.11).
- Agribusiness is indebted to its share holders. The pressure on corporations is to raise the price of the stocks so that shareholders can make a quick profit on the stock exchange. Executives worried about their job next quarter will choose quick

Box 3.11

Both strategies – maximizing power and conserving energy can be found in the plant kingdom. Annual plants and early successional species maximize power. They invest all their energy in getting big fast, but they do not last very long. Late successional plants and "climax" species use energy efficiently to maximize sustainability. They have a long life.

profits that raise the price of their company's shares over long-term stability of the resource that provides the profits.

- On the frontier, short-term exploitation was a matter of life or death for some pioneers. In many regions of the world, this is still the condition.
- The urge to kill the goose that lays the golden eggs is sometimes irresistible.

3.5.7 The Abundance of Resources

The abundance of fresh water. As the Ogallala Aquifer case demonstrates in Sect. 3.5.9, as long as fresh water is abundant, it will not be conserved by most farmers. But soon it will not be abundant, and at that time, water conservation will begin.

The abundance of cheap energy. As long as fossil fuel energy is abundant, it will be cheap, and it will not be conserved. Farmers need to win the competition to produce more. But soon energy will not be abundant, and then conservation will begin.

3.5.8 Attitude Toward Nature

Humans have placed themselves above nature, above the ecosystems we seek to control. We assume that we are not governed by the natural laws that have evolved over millions of years. We assume that we can control nature. But humans, we now know, are inseparably embedded in the ecosystems of which they form part. Maybe we can control nature for a while with plastics and pesticides, but what we forget is that in all systems there is feedback. Insects will evolve resistance to insecticides. Plastics will pollute the environment. We can achieve sustainability only when we understand that we are an integrated part of the cybernetic agricultural ecosystem, and that we must work *with*, not *against* nature.

3.5.8.1 Are Farmers Environmentalists?

Are farmers environmentalists? Some are. Some farmers believe that ecosystems should be managed in ways that do not destroy the integrity of the systems, through pollution, or through exploitation that destroys their structure and function. They understand the value of maintaining soil organic matter, beneficial insects, buffer strips along streams, and of using plants and animals that are adapted to the climate and soil of their farm. These farmers understand that industrial agriculture cannot be maintained without the backup of a fallible technology, and without the federal insurance when fallible technology is not adequate to replace aquifers that have gone dry and soils that have eroded, and when pests have evolved resistance to pesticides.

There are many farmers in the Southeast, as well as the nation and the world for that matter, that are adopting an alternative approach to agriculture. Why are they doing it? They value their independence. They want to be farmers, and they don't consider industrial agriculture to be farming. Factory farms to these people represent much of what is wrong with the technological age – an artificial life that is dependent upon fossil fuels whose mining and drilling is environmentally harmful at the local scale, climatically harmful at the global scale, and socially and economically harmful wherever conflicts occur over control of resources. They resent the "vertically integrated" system employed by much of agribusiness that stifles entrepreneurship and concentrates wealth in the hands of a few corporate executives that live far from the farms owned by their company, and have little understanding of the effort and understanding that it takes to make a living as a real farmer. These farmers want a connection to the earth, and to the source of life. To drive a team of horses is to be one with the team, and to feel the satisfaction that comes with accomplishment. To put a seed in the ground and witness the emergence of a flower, fruit, or vegetable is akin to seeing a miracle. To behold the birth of a calf, a lamb, or even a dozen piglets is to realize that the cycle of life is something that no scientist can orchestrate. And to slaughter your own hog and smoke it in your smokehouse brings a reward that cannot be duplicated in the delicatessen of a supermarket.

3.5.9 The Tragedy of the Commons

The idea behind the Tragedy of the Commons, played out in Chap. 2 by Edwin, Anselm, and other Medieval European farmers, has been criticized because in small villages where everyone knows everyone else, social pressure prevents individuals from overusing commonly owned resources. However, society today in the U.S. is highly dispersed, and social control over use of common resources is largely ineffective. A striking example is the use of water from the Ogallala Aquifer that supplies water for the farmers in the Great Plains, the "bread basket" of the United States. Farmers have been using the Ogallala for irrigation since the 1950s. Today their wells can pump hundreds of gallons a minute onto their fields. Irrigation booms a half mile long spin around a fixed water pipe, creating huge circles of corn and soybeans. Extrapolation of the current depletion rate suggests that 35 % of the southern High Plains will be unable to support irrigation within the next 30 years (Scanlon et al. 2012). While farmers generally agree that cuts are needed, the details of how to do it have been contentious. The High Plains Water Conservation District which stretches across the Texas Panhandle, started for the first time limiting how much farmers can pump. The problem is, the limits are voluntary. In some places farmers conserve water, but across the road, others do not (Peters 2012).

3.5.10 Irrational Exuberance

Joseph Stanislaw, a senior energy adviser to Deloitte LLP said in the December 3rd edition of the Wall Street Journal, "There was enormous irrational exuberance for global shale development. Then the industry ran into reality. Global shale will happen and when it does begin, it will take off with the same force we've seen in the U.S." The reality that Stanislaw was talking about was the technical difficulties of drilling. But recent new advances in drilling technology, say advocates, will give us energy to sustain the economy for decades into the future. One advance is an improvement in fracturing techniques that gives access to tremendous amounts of gas locked in shale rock. Another is access to large reserves of oil sands or, more technically, bituminous sands that are saturated with a dense and viscous form of petroleum.

The energy from these sources, however, will not be cheap because of the severe environmental impacts resulting from extracting, processing, and burning these fuels. Water used in the fracking (fracturing) process to extract shale gas has the potential to contaminate ground water, and shale gas emits a large amount of methane, a potent greenhouse gas. Oil sands require tremendous quantities of water during separation of the oil and the sand, and heavy metals naturally present in oil sands can be concentrated during extraction. And then there is the question of whether the carbon dioxide that enters the atmosphere from burning of fossil fuels causes climate change such as global warming and increased severity of storms.

Claims that shale gas and oil sands can solve our energy problems is reminiscent of the claims made for nuclear energy, before it was realized that the problems of disposing of radioactive waste causes environmental problems that are virtually unsolvable. The potential pollution problems caused by shale gas and oil sand have not yet been completely foreseen. That will occur only when the problem is upon us. The only thing for sure is that there will be unanticipated consequences, and that they will be costly.

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Chapter 4
Energetic Services of Nature that Increase Agricultural Sustainability

Abstract A research agenda for sustainable agriculture would mean looking at how natural systems have evolved to maintain productivity and sustainability, and applying that understanding to managing agricultural ecosystems . It means utilizing the services of nature to achieve long term sustainability goals. Services of nature can increase agricultural sustainability by decreasing the energy subsidies needed to drive agricultural production. Assigning services of nature a value in terms of energy or dollars helps the economic system recognize the benefit of conserving these services.

Services of nature that can contribute to agricultural sustainability include:

- Nutrient recycling by the community of soil micro-organisms
- Control of insect pests by beneficial insects
- Weed control though allelopathy
- Pollution abatement by buffer vegetation
- Pollination by birds, bees, bats
- Disease control through biodiversity
- Improving degraded soil by ants

A comparison of the energetic and economic value of services of nature with costs of industrial management suggests that using nature's services to solve management problems results in increases in sustainability.

Keywords Services of nature • Services of nature and agricultural sustainability • Energy values of nature's services • Economic values of nature's services • Energy efficient farming

4.1 Types of Value

Economists have placed three types of monetary value on the goods and services of an industrial economy. These values can also be used to classify services of nature (Farnworth et al. 1983).

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1. Market Value. This is the monetary value of a service of nature that can be determined by analyzing the energy content of the system that carries out the service and converting that energy value to a dollar value using market prices of energy.
2. Attributable or assignable values. This is the monetary value of a service of nature that can be calculated by determining the cost of carrying out the service in the absence of nature's services. For example, the value of the forests surrounding the Panama Canal for keeping silt out of the canal can be estimated by the costs of dredging the silt that might erode from deforested hills into the canal. In an energetic analysis, it would the amount of energy required to clean out the silt.
3. Intangible or non-assignable values. These are values too abstract for a monetary or energetic assignment. The beauty of an elk grazing in Yellowstone Park is an example.

4.2 Nutrient Recycling – A Market Value

4.2.1 The Service Rendered: Increasing the Efficiency of Nutrient Cycling

In conventional agriculture, fertilizer additions to the soil are sometimes lost through leaching, volatilization, and erosion. In natural ecosystems, most of the nutrients in the soil are recycled by the communities of soil organisms metabolizing energy derived from the soil organic matter. Adapting these services to agricultural systems increases the efficiency of nutrient cycling, and thus sustainability.

4.2.2 Source of the Service: Soil Organic Matter

Soil organic matter is a complex mixture of organic compounds derived from dead plant and animal material. In natural forest ecosystems, the soil organic matter is from leaf litter, decomposing logs and animal remains. Root exudates also contribute to the soil organic matter.

The microbial plants and animals of the soil community comprise only about 5 % of the soil organic matter (NRCS 1999), but it is this 5 % that improve the physical and chemical properties of soil with a resultant increase in nutrient cycling efficiency. In organic agricultural systems, the soil organic matter is from manure or compost added to the soil, and from roots and stems of crops that were left in or on the soil after harvest. Straw or wood chips used as mulch on the soil surface to smother weeds, and the residue of cover crops planted to protect the soil from erosion also contribute to soil organic matter.

Box 4.1

Compounds such as alkaloids cause some plants to be hallucinogenic for mammals as well as harmful to insects and bacteria. Hallucinogenic compounds are common in tropical plants, because insect pressure on plants is often high in the tropics.

Approximately half the weight of soil organic matter is reduced carbon, that is carbon which is combined into organic compounds that release energy when combusted, as in a forest fire, or when respired by microbes or higher animals. Soil carbon compounds can be classified in three pools, active, slow, and passive or sequestered, according to the accessibility of the carbon to decomposer organisms (Wander 2005). The active carbon pool consists of carbon in compounds that are soluble, such as sugars. These can be used immediately by soil microorganisms as a source of energy. The slow carbon pool consists of carbon in compounds such as lignified plant materials, and is only gradually available as an energy source. The passive pool consists of recalcitrant carbon, that is, carbon combined into more complex compounds some of which are very difficult for microbes to decompose. Many of the compounds such as alkaloids in the slow and passive pools are poisonous to insects, and thus defend plants against herbivory. These compounds also cause organic material to be resistant to breakdown by microbes (Box 4.1).

4.2.3 The Community of Soil Organisms

The community of soil organisms consists of all the organisms that live in the soil, from bacteria and fungi, through small mammals (Fig. 4.1).

4.2.3.1 Energy Flow Through the Soil Ecosystem

The soil ecosystem is a sub-system of an organic agricultural ecosystem. Energy flow through this larger ecosystem begins when the sun's energy is absorbed by chlorophyll in plant leaves, and causes carbon dioxide from the air to react with water in the leaves to produce simple sugars and the release of oxygen. The process is photosynthesis, and the chemical reaction, powered by the sun's energy, is:

$$6\,CO_2 + 6\,H_2O \xrightarrow{yields} C_6H_{12}O_6 + 6O_2$$

Light energy is converted to potential energy stored in carbohydrates, which then are used to synthesize the structure of the plant, or to be used in plant metabolism. The fruits, grains, or other harvested portions of the plant are the energy source for

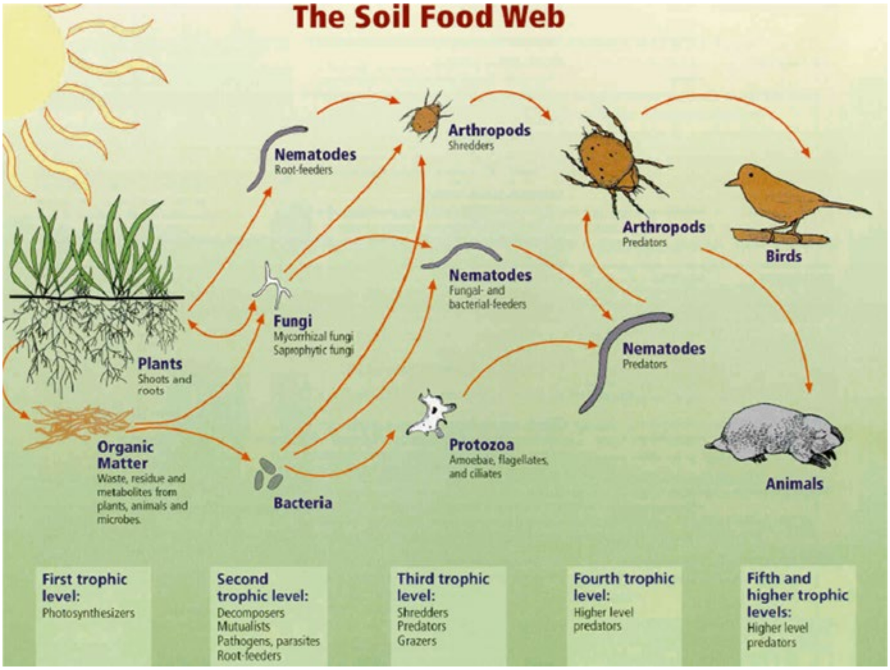

Fig. 4.1 A simplified version of the food chain in a soil community (Drawing by Nancy K. Marshall, Marshall Designs. Published in: Soil and Water Conservation Society (SWCS) 2000)

animals. The unharvested plant material becomes soil organic matter. The energy release that occurs when micro-organisms decompose the soil organic matter is an oxidation reaction, the reverse of photosynthesis. The process is called respiration, and the chemical reaction is:

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{yields} 6H_2O + 6CO_2$$

Figure 4.2 is a more complex flow diagram of the energy flow through the soil. As organisms at one level consume organisms of another level, energy flows from one trophic level to the next. A proportion of the pool of energy originally present in the soil organic matter is lost at each level due to respiration of the organisms, till at the top trophic level, all the energy has been dissipated, and the carbon that stored the energy has been returned to the atmosphere.

The actual flow of energy through the soil is even more complicated than shown in Fig. 4.2. Consider the flagellates in the third trophic level. Ciliates and amoebae consume most of the flagellates, but some of the flagellates can be decomposed by bacteria, in which case energy will flow from the third level back down to the second level. In addition, waste products egested by flagellates will be absorbed by bacteria. These type of “mini-cycles” occur throughout the soil community.

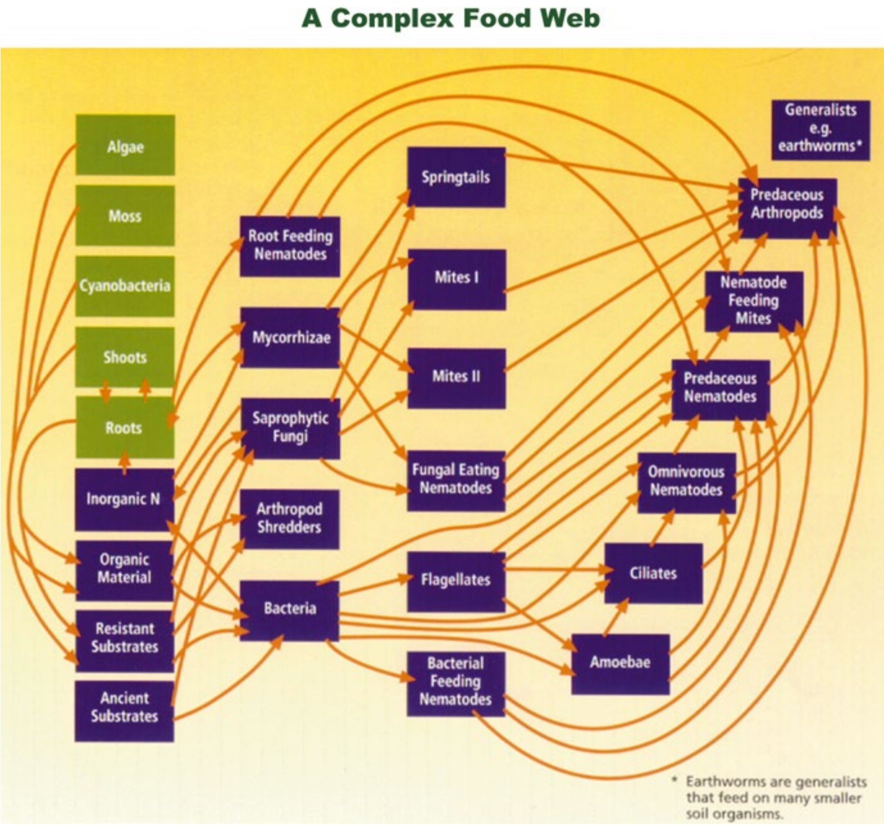

Fig. 4.2 A more complex flow diagram of energy through the soil (Drawing by Elaine Ingham and Andrew Moldenke. Published in: Soil and Water Conservation Society (SWCS) 2000)

If a farmer agitates and loosens the soil in his fields with equipment such as plows, discs, rototillers, harrows, sub-soilers, and cultivators, oxygen will infiltrate the soil. This stimulates bacterial activity, and the rate of decomposition at the lowest trophic level increases. Little or no energy is left for organisms at higher trophic levels (Box 4.2). The result is the disappearance of these organisms and the services that they perform. The key to sustainable farming is to minimize disturbance to the soil so that bacterial decomposition is slowed, and energy availability is assured for organisms at the higher trophic levels (Box 4.3).

Nutrients in the Soil Organic Matter

In contrast to energy, nutrients in the soil are not dissipated. Except for nitrogen and sulfur, they follow the same pathways as energy, but they are conserved. Respiration of the soil microorganisms burns up energy, but does not decrease the nutrient

Box 4.2

One of the exercises that I have students do during my class in organic agriculture is to measure the changes in soil respiration due to cultivation. Respiration rate is an indicator of how fast bacteria in the soil are burning up the soil organic matter. I fill several five-gallon buckets with soil, and let it compact for several months. Then the class measures the respiration (USDA 2012) in an undisturbed condition, and then again after simulating plowing, under both wet and dry conditions. The results show dramatically how respiration increases after plowing due to oxidation of the soil by the disturbance.

Box 4.3

In agricultural systems, decomposition sometimes must be promoted through active management. In Northern regions, the slow decomposition of organic matter due to cold weather early in the spring can delay the availability of nutrients to crops. Tilling speeds up decomposition and the release of nutrients. In the South, droughts can inhibit release of nutrients from soil organic matter.

content of the soil. Nutrients that the organisms excrete or egest are taken up by bacteria, or are exchanged on the surface of clay particles in the soil or on the surface of undecomposed soil organic matter. Nutrients held on clay surfaces are bound by a weak electrostatic charge in a process called ion exchange. These nutrients are easily displaced by hydrogen ions in the soil solution. The nutrients dissolve in the soil water, and then are available for uptake by the roots of plants. But during rainstorms they are leached down into the groundwater or nearby streams. In contrast, only a small proportion of the nutrients in soil that is high in organic matter are held by exchange on clay surfaces. Most are bound in the organic matter and in the organisms that live within the soil, where they are unavailable for leaching or volatilization. As organic matter decomposes, the nutrients are released slowly, at a rate often comparable to the uptake rate of nutrients by plants.

4.2.3.2 Why Food Webs Differ

The nature of food webs differ among ecosystems. One of the most important causes is the ratio of carbon to nitrogen in the initial organic matter. Bacteria require a low carbon to nitrogen ratio in the material they compose. Manure, animal remains, green leaves, fruits and vegetables are initially decomposed by bacteria because of their relatively low C/N ratio of 30/1 or less. In contrast, dried plant materials such as straw may have a ratio of 100/1 or higher, and the trunks of fallen trees may be

300/1. The first organisms to feed on these high ratio materials will be fungi, because they need less nitrogen in order to digest the plant material.

Soil food chains can differ between fields even within the same farm. The chains will differ depending upon the crop that is planted and the season of the year. Carrillo (2007) working in a field at Spring Valley Ecofarm described a reciprocal relationship between a crop growing in the soil and the soil community. The crop that is growing influences the soil community, but the community, in turn, influences the crop. Management also influences the nature of the soil communities. In a field cultivated by no-till methods in the Georgia Piedmont, the soil community was dominated by fungi, whereas a control cultivated by roto-tilling was dominated by bacteria (Coleman et al. 1994). No-till tends to preserve organic matter and thus fungi are favored, while rototilling exposes the organic matter to oxygen, the result being that bacteria play the major role in decomposition.

The Soil Community and Compost

The community of microorganisms that produce compost is similar to the community in the soil organic matter. Ideally the microorganisms decompose raw materials and produce a product with a carbon to nitrogen balance that releases nutrients to the soil at a rate that is optimum for uptake by plants. The balance between raw materials in the compost pile is important in achieving an optimum result. Roughly half of the organic matter should have a high C/N ratio to ensure there is sufficient energy in the form of carbon compounds to fuel the process. Typical materials would be straw, dried leaves, or finely ground wood chips. The rest should be materials with a low ratio to ensure there is enough nitrogen for the bacteria to decompose the high carbon organic matter. Cow manure with a ratio of 18/1 or chicken manure with a 7/1 ratio are ideal to mix with straw or wood chips to obtain a compost pile that quickly (within a few months) decays into a rich mixture that can readily supply nutrients to crop plants.

With a proper mixture of ingredients, the pile will heat up due to microbial respiration, and the high temperature will kill any pathogenic organisms from the manure. Covering the pile with a tarpaulin will trap heat inside the pile and speed the sterilization process (Box 4.4).

4.2.4 How Is Nutrient Cycling Efficiency Increased by Soil Organic Matter?

4.2.4.1 Synchronization

If more nutrients in the soil are in a soluble condition than can be taken up by the crop growing on the soil, the nutrients will be leached or volatilized, and lost to the system. If too few nutrients are available, crops will suffer a nutrient deficiency.

Box 4.4

Compost that is used on the same farm where it is produced increases the sustainability of the operation, because it eliminates the cost of hauling compost. At Spring Valley Ecofarm, we make our own compost. We put old hay for bedding inside the duck and chicken enclosures. The poultry defecate into the hay, and after several months, we pitch-fork it out into a pile, cover the pile with a tarpaulin, and let the microbes go to work. In the winter, we keep the horses in a small winter pasture, where we feed them hay. We put the bales in a concentrated area, so that the horse manure falls into the remnants of each bale. Then in the spring, we use the tractor to scrape the mix of manure and hay into a compost pile. Six months later, the compost is ready to be applied to the vegetable garden.

The soil community regulates the availability of nutrients to plants. It synchronizes the nutrient release from soil organic matter with plant nutrient demand. In the spring, the warm weather and moist soil favor plant growth and thus nutrient demand by plants is high. These same conditions also favor rapid rates of decomposition, so there is a balance – high demand, high supply. Later in the summer, if the weather is dry, plant growth slows, but so does decomposition. But if the farmer irrigates, growth increases and so does decomposition. A problem in balancing arises however, when it gets too hot. Once the temperature gets above 90° F, photosynthesis begins to slow down, while decomposition rates continue to increase. Nutrient uptake by plants decreases, while release from organic matter increases. Thus more nutrients are available for leaching.

4.2.4.2 Phosphorus Solubilization

Huang and Violante (1986) showed that high concentrations of certain organic acids affected the solubility of phosphorus in soils that have a high concentration of iron and aluminum. Such conditions exist in highly weathered soils such as Oxisols and Ultisols that occur in much of the tropics as well as the Southern Piedmont. In these soils, phosphorus is often immobilized in iron and aluminum compounds, and thus is unavailable for plant uptake. Ae et al. (1990) showed that piscidic acid produced by pigeon pea (*Cajanus cajan*) stimulated plant growth in cropping systems of the Indian subcontinent. Rani et al. (2012) showed that organic acids produced by certain rhizobacteria have the ability to increase the availability of phosphorus in highly weathered soils. A proposed mechanism is that organic acids chelate the iron and aluminum that binds phosphorus and results in its availability to plants, thus increasing nutrient cycling efficiency.

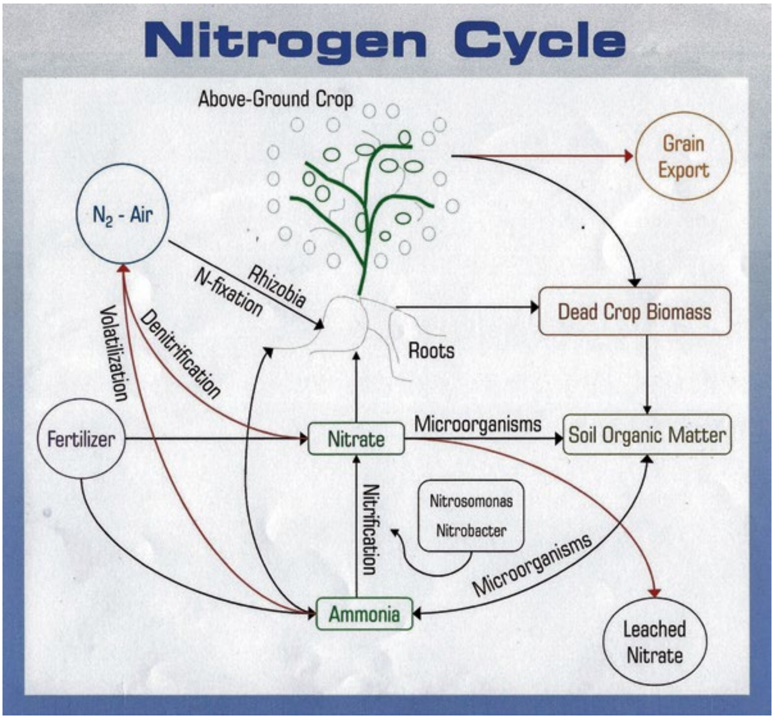

Fig. 4.3 A simplified version of the nitrogen cycle in a farmer's field (Diagram by K.A. Goings, National Soil Survey Center, NRCS USDA, Lincoln Nebraska. http://soils.usda.gov/sqi/publications/publications.html#biology)

4.2.4.3 Nitrogen Fixation

One of the most important functions of the soil community is the fixation of atmospheric nitrogen by rhizobial bacteria that live in a symbiotic relation with the roots of many leguminous plants. The bacteria use energy derived from plant roots to capture atmospheric nitrogen, that is, convert N_2 in the air to soluble nitrogen compounds in the soil. After fixation, nitrogen is converted to nitrate and ammonia, forms available to roots of the above ground plants (Fig. 4.3). If sufficient legumes are used to add nitrogen to the soil, little or even no inorganic nitrogen fertilizer is needed, thus eliminating the need for the energy used in the industrial nitrogen fixation process, the "Haber–Bosch" process.

In a 2-year experiment to evaluate nitrogen contribution of cover crops in organic broccoli production, researchers at Oregon State University found that a phacelia-vetch mixture increased broccoli yield over a fallow treatment by 1.3 tons per acre. This increased the value of the crop by $2,370 per acre (SARE 2012). This however, was the increased value of the broccoli crop, not the energetic value of nitrogen fixation (Box 4.5).

Box 4.5

Organic farmers use leguminous plants such as alfalfa, clovers, and many types of peas and beans as a source of soil nitrogen. At Spring Valley Ecofarm, we use a leguminous shrub called false indigo (*Amorpha fruticosa*) in permanent hedgerows to help enrich soils (Carrillo et al. 2011).

4.2.4.4 Nutrient Uptake by Mycorrhizae

Mycorrhizae are a type of fungus that is symbiotic with the root hairs of many plant species. The fungal hyphae extend the ability of roots to take up nutrients. In exchange, the fungus obtains carbohydrates from the plant. Instead of growing an extensive root system, the plant delivers energy to mycorrhizae. In turn, the mycorrhizae expands the volume of soil that can be exploited by the plant for nutrients. Fungal hyphae have a much larger surface to area ratio than do root hairs, and they fan out up to 8 cm beyond the nutrient depletion zone around roots (Nichols and Wright 2004). They carry out extracellular digestion by secreting enzymes into environment and absorbing the nutrients that are released. There are two types of mycorrhizae, arbuscular or endomycorrhizae that have microscopic hyphae that extend into plant roots, and ectomycorrhizae that form a dense sheath over the surface of the root. Most vegetable crops have the arbuscular type of mycorrhizae.

Herrera et al. (1978) have shown that nutrients in some ecosystems are transferred directly from decomposing litter through mycorrhizae into root hairs on nutrient poor soils such as the Piedmont red clays. This is a nutrient-conserving mechanism, because nutrients are not exposed to mineral soil where they can be readily leached.

4.2.4.5 Physical Properties of Soil

Bacteria produce compounds that help bind the clay particles of mineral soil into aggregates called peds. Fungal hyphae also are important in forming aggregates. Why is this important? If the soil were pure clay, it would be almost impermeable. Water would run off the soil surface, and roots would have difficulty penetrating. Soil erosion also would occur. But as a result of the aggregate forming processes, the soil becomes quite porous (Fig. 4.4). The space between the peds allows water to drain, and roots to penetrate. Physical properties of the soil that result from microbial and fungal activity include:

- Aggregate stability: the ability of peds to resist breaking down into clay particles.
- Lower bulk density, the relationship between volume and weight of soil. Low weight per unit volume of soil means that there are lots of air spaces in the soil horizon.

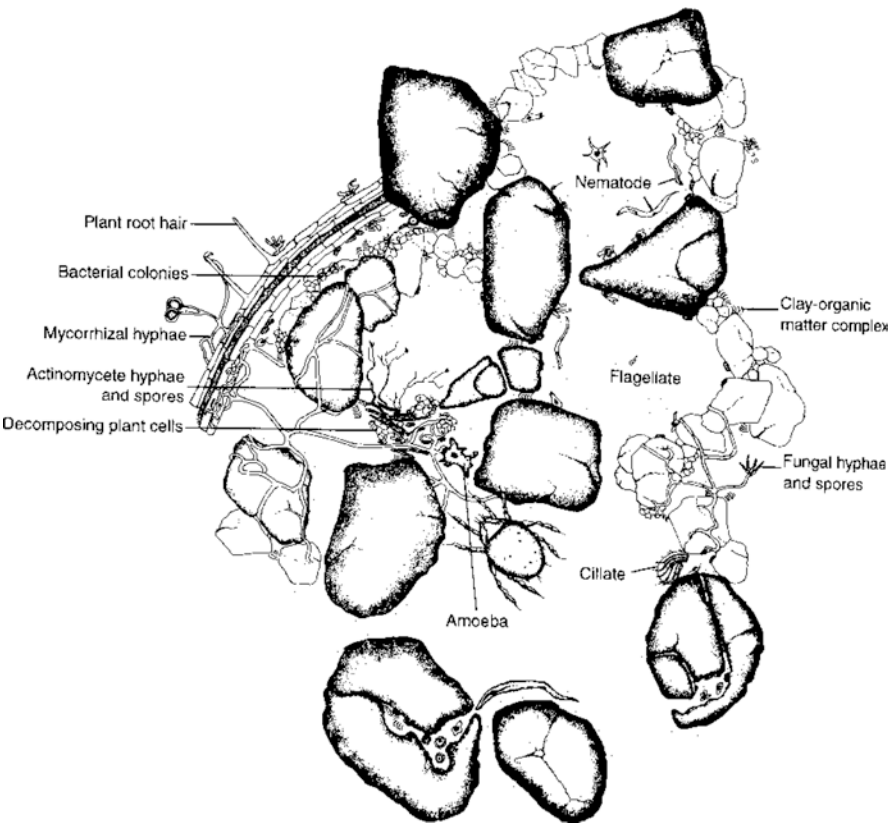

Fig. 4.4 As a result of the aggregate forming processes, the soil becomes quite porous. Organisms live in the microscale environments within and between the peds. Differences over short distances in pH, moisture, pore size and types of food available create a broad range of habitats (Drawing by S. Rose and E.T. Elliot. *Soil Biology Primer* [online]. Available: soils.usda.gov/sqi/concepts/soil_biology/biology.html [access date 8/12/2012])

- High permeability, the ability of roots to penetrate the soil.
- High infiltration, the ability of water to percolate through the soil.

4.2.4.6 Increased Vigor of Plants

Eating nutritious food is important in helping people resist disease. The same principle is true for crop plants. Plants that grow in a soil where there is good nutrient balance provided by the soil community are less likely to be damaged by disease and insect pests. A long held maxim of organic farming is that soil organic matter management can keep diseases and foliage-feeding insects in check without the intervention of pesticides (Phelan 2004), who quotes Howard (1943) who wrote: “Insects and fungi are not the real cause of plant diseases, and only attack unsuitable varieties or crops improperly grown. Their true role in agriculture is that of censor for pointing out the crops which are imperfectly nourished. Disease resistance seems to be the natural reward of healthy and well-nourished protoplasm. The first step is to make the soil live by seeing that the supply of humus is maintained. " Elliot Coleman is one of the most famous and forceful proponents of this view, and his book (Coleman 1995) is a standard for many organic farmers.

4.2.5 The Energetic and Economic Value of Soil Organic Matter

4.2.5.1 Value of Soil Organic Matter

From the viewpoint of sustainability, the most important characteristic of soil organic matter is its energy content. It is the energy stored there that drives the community of soil organisms which in turn, carry out the services of nature such as increasing the nutrient cycling efficiency (Odum and Odum 1981). To estimate the energetic value of the subsidy provided by soil organic matter when it is used instead of industrial energy to produce a crop, we can compare the energy content of organic matter in an hectare of top soil, such as that which the early Georgia colonists found when they cleared the land for agriculture, with the amount of industrial energy subsidy required to produce a hectare of corn.

The caloric content of vegetation, which is the main source of soil organic matter, ranges from 3732 cal/g in tropical forests, through 4759 cal/g in temperate forests, to 5367 cal/g in alpine vegetation (Jordan 1971). The organic matter content of undisturbed soils in humid regions of the temperate zone is about 4 %, and the bulk density (weight per unit volume) of the upper soil horizons where most of the organic matter occurs averages around 1.3 g/cm^3 (Brady 1974). The depth of the topsoil (the O and A horizons) varies greatly, depending on the soil type and the vegetation on top of the soil. In an old growth forest stand at Spring Valley Ecofarms in the Georgia Piedmont, the A horizon reaches a depth of about 12 in., or 30 cm (Fig. 4.5). We know the soil was never cultivated because some of the oaks there are 150 years old, and the farm was founded in 1864. To calculate how much energy is stored in the O and A horizon of the old growth forest, we take:

1. Weight of 1 m^3 of soil = 1.4 metric tons (1.4 mt).
2. The area of soil surface under which a cubic meter of soil occurs is 1 square meter (1 m^2).
3. The weight of soil to a depth of 30 cm is $.3 \times 1.4 = .42$ mt.
4. The weight of organic material in this upper horizon is 4 % of .42 mt, or .02 mt (20,000 g/m^2).
5. Assuming energy content of the organic matter is 4,700 cal/g (Jordan 1971), there will be $4{,}700 \times 20{,}000 = 94(10^6)$ calories under 1 m^2 of soil surface.
6. There are 10^4 m^2 per hectare, so there will be $940(10^6)$ kcal/ha.

Fig. 4.5 Soil profile in a stand of old growth forest at Spring Valley Ecofarm in the Georgia Piedmont. Although the stand had been used by the original farmer as a woodlot, the soil has never been cultivated. The profile represent what the soil looked like when the early colonists settled the region. I am pointing to the transition point between the A horizon, high in soil organic matter, and the B horizon, highly weathered, nutrient poor red clay. In 1917, this red clay was used to cement rocks together to make a pig smokehouse at Spring Valley Ecofarm. That house still stands today

7. 8,115,000 kcal of energy subsidies (does not include solar energy) are required to grow 1 ha of corn for 1 year with industrial type agriculture (Pimentel and Pimentel 2008).
8. $940(10^6)$ kcal/$8.115(10^6)$ kcal = 115.83 Theoretically, the soil organic matter has the potential energy to replace industrial energy input for 115 years, provided there is no energy loss through erosion, and no oxidation that results from plowing.

Figure 4.6 shows what agricultural Piedmont soils look like today. There is no A horizon. The organic matter was oxidized, then eroded away during the epoch of cotton in the South (Box 4.6).

The dollar value of the energy in soil organic matter can be calculated by assuming the market value of 1 kcal of energy is equal to the cost of gasoline that contains 1 kcal of energy.

9. In 2012, the price of gasoline fluctuated around $3.50/gal
10. A gallon of gas contains $31.5(10^3)$ kcal.
11. If $3.50 buys $31.5(10^3)$ kcal of energy in gasoline, how many dollars are needed to buy 940 (10^6) kcal, the amount of energy stored in a hectare of organic top soil?
12. $3.50/$31.5(10^3)$ kcal = **X**/$940(10^6)$ kcal where **X** = $ value of an hectare of top soil. Solve for X

Fig. 4.6 A soil pit in a fallow pasture at Spring Valley Ecofarm. There is no A horizon. The only organic matter is an inch or so of roots of grasses and forbs. The reddish brown soil extending down to just above the blade of the shovel is the "plow horizon", and indicates the depth of the roots of crops previously grown on the site. Behind the shovel blade is pure red subsoil

Box 4.6

Rhizobial bacteria are part of the soil organic matter. Pimentel and Pimentel (2008) estimated that the energetic cost of inorganic nitrogen fertilizers supplied to a corn field to be 2,448,000 kcal/ha. That can be considered to be the energetic value of the services provided by rhizobial bacteria when legumes are used to supply nitrogen to the soil. Since 8,115,000 kcal of energy subsidies are required to grow 1 ha of corn for 1 year with industrial type agriculture, rhizobial bacterial contribute approximately 30 % of the total energy input when legumes such as clover are used as the sole nitrogen source.

13. **X** = $104,000
14. Soil organic matter would be burned up at a little less than 1 % per year under conservation tillage with no erosion, (line 8. above). If 1 % of the energy in the topsoil is used by soil microorganisms to recycle nutrients and maintain good soil structure during one season of cropping, then the value of their services is $1,040 per hectare per year.

15. If soil organic matter was burned up at about 1 %/year, then .01 of the energetic content of the original energy it contained {940(10^6) kcal} is 940(10^4) kcal. This is not much different from the value of 811(10^4) for the industrial energy subsidy needed to produce a crop for a year (line 7 above).

Nelson et al. (2009) give values of total energy inputs for a season of corn production to be 3,669,532 kcal/ha (15.36 GJ), and for cotton to be 3,910,825 kcal/ha (16.37 GJ). These are about half the estimates of Pimentel and Pimentel (2008). Estimates of energy requirements for crops will vary depending on the climate and the soil where a crop is grown, the type of machinery used to produce the crop, the efficiency of industrial nitrogen fixation, and the energy used in fabricating the farm machinery used for crop cultivation, pro-rated over the life of the machinery. Energy that was used in making a product is known as embedded energy, or embodied energy (Odum and Odum 1981). Odum (1988) later refined the term to include the quality of energy, not just the quantity, and called it "Emergy". The distinction is important. The caloric value of the paper on which a tractor manual is printed is equal to that of the pulp from which the paper was made, but the emergy value includes all the energy expended by people while compiling that information.

4.2.6 Energy Subsidies Replaced by Soil Organic Matter

The energy subsidies that comprise the industrial energy required to produce a hectare of corn derive from:

- The fuel to power the tractors
- The energy embedded in tractors and cultivators used to loosen soil and bury weeds (prorated over life of machinery)
- The fertilizers needed to promote crop growth
- The insecticides to kill pests
- The herbicides to control weeds

Under sustainable agriculture, these subsidies would be replaced by the free services of nature.

4.3 Pest Control – An Attributable Value

4.3.1 The Service Rendered – Controlling Insect Pests

Insect pest damage varies according to the crop planted, the climate, and the population dynamics of the pest. In some situations, pest damage is negligible. In others, pests can destroy a whole crop. The value of nature's services for pest control can be calculated on the basis of the value of the crop saved, or on the value of the insecticides used to save the crop.

4.3.2 Source of the Services

4.3.2.1 Beneficial Insects

Beneficials are predatory and parasitic insects and spiders that have the potential to control pest insects in a farmer's field. There are hundreds of different species of beneficials. Population outbreaks of pests often occur because beneficial predator populations to control them are lacking. Importing predator species from regions where the pest populations are under control is a strategy known as biological pest control. An example is its use to control red scale (Luck 1986). Red scale is an insect pest of grapefruit, lemons, and oranges in arid and semiarid regions. It inhabits all aboveground parts of citrus plants, inhibits fruit production, and kills branches. Red scale was introduced into southern California around 1870 on shipments of citrus nursery stock from Australia. Many potential predators of red scale were introduced form Australia. The most successful were ladybird beetles and parasitic wasps. In Southeastern U.S., Florida red scale is under effective biological control, also by parasitic wasps and lady bird beetles. Heavy infestations of Florida red scale generally occur only when the improper use of pesticides has severely reduced or eliminated the parasite population (Fasulo and Brooks 2010). There are almost a hundred other examples of the services of the predatory insect community in controlling pests and disease. Mahr et al. (2008) gives a comprehensive review of beneficials in 24 families of insects, along with the pests that they control and the crops that the pests damage.

Pest control by beneficials does not mean pest elimination by beneficials. It is important that at least a few pest insects remain available as food for predators in the crop habitat. If the prey becomes locally extinct, the predators would disappear, leaving the system more vulnerable to the next pest attack. Inoculating a crop with a low level of pests is analogous to vaccinating a child with a virus. It has long been accepted by medical doctors that giving a child a vaccination against diseases such as polio and diphtheria gives the child a low dose of these diseases that confers an immunity against catching them during an epidemic.

4.3.2.2 Complexity and Diversity of Crop Systems

One of the most effective ways to encourage beneficials is to provide them with a suitable habitat. Often this will be a crop ecosystem that is complex and diverse. Why are pests often less of a problem in structurally complicated crop ecosystems than they are in simple ones? There are two major hypothesis (Altieri and Liebman 1986). The *Natural Enemy Hypothesis* predicts that there will be more predators that prey on insect pests in complex polycultures than in simple monocultures. One reason for this is that polycultures can provide a more reliable source of food for the predators. Some predators often consume a wide variety of prey, and therefore are more likely to find a continuous source of food in a heterogeneous habitat. Other predators are specialized, but ecosystem complexity also helps maintain their populations. Their

Box 4.7

We tested the Resource Concentration hypothesis in a temperate zone at Spring Valley Ecofarm, by grouping a traditional combination of corn, beans, and squash close together in patches in one field, and comparing pest damage to these plants when planted in monocultures. We found that damage to squash plants by squash bugs and stem borers was not reduced in the polyculture. However, there was a big difference in damage to the beans not because of insects, but due to deer (White tailed deer are a major pest species). When beans were planted alone, the deer would mow them down overnight, but when the beans were hidden by the corn stalks, there was little damage. We found that it was important for the corn to have about 2 weeks head start on the beans in order to achieve this effect.

populations are less likely to fluctuate widely in a heterogeneous system because its complexity allows the prey to escape local extinction. It is important that a small population of pests exist in the crop ecosystem to encourage the predators to remain. The other major hypothesis is the *Resource Concentration Hypothesis*, which predicts that insects are more likely to find and remain on hosts that are growing in monocultures. In complex diverse systems, pest species with a narrow host range have greater difficulty in locating and remaining upon host plants in small, dispersed patches as compared to large, dense, pure stands. Risch (1981) found that pest beetles emigrated more from polycultures of corn, beans and squash in a tropical field than they did from monocultures (Box 4.7).

A number of mechanisms have been observed that underlie these hypothesis (Lampkin 1994).

- In a complex system, overlapping leaves of various species camouflage the host crop, making it more difficult for the pest to locate the host species that it is seeking.
- Some types of pests are more attracted to crops with a bare background of soil (as in a weed-free monoculture) than to ones where the soil is covered with plant remains.
- Non-host plants can mask or dilute the attractant stimuli of host plants, leading to a breakdown of orientation, feeding, and reproduction processes.
- The odors of certain plants such as garlic can act as pest repellents.
- Predatory insects that prey upon pests are more likely to encounter suitable habitat, nectar, and pollen sources in diverse environments, thus reducing the probability that they will leave or become locally extinct.

4.3.2.3 Natural Insecticides

An important advantage of natural pesticides is that they are much less likely than synthetic pesticides to cause ill effects in vertebrates through eating treated plants and plant parts. Natural pesticides also do not seem to affect many pest predators (Stone 1992). There are a number of natural pesticides, among which are:

- The extract from pyrethrum (*Chrysanthemum coccineum*), a herbaceous plant in the composite family that has been used as an insecticide for over 100 years (Bhat 1995). The flowers contain a mixture of pleasant-smelling esters that can be extracted and used to control insects. Compared to artificially synthesized insecticides, it has low toxicity to mammals and is rapidly degraded by ultraviolet radiation. Pyrethrum is one of the insecticides that may be applied to crops up to, and including the day of harvest. Because growing and harvesting the pyrethrum plant can be labor intensive and thus expensive, it is not as economical as synthetic pesticides. However chemists have not been able to artificially synthesize insecticides that are as environmentally benign. Consequently, pyrethrum still has a special niche. It is used as a broad-spectrum insecticide for use on minor crops, and as a quick "knockdown" spray on the day of harvest when high levels of chemicals are not acceptable (Silcox and Roth 1995).
- The bacteria- and insect killing properties of extracts from the seeds of the neem tree (*Azadirachta indica*) have been known to scientists in India for almost a century. However, only recently have western scientists begun to explore the chemical nature of the seed extracts (Stone 1992). They have found that it wards off more than 200 species of insects, including locusts, gypsy moths, and cockroaches.
- *Bacillus thuringiensis* (Bt) is a naturally occurring bacterium common in soils throughout the world. Several strains can infect and kill insects. Because of this property, Bt has been developed for insect control. Unlike typical nerve-poison insecticides, Bt acts by producing proteins that reacts with the cells of the gut lining of susceptible insects. These Bt proteins paralyze the digestive system, and the infected insect stops feeding within hours. Bt-affected insects generally die from starvation, which can take several days.

4.3.3 The Energetic and Economic Value of Insect Pest Control

The energetic value of insecticides per hectare for corn is $280(10^3)$ kcal/year. The energetic value of fuel used for all agricultural operations per hectare is $1{,}408(10^3)$ kcal (Pimentel and Pimentel 2008). Assuming that one third is used for crop dusting, energetic cost of fuel for insecticide spraying is about 500 (10^3) kcal/ha. Total energetic cost of insecticide use then would be $780(10^3)$ kcal/ha. The dollar value of that, calculated on the basis of a gallon of gasoline at \$3/50 per gallon of gas containing $[31.5(10^3)]$ kcal of energy would be \$86.67. If the services of nature were used to control insect pests, their value then would be \$86.67 per hectare.

4.3.4 Energy Subsidies Replaced by Nature's Insect Control

The direct costs of industrial pest control would be that of synthesizing and marketing the pesticides, and that of applying the insecticides to the field. Costs such as that of human health affected by the pesticides, the cost of beneficial insects poisoned by the pesticides, and the fish kills resulting from runoff of the pesticides should be added to the costs using synthetic pesticides. These costs are eliminated when they are carried out by nature's services.

4.4 Weed Control – An Attributable Value

4.4.1 The Service Rendered – Fighting Succession

Agriculture is sometimes defined as "the fight against succession." Succession means the invasion of wild plants in areas where natural plant communities have been cleared. In the context of agriculture, successional plants are called "weeds". For row crops and vegetable gardens, fighting succession means getting rid of early successional species such as pigweed with mechanical tools such as the hoe or the cultivator. For pastures, it means getting rid of woody plants that will eventually convert the pasture into woodland (Box 4.8).

4.4.2 Source of the Services

4.4.2.1 Allelopathy

Allelopathy refers to the effects of one plant on another plant through the release of chemicals from plant parts by leaching, root exudation, volatilization, residue decomposition and other processes in both natural and agricultural systems. Rye is a cultivated species that produces a strong allelopathic reaction. It used in the Southeast as a winter cover crop to prevent erosion, add carbon to the soil, and suppress weeds. It is planted in the early fall, and grows to a height of a few inches before the first heavy frost. It remains dormant until late March, and then begins to grow rapidly. At Spring Valley Ecofarm, we roll it flat in April with a roller-crimper (Fig. 4.7) which rolls the rye flat, and then crimps it with the angle irons to kill it and prevent re-sprouting. Summer crops are then planted directly through the residue, either with a no-till planter for direct seeding, or a no-till seedling transplanter for seedlings started in the greenhouse. The rye residue inhibits weeds in two ways: physically by blocking the growth of weeds; chemically through the release of allelopathic chemicals that inhibits the germination of weed seeds. The physical and chemical properties last for about 6 weeks, enough time for the crop species to grow large enough to compete successfully with weeds that eventually break through the residue.

Box 4.8

When crops are well established and early successional plants that invade are not serious competitors with the crops, these plants are called "companion plants". They take up nutrients from the soil that otherwise would be lost if the field were cultivated "clean". These companion plants then become part of the soil organic matter at the end of the growing season, and the nutrients in them are conserved. The idea that corn fields do not have to be "clean" is a difficult concept for traditional farmers to accept.

Fig. 4.7 A roller crimper being towed behind a tractor. The angle irons crimp and kill the rye, preventing it from sprouting

The Energetic and Economic Value of Weed Control

The energetic value of herbicides per hectare for corn is 620 (10^3) kcal/year (Pimentel and Pimentel 2008). Using the energetic value of fuel and the dollar value of herbicides and fuel in the same way as in 4.3.3 above, the cost of weed control by herbicides is $124.44 per hectare. This is the value of weed control by allelopathy (Box 4.9).

Box 4.9

Strips of plastic ground cover put over vegetable beds is an organically approved method of controlling weeds. It is held in place by wire staples pushed through the cover into the soil. We have tried it at Spring Valley Ecofarm, and found that putting it in place is relatively easy. The energy consuming part is pulling it up and disposing of the plastic sheets.

4.4.2.2 Fire

In 1993 when I bought the farm that became Spring Valley Ecofarm, most of it was in cultivation of annual grains. The fields were plowed annually, and fertilized heavily with chemicals. This was not what I, as an ecologist, wanted for the farm, so for the first few years, I left the fields fallow till I decided how to manage them. By the second year, I noticed that native bunchgrasses such as broom sedge and little bluestem dominating the field. They are beautiful in the fall, when they turn golden brown, and when the wind blows, they look like waving wheat. I would have liked to keep it that way and use the fields for pasture, but after a few years, I noticed the beginning of an invasion of woody plants such as sumac, persimmon and blackberry. At first I mowed the fields with a tractor. It took several days to do the 40 acre back pasture. Then I thought back to the research that I did for my Master's degree in an abandoned old field of the New Jersey Piedmont, where native bunchgrasses also were dominant (Jordan 1965). I had found that annual burning favored the grasses over the trees. Fire destroyed the above ground buds of woody plants, and if the trees were small, effectively killed them. The growing point for grasses however, is at or below the ground level, and thus is protected from the flames. In addition, the removal of the upright, dried leaves by the fire enabled more sunlight to reach the growing point of grass, thereby stimulating a more vigorous growth. So I decided to burn the old fields at Spring Valley Ecofarm. It was an easy an effective management tool. I substituted the free services of fire for the 500 (10^3) kcal/ha of fuel needed to control woody plants by mowing, for a saving of $55.56 per hectare.

Fire Research

Tall Timbers Research Station is a facility in Florida that for many years has been dedicated to studying the beneficial effects of fire in the Southeast. Fire improves the habitat for bobwhite quail, turkey, and grazing mammals that utilize large amounts of hardwood browse. In stands of hardwoods, browse quickly becomes beyond the reach of grazers such as deer. In addition, both palatability and nutritive value are lower in older browse. It is the tender sprouts that grow after fire that provide the highest quality food for browsers, and the grass that is favored provides ideal cover for quail (Bateman 1968). Fire research also is conducted at Ichauway, a 29,000 acre laboratory of the University of Georgia's Joseph W. Jones Ecological Research Center located in Southwestern Georgia. Part of their program is dedicated to studying the role of fire in restoring and regenerating the long leaf pine ecosystem. In its early growth stages, this valuable pine is highly resistant to fire, and so fire favors this species over broadleaf hardwoods that would out-compete the pine in the absence of fire.

Until the Forest Service's Smokey Bear campaign to prevent forest fires, there was a long tradition of annual burning of forest land in many parts of the South, particularly where the land was also used for cattle. Fire cleared out thorny vines like cat brier, and shrubs like palmetto, and gallberry that accumulate in unburned pine stands and are collectively termed the "rough" (Davis 1959). Fire stimulated growth of grass upon which the cattle could feed. Perhaps the old "Crackers" learned the technique from the Indians who set fires to stimulate grasses that attracted game in burned areas.

Is fire a service of nature? We know that in the past, frequent lightning-caused fires in the arid west burned up dead woody debris that accumulates on the forest floor and prevents dangerous accumulations of the fuel. In the absence of fire, the debris piles up, and then when a fire starts, the forest can be destroyed.

4.5 Pollution Abatement – An Attributable Value

4.5.1 The Service Rendered: Prevention of Stream Pollution

4.5.1.1 Source of the Service: Bottomland Forests

In 1980, I was a committee member of Richard Lowrance, a graduate student at University of Georgia's Institute of Ecology. He was doing his dissertation research on the effectiveness of trees growing along streams to filter agricultural pollutants before they contaminated the water. The study sites were pig farms in the Coastal Plain of South Georgia. In some of the farms, pigs grazed and rooted all the way to the stream's edge, while in others, there was a buffer of trees between the pigs and the streams. He found that the trees took up much of the nitrogen and phosphorus in the runoff from the pig manure. The trees were effective in reducing the amount of pollution entering the stream (Lowrance 1981). How could the energetic value of the service of nature – pollution abatement – be estimated in cases like this? On industrial hog farms, the pregnant sows are often kept locked in "gestation crate". When the cells are flushed out, the manure flows to retention ponds. Eventually the ponds fill up, and must be cleaned out. The farmer can pump out the slurry into a nearby pasture, but the amount that can be pumped is limited due to nutrient build-up in the pasture. The alternative is to pump it into a tanker truck, transport it to a distant farmer's field, and pump it out there. The energetic cost would be the energy used to pump the slurry into the truck, to transport the slurry, and to pump it onto the field. That would be the energy savings by nature's pollution abatement service.

4.6 Pollination – An Attributable Value

4.6.1 The Service Rendered – Fertilizing the Ovary of Plants

4.6.1.1 Source of the Service – Birds, Bees, Bats

Wild bees, and native birds and bats are important pollinators of fruit crops. However, if local populations of these pollinators are insufficient to do the job, there are alternatives. Commercial bee keepers rent out hives and move from farm to farm where naturally occurring pollinators are absent or insufficient. Species that are directly dependent on insects for pollination for fruit production include apples, almonds, blueberries, cherries, oranges and squash. Vegetables dependent on pollinators to produce seed include sugar beets, asparagus, broccoli, carrots and onions. When you rent a colony of bees, you aren't just paying for the insects. The per-colony rental fee also covers the cost of transporting the bees, setting up the hive and collecting the colony at the end of the contract. The almond crops in California are entirely dependent on honeybees, and every spring they require more than half the commercial bee colonies in the nation. Colony rental prices are highest from early February to mid-March, during the pollination season for almonds. California almond farmers paid up to $180 a colony (Leibenluft 2008).

The services of pollinators however, are worth much more that the cost of renting a bee colony (Allsopp et al. 2008). It can be argued that the value of pollination is worth the market income that is generated by the sale of the pollinated crops, because without this service, there would be no income.

4.7 Biodiversity – An Intangible Value

4.7.1 The Service Rendered – Increasing Sustainability

At the level of plants and animals, sustainability is increased when their genetic component is broad enough to enable the organisms to adapt during changing environmental conditions. At the ecosystem level, sustainability is increased when the ecosystem contains enough species so that if one species becomes extinct, there are others that can replace its function in energy flow and nutrient cycling.

4.7.2 Source of the Service – Genetic Diversity

4.7.2.1 Selective Breeding and Reduction of the Genetic Pool

One of the goals of plant and animal breeding has been to select individuals that maximize short-term yield. The goal of genetic engineering has been to speed up this process and eliminate genetic material that does not contribute to this goal. Plant and animal breeding, and genetic engineering have decreased the genetic diversity of domesticated species, and eliminated many of the attributes that enabled a species to survive without the subsidies provided by humans.

Farmers who favor sustainability over short-term yield have turned to heritage varieties, that is races that are ancestors of modern genetically reduced varieties. At Spring Valley, we raise an old French Heritage variety of chicken called the Mottled Houdan. Such traditional breeds have a broader spectrum of qualities than the modern Cornish Rock and Leghorn which have been bred to quickly convert feed into meat or eggs (Heinrichs 2009). Our Houdans are slower to mature than the modern breeds, and their eggs are smaller than what one finds in the Supermarket. However, they are better able to withstand the low January temperatures in Athens. Some of our neighbors raise "Piney Woods" Cattle and "Gulf Coast Sheep". These are races descended from animals that Spanish colonists brought to Florida in the 1500s, and later became feral. Through natural selection, the descendents have evolved the ability to survive in the rough brush under pine stands, to resist the pests and disease of the Southeast, and to reproduce naturally.

4.7.2.2 Insect Resistance and Genetic Variation

In 2008, there began a significant infestation around Athens of the black dotted brown moth (*Cissusa spadix*) (Tree Conservation Notes 2012). The caterpillar of this moth spends much of the early spring feeding on some of the species of oaks at Spring Valley, and in several cases, caused complete defoliation. We lost a nice big white oak near the farm house due to the caterpillar, and a post oak in the back field. However, the majority by far of the oaks were undamaged. Why was this? Each individual oak, even of the same species, has a unique genetic makeup, just like every human being has a unique genotype. One possibility is that the trees that suffered little or no damage had part of their genetic makeup that conferred resistance against this pest, which has always been part of the native ecosystem in the Eastern United States. If this is the reason, then once again it is apparent that genetic diversity is important in shielding a species, but not necessarily an individual, against attack from an enemy. Another possibility is that the high diversity of tree species on the farm inhibited the spread of the moth from one susceptible individual to another.

The Evolutionary Race

In nature, there is a continual battle between plants and the insects that prey upon them. If a species is to survive, it must continually alter both its offensive and defensive capabilities. Only through genetic diversity can it continually adapt to new circumstances. An example comes from rain forests of the tropics, where the root of manioc (cassava) *Manihot esculenta* is a staple agricultural crop. There are two kinds of: one is "sweet" and the other, "sour". The sweet is generally grown on nutrient rich soils. The sweet must be harvested soon after maturity. The root can then be ground, and then boiled or baked with no further preparation. Sour manioc contains hydrocyanic acid which is a powerful poison, and is a strong defense against insects and nematodes. It is more common on nutrient poor soils, where plant defenses against insect pests is important because of the nutrient "cost" of replacing damaged leaves. Before it can be eaten, the ground root must be soaked and squeezed to rid it of the poison.

Florencia Montagnini, when she was studying the nutrient dynamics of shifting cultivation in the Amazon region, noticed that despite the hydrocyanic acid, sour manioc was still preyed upon by sucking insects. What was their adaptation to avoid poisoning? Using Phosphorus −32 injected into the plant as a tracer for the pathway of sap in the plant-insect interaction, she found that the insects inserted their proboscis between the plant cells, thus avoiding the cyanide that forms when cell walls are broken (Montagnini and Jordan 1983).

4.7.2.3 Increasing Efficiency of Ecosystem Function

On my research farm I take students into a 2 acre stand of old growth hardwoods that the original farmer, a Civil War Veteran, used as a woodlot. The oldest trees there are 150 years of age. I point out that there are about 22 species of hardwood trees in the stand. I ask them why there are so many species. I ask them," wouldn't you expect that competition between species would eliminate all but the one species that is best adapted to the ecological niche supplied by the uniform soil and topography." Few students get the answer. The answer is that although the environment looks homogeneous, there actually is tremendous variation both spatially and temporally in the ecosystem. The ecosystem changes, from season to season, and from year to year. Some species put on maximum growth early in spring, others in early summer. Some species do well in wet years, others do well in dry years. The trees themselves create separate niches. Some, like dogwoods, are calcium accumulators. Others, like black locust in conjunction with symbiotic bacteria, fix their own nitrogen. The sunlight that comes into the stand comes at different angles in the early morning and at noon. It comes in at different intensities on sunny days and on cloudy days. Different species of trees are adapted to different angles and intensities of light. Tulip poplars are tall and straight and are good at capturing light from directly above. Others like the oaks have a more spreading crown that capture light coming from different angles. Still others such as hackberry are adapted to the shade of the taller trees. I also point out the magnolia saplings in the forest, present because the fires that favored the resistant oaks and hickories no longer occur and thus the fire sensitive magnolias are present.

Then I take them to a pine plantation, and point out that they are all competing for the same light, the same nutrients, and the same water, because all the trees are the same height, the same shape, and have the same rooting depth. Then I ask them, which of the two ecosystems has the most efficient use of light, nutrients, and water? And as a result, which has the highest net primary productivity? The student's take-home lesson is that an ecosystem with a diversity of species will have a greater energy use efficiency and a higher nutrient recycling efficiency than an ecosystem with low diversity.

Overyielding

Like every species of tree, every agricultural crop has a different niche, that is, a different set of environmental variables under which it has optimal growth. When several crops with complimentary niches are planted together, such as corn, beans, and squash, we may observe an increase in ecosystem efficiency called "overyielding." Let us suppose that corn, beans, and squash when planted in three separate one-acre monocultures each yield 100 kg of fruit per hectare. When planted together however, each species yields 50 kg/ha, for a total yield of 150, and 450 kg/ha on 3 ha, an "overyield" of 150 kg. Why does this occur? The corn provides a stalk upon which the beans can grow, the bean plants provide the nitrogen used by the corn, and the squash leaves cover the soil and inhibit weed growth and soil erosion due to splatter from rain drops.

The problem of such combinations for industrial agriculture is that they are hard to harvest by machine. Where hand harvesting is used, there can be beneficial combinations. Two crops that have been shown to intercrop well are broccoli and lettuce (Gliessman 1998). Lettuce matures rapidly, completing nearly all of its growth within 45 days of being transplanted into the field. It also has a relatively shallow root system. Broccoli matures much more slowly and its roots penetrate much deeper into the soil. When the two are planted nearly simultaneously, lettuce receives all the resources it needs to complete its growth before the broccoli grows very large. After the lettuce is harvested the broccoli can take full advantage of the nutrients and moisture in the soil.

Facilitation and Mutualism

There are many pairs or groups of species that interact with each other, and as a result, enhance ecosystem function. Facilitation is an interaction in which two individual plants or two populations of plants interact in such a way that at least one exerts a positive effect on the other. If both individuals or populations exert a positive effect, that is they complement each other, the process is mutualism.

Boucher (1985) has described five types of mutualistic interactions in agricultural ecosystems:

1. Nutrition and digestion, such as that performed by microbial species living in the guts of ruminant animals and other specialized species.
2. Protection such as that performed by ants that protect the plants in which they live from being eaten by herbivores.
3. Pollination which is critical for the production of crop harvests.
4. Seed dispersal by birds which gets seeds to new and possibly better habitats.
5. Agriculture, which can be viewed as a change from predation to mutualism in a farmer's relation with food organisms.

Facilitation can have important agricultural benefits in the red clay Ultisols of the Georgia Piedmont where phosphorus is often limiting. Guedes (1993) found that sorghum grown together with pigeon pea (*Cajanus cajan*) on a farm near Athens, Georgia grew significantly faster than sorghum grown alone, when the roots were in close proximity. The reason comes from the results of experiments of Ae et al. (1990) who showed that piscidic acid produced in the roots of pigeon pea has the capability to solubilize phosphorus bound with iron in the Ultisols and Oxisols.

Defense of crop plants can result from the interaction between species. There are dozens of plants that can be effective in repelling insects when planted in close proximity to crop plants. African marigold is said to deter insect pests as well as nematodes, and often is used in companion planting for tomato, eggplant, chili pepper, tobacco and potato. "Trap crops" of a less valuable species are sometimes planted as a defense for more valuable crops. Chinese cabbage has been found to attract flea beetles, and thus lessen beetle pressure on white cabbage (Trdan et al. 2005).Understanding how the responses of these pair-wise interactions scale to entire ecosystem assemblages is one of the great challenges for those concerned with agricultural management for sustainability (Bascompte 2009).

4.8 Soil Rehabilitation – An Intangible Value

4.8.1 The Service Rendered: Improving Structure of Georgia Red Clay

Georgia red clay is the subsoil that remains after all the topsoil has been depleted by erosion and plowing. It is so compact that it cannot be cultivated except with the use of heavy plows. When dry, it is so hard that early settlers used it in the Georgia Piedmont in place of mortar.

4.8.2 Source of the Service

The Red Fire Ant was accidentally introduced into the United States aboard a South American cargo ship that docked at the port of Mobile, Alabama, in the 1930s. The fire ants have come to infest the majority of the Southern and Southwestern United States. It is estimated that more than $5 billion is spent annually on medical treatment, damage, and control in fire ant infested areas. Furthermore, the ants cause approximately $750 million in damage annually to agricultural assets, including veterinarian bills and livestock loss, as well as crop loss.

Fire ants reached Spring Valley Ecofarm in the 1990s. I noticed them mainly in the upland fields that once produced cotton, and that in recent times, were used for sorghum and wheat. However, no colonies appeared in soils of the old growth forest at Spring Valley. The probable reason is that fire ants are pioneer species that do well where the environment is too harsh for native species of ants, but when there is plenty of soil organic matter as in our old growth oak-hickory stand, the natives outcompete the fire ants.

I planted a small vineyard of muscadine grapes toward the top of one of the rises of Spring Valley Farm. I chose a spot that had the worst soil on the whole farm, because I wanted to save the better soils for annual vegetable crops. Because grapes are a perennial crop, the soil does not have to be cultivated. Mulch was spread around the base of each vine, to add organic matter to the soil. Fire ants occasionally built a nest around the base of seedlings, and usually killed them, perhaps by eating their roots. However, when the vines became larger, I noticed that those having a fire ant next at their base grew better than those that did not. A possible reason is that the burrowing of the ants improved the permeability of the compact red clay, and allowed better penetration of roots. If this is true, then the fire ants may play a role in soil restoration when old fields are abandoned. The improved permeability accelerates establishment of tree species that in turn would increase the organic matter content of the soil.

4.9 Ecosystem Services in an Energy-Scarce Future

Energy savings occur in agriculture by substituting services of nature for energy derived from fossil fuels. For some services like recycling nutrients by the community of soil microorganisms, there is high variation in the values used because of variables such as soil type and crop cultivated, but nevertheless the calculation is straightforward. For other services such as pest control by beneficial insects, it is clear how natural services can be important in reducing energy subsidies, but it is difficult to assess their energetic value quantitatively due to the diffuse nature of the service. And for some services such as maintaining disease and pest resistance through biodiversity, it is not even theoretically clear on how assessing value could be done. Despite these problems, it is clear that the services of nature have both energetic and economic value. The bottom line is that to increase the sustainability of agriculture, we should begin to substitute the services of nature for the energy subsidies now required in industrial agriculture. Replacing inefficient use of fossil fuel energy with services supplied by nature increases sustainability in agricultural ecosystems.

"In an energy-scarce future, ecosystem services will become more important in supporting the human economy. The primary role of ecology will be the sustainable management of ecosystems. Energy scarcity will affect ecology in a number of ways. Ecology will become more expensive, which will be justified by its help in solving societal problems, especially in maintaining ecosystem services" (Day et al. 2009).

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Chapter 5
Applied Tools and Practices for Sustainable Agriculture

Abstract Many of the tools and management practices needed to take advantage of nature's services are already known. They include:

- Cover crops
- Conservation tillage
- Contour plowing
- Wind breaks
- Hedge rows
- Manuring and composting
- Crop rotations/rotational grazing
- Integrated pest management
- Resource use efficiency through diversity
- Drip irrigation

Other tools and management techniques that need development include:

- Perennial grains
- Weed control through allelopathy
- Microbial priming
- Natural pesticides
- Beneficial interactions in mixed species agriculture and forestry
- Intensive grazing management
- Mixed species grazing
- Integrating livestock with cropping
- Farmscaping -matching crops with environment
- Increasing resource use efficiency
- Evaluating sustainability of various organic practices
- Evaluating all agricultural practices in terms of energy efficiency instead of yield
- Herbicides – the puzzle for sustainability

Replacing energy intensive tools and practices with methods that utilize the services of nature will increase the sustainability of agriculture.

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Keywords Management for sustainable agriculture • Sustainable agriculture practices • Agricultural practices to increase energy use efficiency • Agricultural practices using the services of nature • Management using the services of nature

5.1 Combating Soil Erosion

Erosion is a major hazard over half of all cropland in the United States (Magdoff and van Es 2000). Erosion occurs when vegetation is removed from the soil surface, and the mineral soil (sand, silt, clay) is exposed to water or wind energy. This occurs when fields are plowed, harrowed, disked, rototilled, or cultivated by any other soil-disturbing practice. In undisturbed soils, plant roots bind the mineral soil and keep it in place. Relatively little erosion occurs under the cover of natural ecosystems such as forests or prairies. but when plants are removed to begin an agricultural operation, the soil-binding property of the roots is lost. The roots of many agricultural crops also bind the soil, but the plows, cultivators, and tillers that farmers use to prepare the soil as a seed bed destroy the residual crop roots as well as the roots of weeds (Box 5.1).

5.1.1 Cover Crops

After fall harvest during the cotton era of the South, fields were often left barren and winter rains carved out gullies. Cover crops are commonly used now to prevent erosion through soil-binding properties of their roots. They frequently are part of a crop rotation sequence, and some, such as oats, produce economic yield as well as ecological benefits. There are many kinds of cover crops: winter cover crops and summer cover crops, leguminous crops and non-leguminous crops. In the South, winter cover crops are planted in the early fall, and become established before the first heavy frost. They remain semi-dormant throughout the winter, and when the weather turns warm in March, they put on a vigorous spurt of growth. At Spring Valley Ecofarms, we have used rye, oats, wheat, winter peas, and various clovers as winter cover crops. Rye, oats and wheat add carbon to the soil, while the clovers and peas enrich the soil with their nitrogen-fixing capacity.

Summer cover crops are used as part of crop rotation, or after a spring crop is harvested and before a fall crop is planted. At Spring Valley Ecofarm, we plant

Box 5.1

During heavy rains in the Georgia Piedmont, rivers still run red. Even though destructive plowing in cotton fields ended more than a half century ago, the reddish brown sediment that was eroded still lies on the river bottoms until a storm stirs it up.

Sudan grass during dry spells because of its drought resistance. Field corn is good during the summer because the fruit can be used as hog feed, and the stover spaded into the soil provides soil organic matter. Buckwheat grows rapidly and provides quick cover, but the biomass is low. Traditional Southern crops such as cow peas provide ground cover as well as nitrogen. We have also tried pigeon peas (*Cajanus cajan*) because of its ability to solubilize phosphorus that is immobilized in Piedmont soils. One of the newest summer cover crops in the South is a tropical legume called Sunn hemp (*Crotalaria juncea*). It provides an extraordinary amount of biomass and enriches the soil with nitrogen. Seeds however are expensive, because it does not fruit except in tropical regions, so seed must be imported.

5.1.2 Conservation Tillage

Conservation tillage works together with cover crops to prevent erosion, suppress weeds, and add organic matter to the soil. Typically, the sequence starts in the fall, after an economic crop has been harvested from a field. The cover crop can be a grain, such as rye, oats, or wheat, or a legume such as clover or winter peas. In the South, the crop is planted in September or October, and by the time of the first heavy frost, the crop has grown several inches. There is very little growth during the winter, but the roots help prevent soil erosion. As the soil starts to warm up near the middle of March, there is a sudden burst of growth. Six weeks later, the seeds start to set. At Spring Valley Ecofarm, we use the oats as a feed supplement for our horses, so we wait with harvest until the seeds are ripe. For rye, we roll it down as soon as the seeds starts to set, so that the nutrient component is not drained out of the roots and stem to nourish the seed. The roller crimper (Fig. 4.7) flattens the rye. The angle irons crimp the stems, killing the plant. There is no further preparation before planting. The soil is not plowed or otherwise turned over. This conserves the organic matter in the soil, by not exposing it to oxygen. If we are planting a crop with a large seed such as corn or beans, we can drill the seed directly through the residue with a no-till planter (Fig. 5.1). Alternatively, we can "strip till" by lowering the shanks on the planter to open up a narrow strip of mineral soil into which the seeds are dropped. If we are planting vegetables that have small seeds such as lettuce, we start the plants in containers, and then use a no-till vegetable transplanter (Fig. 5.2) to transfer the seedlings to the field. The residue suppresses the weeds for a month or more, both by physical blockage, and through the release of allelopathic chemicals that inhibit the growth of weeds. By the time weeds start to break through the residue, the crop is usually large enough so that weed competition is not important. Nevertheless, no-till cotton farmers in South Georgia still use herbicides (Box 5.2).

If the cover crop is legume, we can roll it, or we can mow it and then use a spader (Fig. 5.3) to incorporate the nitrogen-rich stems and leaves into the soil. Seeds can then be broadcast directly onto the soil, and then rolled with a "culti-packer", a roller with small blunt teeth that pushes the seed into the soil. Alternatively, no till planters can be used (Box 5.3).

Fig. 5.1 A no-till planter used to plant corn or beans directly through the reside of a winter cover crop, in this case, crimson clover. For strip tilling, the shanks can be lowered to open narrow strips of mineral soil. The seeds are inside the hoppers and drop out into a slit opened up by the coulter wheels preceding the hoppers. Tamping wheels behind the hoppers close up the slit. In South Georgia, no-till planters can consist of 16 or more hoppers on the same piece of equipment

Fig. 5.2 A no-till seedling transplanter. The two workers take seedlings from the pots on the tray and place them in open-top, clamp-like spades hanging from a ferris-wheel- like device between them. As the wheel rotates and a spade enters the soil, the spade opens up and the seedling drops out. The tamping wheels close the soil. The tank of water behind the tractor supplies a shot of water as the machine moves forward

Box 5.2

At Spring Valley Ecofarm, we use no-till to plant field corn in the residue of winter rye, but we don't need to use herbicides. The residue alone suppresses weeds for a month or more, and by the time it decomposes, the corn is already so tall that weeds offer no serious competition. The "weeds" are sometimes called "companion plants" because they store nutrients not needed by the corn, and prevent soil compaction by covering the soil in-between the corn plants.

Fig. 5.3 A spader pushing the residue of crimson clover into the soil. The spades, solid and wedge-like, are attached to an articulated arm that pushes the spade into the soil, gives it a little kick, and then pulls it out as the next spade digs in. The advantage is that the soil is not turned over, as it would be by a plow or rototiller. Organic matter is conserved by minimizing oxidation

5.1.3 Contour Plowing

Contour Plowing means plowing along a constant elevation instead of plowing across contours. When plowed ridges cross contours, the furrows act as channels that speed the flow of water, and this flow is what causes gullies. The ridges created by contour plowing act as dams that slow down or stop water that is flowing downhill. The service of nature here is the slowing of water flow that allows water to percolate into the soil instead of running off the soil surface.

Box 5.3

In the 1970s, no-till cultivation along with cover crops was becoming recognized as a way to prevent erosion, preserve soil organic matter and improve soil fertility. In 1978, several Ecologists at the Odum School (then Institute) of Ecology established a field experiment to compare soil fertility and yields of cotton and other annuals in plots cultivated with no-till management with those farmed conventionally, that is, with rototilling and inorganic fertilization (Hendrix et al. 2001). The research continued for 20 years, but the researchers were unable to find significant differences in soil fertility between the experimental and control treatments. The reason was that the plots were established at a lowland bend in the North Oconee River in Athens, where several storms during the research period produce floods that enriched the soil through deposition of silt. The benefits of alluvial deposition was an overriding effect that obscured the benefits of no-till cultivation. The most significant finding of the project was that in no-till, decomposition was primarily by fungi, while in conventional till, bacteria were the primary decomposers. Because of their larger structure, fungi may be more effective in conserving soil nutrients than bacteria.

5.1.4 Hedge Rows

On some of the Philippine Islands, annual crops are planted on mountain slopes that are too steep for tractors with the use of a technique called Sloping Agricultural Land Technology (SALT). The farmers plant lines of perennial shrubs spaced 5–10 yards apart along contours. These shrubs act as barriers to erosion, and terraces form naturally between the hedges. At Spring Valley Ecofarm, I have tried something similar called “Alley Cropping”. Leguminous shrubs have been established along the contours of a slope, and economic crops are planted in the “alleys” between the hedges (Fig. 5.4). After various trials, I found the species best suited for hedgerows was false indigo, *Amorpha fruticosa*. The hedges not only help control erosion, they provide a habitat for beneficial insects that prey upon pest insects in the alleys. Several times during the growing season, the shrubs are pruned, and the litter adds nitrogen and carbon to the soils. The sustainability value of contour hedgerows becomes significant only after 2 years, when they become well established (Matta-Machado and Jordan 1995).

5.1.5 Wind Breaks

On dry, windy, spring days I have driven through cropland in Central Georgia where dust kicked up from fields was so thick I could hardly seen the road. Rows of trees

Fig. 5.4 Corn and beans "alley cropped" between hedgerows of *Amorpha fruticosa*

as windbreaks are used in some regions of the world, but they are not common in the Southern U.S. Like hedgerows, it takes several years for their services to develop.

5.1.6 Kudzu *(Pueraria sp.)*

Kudzu is a vine that was introduced to the South from China to control erosion after the dust bowl in the 1930s. Today it is sometimes regarded as a pest species, because it spreads rapidly and can strangle trees, or shade out trees when it reaches the canopy. However from a sustainability standpoint, it gets high grades. It is very effective in reducing erosion. It is a legume, and symbiotically fixes nitrogen. On the terraces of Spring Valley Ecofarm where kudzu was planted during the 1930s, soils are much richer and higher in organic matter than between terraces. Where it climbs the trees along the edge of my pasture, I cut it at about 3 ft. It then sprouts from the cut, and my horses eat it faster than it can grow. It is easily planted by simply cutting a piece of root from an existing vine and sticking it into the earth somewhere else.

5.1.7 Perennial Grains

The biggest cause of soil erosion is the yearly plowing of soil in order to grow annual grain crops such as wheat and corn, almost all of which are annuals. One of

Box 5.4

I once asked Wes Jackson, Director of the Land Institute, if modifying annual wheat into perennials would decrease wheat yield, because the energy devoted to seed production in annuals would be diverted to synthesizing carbohydrates in perennials needed for the wheat to overwinter. He conceded the point, but argued that perennial grains can start producing earlier in the growing season, and that this longer growing season would enable a higher production. That remains to be proven. Is grain yield dependent on length of growing season, or is yield the same no matter if it begins growing in March or in May?

the biggest contributions to sustainability that plant breeders could make is to create perennial grains. The researchers at the Land Institute, Salinas Kansas are looking in this direction. They are trying to breed the capability for overwintering into annual crops such as wheat so they become perennials (Box 5.4). Ability to overwinter is a service of nature.

5.2 Increasing Soil Fertility

An important problem with inorganic industrial type fertilizers is that they are too soluble. Once they are applied to the soil, they dissolve and are leached or vaporized before they can be taken up by the crop plants. Farmers try to time their fertilizer applications so that there is a minimum of wastage, but it is difficult to due. Often, much of the fertilizer washes into nearby streams and rivers, and ends up in the Gulf of Mexico or Chesapeake Bay, where the nutrients stimulate growth of algae that eventually leads to huge areas of hypoxia. Slow release inorganic fertilizers are available, but they are expensive. The solution to this problem is application of organic fertilizers. The advantage of organic fertilizers is that they release nutrients at approximately the same rate that plants need them, because the environmental conditions that stimulate plant growth are the same ones that stimulate organic matter decomposition. The service of organic fertilizer is that it is the energy source for the soil micro-organisms that conserve and recycle nutrients, and that improve the porosity and permeability of the soil

5.2.1 Manuring

Manuring is the addition of animal dung to a field that is to be cropped, in order to add nutrients and to feed the community of soil microorganisms that increase

Box 5.5

For the small scale home gardener, compost is often made of food scraps (but not meat) and grass clippings mixed with a high carbon product such as dried leaves.

nutrient recycling. On the scale of an entire farm, manuring may or may not increase energy efficiency, depending on how the manure is collected. In the industrial chicken broiler system, where chickens are housed in crowded conditions and straw, rice hulls, or other dry litter is used to absorb chicken manure on the floor, it is relatively energy cheap to scrape out the litter, load it onto a truck, and spread it on corn fields. The industrial chicken broiler system, however, is unsustainable because of the high energy costs of heating and lighting the buildings, and feeding the chickens with grain.

In the dairy industry, where milk cows are brought into the barn twice a day, manure collection can be done with little energy because the manure is concentrated. However, in most dairy farms, the manure is usually washed out into lagoons where it is subject to overflow during storms. Sometimes the lagoons are pumped out into nearby pastures to enrich the soil, but transporting the liquid beyond the farm that produces the manure is impractical.

Integrated crop-livestock systems are a promising way to utilize manure without having to collect it. A research project was developed near Moultrie Georgia to integrate cattle during winter onto traditional cropland. Cotton and peanuts were grown in rotation during the summer with rye of ryegrass as cover crop in the winter. Ten steers grazed the entire 4 ha area for two to three winter months. Although crop yields did not increase in the grazed area compared to a control, the manure generated enough cover crop production to enable the cattle to gain weight (Franzluebbers 2007).

5.2.2 Composting

Composting is when the manure is mixed with wood chips, straw, or other carbon-rich litter to produce an organic fertilizer (Box 5.5). There are two benefits of composting over manuring: Pathogenic bacteria are destroyed by the heat generated by the composting process; Nutrient release from compost more closely matches the rate of demand for nutrients by plants – nutrient release from manure is rapid, and can result in nutrient leaching. Composting and manuring are beneficial for sustainability, because they are energy and nutrient sources for the soil community that recycles nutrients (Box 5.6).

Box 5.6

Manure from industrial chicken operations is sometimes composted and sold to farmers as a value-added product. At Spring Valley Ecofarm, we use old hay for bedding for our chickens, ducks, and geese. After several months, we clean out the hay, well enriched with poultry manure, and make it into a compost pile. We also compost horse manure. During the winter, we keep the horses in a small paddock, and feed them bales of hay. At the end of the winter, there is a rich mixture of left-over hay and manure on the soil which we scrape together into a compost pile which is then used to fertilize the beds of vegetables.

In Athens, Georgia, there is now a system of nutrient recycling which would seem to increase sustainability on a county-wide scale. Municipal sewage waste is dewatered in tanks, and after treatment, the water is returned to a nearby river. The solids that accumulate on the bottom of the tanks are transported to a facility where they are mixed with wood chips from urban forestry operations. The mixture is composted for several months or more until the compost is certified pathogen free. The compost is then made available to farmers at minimum cost. This system works well where there are no heavy industries pouring toxic heavy metals such as cadmium, lead and mercury into the sewage system. A big disadvantage of composts and manures is that that they are bulky and more difficult to handle than inorganic fertilizers.

5.2.3 *Other Organic Amendments*

Blood meal is dried animal blood, typically cow blood, but it can also be the blood of any animal that goes through meat packing plants. The blood is collected after the animals are killed and then dried to make a powder that is rich in nitrogen. Because of its high cost, it is used mostly by home gardeners.

Fish oil fertilizer, also called fish emulsion, has been used for centuries to promote vegetable growth. Many native Americans placed fish remains in the trenches used to plant maize. The emulsion can be sprayed on the leaves of plants to stimulate growth. But because fish are used as food for humans and for cats, it is too expensive, both in terms of money and energy for large scale agriculture.

5.2.4 *Liming*

Most agricultural crops grow best when the acidity (hydrogen ion activity) of mineral soil has a pH value between 6.0 and 7.5 (National Research Council 1989). Most of the red clay and sandy soils of the South have a lower pH, between 4.5 and 5.5. To adjust mineral soils to the point where essential nutrients such as nitrogen, potassium, and phosphorus are most readily available, agricultural lime is often applied to the soil. It is comprised of pulverized limestone, and may include calcium oxide, magnesium oxide and magnesium carbonate. When applied to conventionally tilled fields where the soil is clay or sand, it increases the availability of nutrient elements. Liming is an essential subsidy for farmers in the South who plant their seeds in pure red clay. Depending on the organic matter content of the soil, liming may also help organic farmers. Since lime occurs naturally, the service that it provides, reducing soil acidity, is a service of nature.

5.2.5 Microbial Priming

Microbial priming is a process whereby soil microbes increase the rate of nutrient release from the soil in response to amendments such as compost tea that stimulate microbial activity (Fontaine et al. 2003). To make compost tea, you mix water with a high quality biological inoculant (either worm castings or hen litter based compost) and various food sources including simple or complex sugars (table sugar or molasses or sorghum syrup) and mineral mixture (sometimes including humic acid, azimite, gypsum, soft rock phosphate, high calcium lime) to stimulate a microbial flush. Aeration or mixing for 12–24 h is desired to stimulate the microbial flush. Application of the liquid compost is then by sprayer or by hydroseeder as a slurry. Mountain Earth Farms in Georgia in their first year of application of slurry to corn, tomatoes, and blueberries in 2010–2011 experienced the following results (Ellis 2012):

- Organic corn with no additional pest control showed few to no earworms, and a sweet flavor, with a brix rating of 56 when 24 is considered to be excellent (using the standard refractive index of crop juices chart) allowing ears to be sold for $1.00 each a 100 % increase in price from the prior year. (brix method = testing sugar content as an indicator of plant health and quality).
- Mature blueberries yielded 10 gal a bush (a 1/3 increase) and maintained full size berries over the course of the season. New bushes in their second year gained considerable growth in comparison to expected growth.
- Tomatoes and Peppers were exposed to a late freeze (May 5, 2011 – observed 28 °F, recorded 31 °F). Plants had been treated with compost sprays in prior weeks and a mineral application the day before the event. 1,800 tomatoes and 1,200 peppers survived the event with less than 5 % loss.

This technique has particular appeal as a substitute for other more costly and more difficult soil organic matter management techniques such as extensive inputs of large volumes of compost to replace N and C losses by tillage, additions of hay mulch or management of cover crops. The question arises, from where does the sudden pulse of nutrients come from that follows microbial priming. If the source is the active or slow pools of soil organic matter, priming would not make any new nutrients available, but simply reduce the pools more quickly. However, if the priming releases nutrients held in the passive or recalcitrant pools, this then would represent a net gain for the total available nutrient pool.

Disease suppression. Compost tea also is effective for disease suppression in crops. St. Martin and Brathwaite (2012) found that the mechanism is predominantly biological, although chemical and physical factors have also been implicated.

Unpasteurized milk. There is anecdotal evidence that spraying unpasteurized milk on pastures stimulates the growth of grasses. However, accounts of the effect give no hypothesis as to the underlying mechanism. Microbial priming could be an explanation.

Biodynamic Agriculture. "Biodynamic Agriculture" was developed in Austria by Rudolf Steiner in the early 1900s. He characterized it as a "spiritual science" and used an astronomical calendar to guide planting and sowing. The system uses certain "Biodynamic Preparations" to increase crop vigor and yield. These preparations include such compounds as: cow manure fermented in a cow horn which is then buried and over-wintered in the soil; ground quartz mixed with rain water and packed in a cow's horn buried in the spring and dug up in the fall; flower heads of yarrow fermented in a stag's bladder; and many more. Practitioners say that the preparations can't be tested scientifically. Evidence for their effect is anecdotal. If the preparations do have an effect, it may be related to microbial priming.

5.2.6 Crop Rotations

Crop rotations have been practiced in Northern Europe for hundreds of years. Typically a legume such as clover or alfalfa has been included in the rotation to add nitrogen to the soil. In the United States, the recent desire for "economic efficiency" has transformed much of commodity production to continuous cropping, or alternating between only two crops. However, there is renewed interest in crop rotations. Davis et al. (2012) working on an Iowa State University Farm compared grain yields, mass of harvested products, and profits in three types of crop rotations. One type of plot replicated the typical Midwestern cycle of planting corn 1 year and then soybeans the next, along with a routine mix of chemicals. On another, they plated a 3-year cycle that included oats. To the third type was added a 4-year cycle and alfalfa. The longer rotations also integrated the raising of livestock, whose manure was used as fertilizer. The results of the study indicated that more diverse cropping systems can use small amounts of synthetic agrichemical inputs as powerful tools with which to tune, rather than drive, agroecosystem performance, while meeting or exceeding the performance of less diverse systems.

5.2.7 Tightening the Nutrient Cycle

The efficiency of nutrient cycling can be high on a farm that has both plants and animals. The animals produce the manure that is then composted and added to the crop land. Some of the crop yield can then be used to feed the animals. The efficiency of

Fig. 5.5 "Pasturized poultry". The "Chicken tractor" and the portable fence are moved every few days to give the chickens new pasture soil upon which to graze

Box 5.7

Most Colleges of Agriculture carry out very little research on farming that combines crops and animals. Research professors need to isolate all the variables in order to prove the effect of a management technique. Animals are a difficult variable to control in a farm-level experiment.

nutrient cycling can be even higher if the animals graze on the crop land, because their manure doesn't need to be collected. Chickens grazed on a segment of a pasture surrounded by a portable fence (Fig. 5.5) is called pastuerized poultry. The chickens eat the insects and worms in the soil, and fertilize the pasture with their manure. At Spring Valley Ecofarms, we allow our hogs to graze in patches of corn specifically planted for them (Box 5.7).

5.3 Suppressing Weeds

Weeds are better competitors for nutrients and water than are most crop plants. They are usually more insect and disease resistant also. The reason is that competitive ability and pest resistance have been bred out of most crop plants, so that all or most of the energy obtained through photosynthesis can be used to produce yield.

Box 5.8

If seeds or seedlings are planted close together, weeds will be less of a problem because the crops themselves will shade out many weeds. However, plants that are growing close together compete with each other as they grow, and if they are not thinned, the plants do not grow optimally. In the days when cotton fields were managed by hand, this thinning with a hoe was called "choppin' cotton". Control of spacing in tree plantations also provides an environmental service. Foresters often plant trees close together so that they tend to grow straight and tall, because side shading inhibits the growth of branches. As the trees mature however, they tend to stagnate because of intra-species competition.

For thousands of years, mechanical control was the only known method of weed control, besides pulling them out by hand. For small plots, various types of hand hoes have been used. On larger fields, plows pulled by humans, draft animals, and by tractors were used. Plows and other mechanical devices such as roto-tillers are now commonly used to turn the soil to bury the weeds, and cultivators with tines scrape weeds between rows of corn and other crops. From the viewpoint of sustainability, mechanical control of weeds is undesirable because it destroys the soil organic matter, but there are only a few natural techniques to control weeds. One is the use of rye as a cover crop, and then roller-crimping it as in Fig. 4.7. Rye releases a chemical that inhibits the germination and growth of seeds. Vegetable beds can be covered with straw mulch, or hay that is too old for livestock feed. Straw and old hay are normal by-products of a farm operation. Farmers sometimes plant seeds close together because this decreases the ability of weeds to become established (Box 5.8). Another technique used by small scale farmers is allowing geese to graze in the rows once the crops are big enough not to be damaged.

The weed control methods discussed next are not services of nature, but are more sustainable than mechanical cultivation.

5.3.1 Herbicides

Certain herbicides, such as paraquat, have been shown to be harmful to the health of mammals. Use of paraquat is severely restricted. The herbicides 2,4-D and 2,4,5-T were used in the Vietnam war. When veterans that had been exposed to these chemicals came down with various illnesses, it was thought that the herbicides themselves were responsible, but it turned out that the harmful agent was dioxin that was an unanticipated byproduct of the synthesis process. Most herbicides now in use have not been shown to be harmful to mammals. The reason is that herbicides target highly specific biological or biochemical processes within plants, such as photosynthesis and production of branch-chain amino acids. Mammals (humans included) do not

Box 5.9

A high sustainability value for herbicides occurs only if they are used in conjunction with no-till planting, still not widely practiced. In Southern farms where herbicides are applied over herbicide resistant cotton, soil is usually tilled mechanically before planting the cotton.

Box 5.10

The research cost of developing an herbicide is a recurring cost, because many weeds quickly evolve herbicide resistance, and new types of herbicides must be developed. For example, pigweed (*Amaranthus* sp.) is now resistant to many of the herbicides used to control weeds in fields planted with cotton that is genetically modified to resist herbicides.

photosynthesize or produce branch-chain amino acids. Therefore, herbicides that target photosynthesis or branch-chain amino acid production have no place to bind in mammalian bodies and therefore have very little impact (Fishel et al. 2012).

Herbicides are not permitted on farms that are certified organic. To be certified, a farmer must use only products that are "natural", and since commercial herbicides are synthesized in a factory, they are not natural. But how do herbicides fare in a discussion of sustainability? A big plus for herbicides is that when used in no-till agriculture, they kill weeds without disturbing the soil, thus conserving all the energy embedded in the soil organic matter. Another plus for herbicides is that weeds killed by herbicides release their stored nutrients and carbon slowly as the weeds decompose. Slow release facilitates carbon use and nutrient recycling by the community of soil micro-organisms. The question from the viewpoint of sustainability is the energy cost of herbicides. From a farmer's point of view, they require less energy to control a field full of weeds than hoeing by hand. They also may cost less energy, when compared to tractor fuel needed to plow the field mechanically (Box 5.9).

However there are other costs associated with herbicides. The energy cost is not only that of synthesizing the compound, but also the research cost of developing the herbicide, building the factory to synthesize it, and the marketing cost of getting it out to farmers (Box 5.10). This has been called "embedded energy" (HT Odum 1988). When embedded energy is taken into consideration, the energetic costs of herbicides is higher. But all these energetic costs cannot be allocated to each individual farmer that uses herbicides. The cost must be pro-rated among all the farmers that use herbicides. The same problem of analyzing energy costs for herbicides also arises when analyzing the energy costs of using a tractor. Clearly the energy cost of the fuel that propels the tractor while spraying the herbicide must be counted, but the energy embedded in the tractor must be pro-rated over the lifetime of the tractor.

5.3.2 Plastic Weed Barriers

Plastic weed barriers are layers of thin plastic laid on top of a vegetable bed to prevent weed growth. They are held down by steel wires called ground staples. Drip lines for irrigation are laid down on the bed before the barrier is laid. Holes are punched or burned in the plastic, and seedlings started in the green house are inserted through the holes. So far, the process seems cheap energetically, the only cost being the energy used to manufacture the plastic. The downside comes after the crop is harvested and the mulch must be removed. Pulling up the plastic is energetically expensive, and disposing of it even more expensive.

5.3.3 Flaming

Flaming is a technique whereby a modified propane flame thrower is pointed at the weeds. The weeds are not actually oxidized, but simply dehydrated (Lampkin 1990). The method seems less expensive than weeding by hand labor, but the organic matter that the weeds could contribute to the soil is lost.

5.3.4 Soil Solarization (Sterilization)

This involves laying a layer of thick clear plastic over a bed. Heat from the sun kills weed seeds. It may take several months to be effective. Like plastic weed barriers, it is energetically expensive.

5.4 Controlling Insect Pests

Until the synthesis of chlorinated hydrocarbons such as DDT and other persistent pesticides in the 1940s, there were few things that a farmer could do to prevent damage to crops by insects and disease. Copper sulfate, a highly toxic persistent chemical was one of the few poisons available to control pests. It was sprayed on directly, or used together with lime in Bordeaux mixture to form a fungicide used against molds on grapes, potatoes, and other crops. Another alternative was to look for, or to breed resistant varieties (Box 5.11).

Box 5.11

Insects damage plants either through direct consumption of the plant by the adult or larval (caterpillar) stage, or by transmitting diseases by the adult stage. Plant diseases are caused by fungi, bacteria, and viruses, and some nematodes (roundworms).

As a result of the discovery that persistent (hard) pesticides were toxic not only to pests, but to all types of creatures including humans, agricultural scientists began looking for alternative ways to control insects and disease. It turned out that there were many ways, all classified together as Integrated Pest Management (IPM). Integrated pest management means controlling pests in ways that are an alternative to frequent, periodic applications of “hard” pesticides and fungicides.

5.4.1 Crop Management

- **Ensure that your soil has a high content of soil organic matter**. Soil organic matter supplies the nutrients that enable a plant to grow rapidly, and to synthesize chemical defenses against many insects and diseases. Farmers that build soil organic matter already are using a sustainable technique, so the insect and disease repellent benefit is already included in the cost of the organic matter.
- **Encourage diversity/avoid monocultures**. Pest insects are more likely to find and remain on hosts that are growing in monocultures. In complex, diverse systems, pest species with a narrow host range have greater difficulty in locating and remaining upon host plants in small, dispersed patches, as compared to large, dense, pure stands. In many cases, there will be more predators that prey ion insect pests in complex polycultures than in simple monocultures. Polycultures can provide a more reliable source of food for the predators. Some predators consume a wide variety of prey and therefore are more likely to find a continuous source of food in a heterogeneous habitat. Other predators are specialized, but ecosystem complexity also helps maintain their populations. Their populations are less likely to fluctuate widely in a heterogeneous system, because its complexity allows the prey to escape local extinction. In other words, you don’t want to eliminate completely the prey species, because if you do, the predators will then leave (Box 5.12).

Box 5.12

Question: Why are there so many plant species in the humid tropics?
Answer: The diversity is a defense against insects and disease that reproduce continually throughout the year in the hot, wet climate (Montagnini and Jordan 2005).

- **Rotate your crops**. Planting the same crop year after year in the same field allows pest populations to build up in the soil Take the example of the European corn borer and corn earworm. In the first year of a corn crop, the insects will eat their fill, and leave eggs or overwintering pupae in the debris that remains after harvest. The following spring, the new generation of pests can get right to work, feeding and reproducing themselves. The same is true for disease organisms that

Box 5.13

T Methyl bromide (MeBr) is an odorless, colorless gas that has been used as a soil fumigant to control nematodes across a wide range of crops. Because MeBr depletes the stratospheric ozone layer, the amount of MeBr produced and imported in the U.S. was reduced incrementally until it was phased out in January 1, 2005. Although other soil fumigants have become available, the most effective sustainable control of nematodes is to rotate crops.

develop in the field. Favored host plants are easy to find and are available every year. As a consequence, pest populations explode (Ellis and Bradley 1996). Bacteria also can survive indefinitely in the soil. For tomatoes, plant them no more than once every 4 years in the same spot. Avoid planting other *Solanaceous* crops (potato, pepper, and eggplant) in the same area, too – they are susceptible to the bacteria (Box 5.13).

- **Select crop varieties that are disease resistant**. Modern crops all have distant wild relatives that evolved chemical and physical defenses against insects and diseases. As these wild species were selected and cultivated to produce food for humans, these defenses were bred out in favor of high yield. Many heritage varieties, however, have maintained part of the genome that helps them resist insects and disease. Using such heritage varieties will decrease the cost of insect and disease control. An alternative choice would be to use genetically modified crops in which genetic engineers have re-inserted, at an energetic cost of yield, the previously bred-out gene that confers disease and insect resistance (Jordan 2002).
- **Exclusion.** Keep materials, plants, or objects that are contaminated with pathogens out of the greenhouse or tool shed and prevent their introduction into the production system. For seedling starts, use new or disinfected pots, trays, and potting mix. Contaminated spades or clippers can spread disease from one plant to another, or one field to another.
- **Remove and destroy affected plants**. This will inhibit the spread of disease.

5.4.2 Beneficial Interactions

- **Encourage Natural Predators – Provide beneficial refuges and habitats**. Plant unsprayed, flowering vegetation that provides shelter, prey, pollen and nectar, so beneficial, both natural and released live longer and reproduce better. Perennial hedgerows sometimes still found in rural European farms, provide habitat for beneficial insects. In an alley cropping system at Spring Valley Ecofarms, we found that the hedgerows of false indigo (*Amorpha fruticosa*) supported heavy populations of predatory spiders. Thies and Tscharntke (1999) showed how old field margin strips along rape fields was associated with increased mortality of pollen beetles, a pest on oilseed rape, because of the habitat it provided for parasitic insects.

- **Release beneficial organisms**. Population outbreaks of pests often occur because there are no predator populations to control them. Importing predator species from regions where the pest populations are under control is a strategy sometimes know as biological pest control. Predatory insects such as lady beetles or ground beetles eat many other insects during their life cycles. Some have restricted tastes; for example, aphid midges feed only on aphids. Others, like praying mantids ("mantises") or assassin bugs may be able to eat almost any species of insect they catch (Ellis and Bradley 1996). Insects such as parasitic wasps are called parasitoids. They lay eggs singly or in groups near, on, or inside the bodies of other insects. The parasitoid larvae develop as internal parasites. Parasitoids eventually kill the host, then pupate inside or crawl outside and pupate near the dead husk.
- **Look for allelopathic interactions**. Cover crops also may help the fight against pests. Investigators are testing various cover crops to help control tomato spotted wilt virus transmitted by thrips. It is one of the most devastating insect-transmitted vegetable diseases. In the Southeast, it affects everything from peppers to peanuts and can cause complete crop failures in the field. A rotation of lupin, bidens, and sunn hemp has promise of repelling the thrips (Cooper 2012).

5.4.3 Natural Pesticides

Biopesticides (also known as biological pesticides) are pesticides derived from such natural materials as animals, plants, bacteria, and certain minerals. For example, canola oil and baking soda have pesticidal applications and are considered biopesticides.

- Biopesticides usually are inherently less harmful than conventional pesticides.
- Biopesticides generally affect only the target pest and closely related organisms, in contrast to broad-spectrum conventional pesticides that may affect organisms as different as birds, insects, and mammals.
- Biopesticides often are effective in very small quantities and often decompose quickly, thereby resulting in lower exposures and largely avoiding the pollution problems caused by conventional pesticides.

When used as a component of Integrated Pest Management (IPM) programs, biopesticides can greatly decrease the use of conventional pesticides, while crop yields remain high. (Environmental Protection Agency 2012). Some of the well known biopesticides include:

Bacillus thuringiensis (or **Bt**) is a soil-dwelling bacteria, commonly used as a biological pesticide; During the formation of spores, many Bt strains produce crystal proteins (proteinaceous inclusions), called δ-endotoxins, that have insecticidal action. This has led to their use as insecticides, and more recently to genetically modified crops using Bt genes.

Neem. Neem is a botanical pesticide derived from the neem tree, a native of India. This tree supplies at least two compounds, azadirachtin and salannin, that have insecticidal activity and other unknown compounds with fungicidal activity. The use of this compound is new in the United States, but neem has been used for more than 4,000 years for medicinal and pest control purposes in India and Africa. It is not highly toxic to mammals.

Pyrethrum/Pyrethrins. Pyrethrum is the most widely used botanical insecticide in the United States. The active ingredient, pyrethrin, is extracted from a chrysanthemum plant. Most insects are highly susceptible to pyrethrin at very low concentrations. The compound acts rapidly on insects, causing immediate knock down. Flying insects drop almost immediately after exposure. Fast knock down and insect death don't, however, always go hand in hand; many insects recover after the initial knockdown phase.

5.4.3.1 Before You Use Pesticides

Before using pesticides to control insects and disease, it is economically and energetically worthwhile to do a cost/benefit analysis. The things to consider are:

1. The cost of control
2. The benefit of control

If the cost per acre of spraying insecticide is greater than the economic loss caused by insects, spraying loses more money and energy than it gains. An important thing to remember is that the number of insects killed is not proportional to the amount of insecticide applied. For example, 95 % of the insects on a crop might be killed by 1 gal of insecticide concentrate, but it might take another gallon to get the last 5 %. That last gallon may not be economically nor energetically worthwhile. Plus you should leave that last 5 % to keep beneficial insects from going to your neighbor's field for sustenance.

Monitoring. Before you spray, be sure that you have a problem. Several times a week, you have to examine your crop to see what insects or disease might be there, and if they pose a threat. Another type of monitoring is the use of traps baited with insect attractant, often sex pheromones. Crops are sprayed only upon evidence that dangerous levels of pests are in the area. Once it is determined that spraying with insecticides or fungicides is necessary, the next decision is what insecticide or fungicide to use. If you are growing crops to be certified organic, your choices are limited. Organic gardeners can use certain pesticides – chemicals that are derived from botanical sources. These chemicals may be highly toxic, but they break down more rapidly than common chemicals, such as the Sevins, Malathions and 2,4,Ds.

5.5 Increasing Resource Use Efficiency

One of the topics in my organic agriculture class is increasing the efficiency in the way plants use their available resources. To begin the session, I take them into a an old-growth forest that is at least 150 years old. I point out that there are about eight species of oaks, two species of hickories, and about a dozen more tree species including sweet gum, tulip poplar, red maple, mulberry, hackberry, and magnolia. Then I point out that the soil and the terrain in the forest appears homogeneous. The site looks uniform. Then I ask them why are there so many species in the forest, when classical population theory predicts that the one species that is best adapted to a particular niche will eventually crowd out other species from that niche. The answer is that just because the site and the soils are uniform, that does not mean that the environment and the way species have adapted to the environment are uniform. Climate is a factor. Some species do well in dry years, and gain a competitive advantage during a drought. The next year may be wet, thereby giving another species a short term advantage. Nutrient requirements are important. Some species need lots of calcium, and exploit that resource in the soil, while others accumulate one or another of the other essential elements. Light intensity varies through a forest stand. Canopy species do best in the overstory, while others are adapted to the shade of the understory. Another reason that a tree happens to grow in a particular micro-environment is that it is where a squirrel happened to bury an acorn. Heterogeneity within the soil itself occurs when an old tree falls over. The upended roots expose mineral soil, and the gap in the canopy allows sunlight to stream in, thereby opening up an opportunity for a pine to get started. The result of all these factors in a seemingly homogeneous stand is that the resources necessary for functioning of an ecological system – energy from sun, nutrients, and water – are more fully utilized.

Then I take the students to an early successional pine stand. There, all individuals occupy the same niche. The trees all have the same architecture and structure, so there is competition for light. They all have the same rooting depth and nutrient requirements, so there is competition for essential elements. If the stand is unthinned, the competition between individuals results in stagnation.

5.5.1 Mixed Species Agriculture

Just like every tree species, every crop species has its own "niche", that is, the combination of resources to which it is best adapted. When species with different niches are planted together in close proximity, resources are used more efficiently. A classical example is the "three sisters" a combination that was used by native Americans in the Southeast. It consists of corn, squash, and beans. Corn grows tall and has many vertical leaves which efficiently capture sunlight in early morning and late afternoon. Squash has horizontal leaves, which are good at capturing light from directly overhead, and also that shields the soil from raindrop impact. Beans supply nitrogen to the soil and use the corn as a trellis.

There are various types of mixed species agriculture that are designed to mitigate the problem of harvesting that occurs with the three sisters combination.

- **Multiple Cropping**. Two or more crops with different architectures or life forms are grown in the same field at the same time. Annuals and perennials can be organized in fields together. Rows of fruit or nut trees can be interplanted with cereal grains or vegetables in between. This arrangement is called agroforestry. When timber trees are interplanted with agricultural crops, the system is called "taungya".
- **Mixed cropping**. Two or more crops are mixed together in the same field at the same time without a definite row arrangement. Complimentary cover crops include oats and peas. Mixtures of forage grasses and legumes work well in pastures.
- **Strip-intercropping**. Two or more crops are planted in the same field in alternate rows. The system is most efficient if the two species have different niches, and mature at different times (Fig. 5.4).
- **Crop rotations**. Because of the difficulty of managing and harvesting mixed species agricultural crops, organic farmers often plan rotations of crops to more fully use the nutrients in the soil. The first year, could be a soil building crop. Legumes such as alfalfa and clover are good, and also prairie grass sods. If there has been sufficient build up of nutrients, soil depleting crops such as corn, soybeans, or potatoes can be planted the next year. Soil conserving crops such as wheat, barley and oats could follow. The rotation can be more finely tuned by looking at the particular nutrient that is heavily fed upon – for corn it is nitrogen, for soybeans it is potassium (SARE 2009).

Although it is more challenging and more expensive to cultivate a variety of crops and animals on a single farm, variety can be a type of insurance. Weather one year can favor a certain crop, a different crop the next year. Weather can affect severity of crop disease on one species more than another. Economic demand can change from year to year. A farmer who produces a diversity of products can be more sustainable than a farmer who specializes in one, because diversity provides economic stability, and stability provides sustainability.

Theory may conflict with practice. Mixed species agriculture and crop rotations based on ecological theory can conflict with economic considerations. Should a farmer buy all the machinery that he needs for each species of the rotation or mixture, and expensive proposition, or is he better off to specialize in just one crop? Suppose the theoretical rotation calls for a member of the Brassica family such as brussel sprouts, but the market is much better for Romaine lettuce, a member of the Composite family. Should he grow the brussel sprouts anyhow, despite a projected lower income?

5.5.2 Mixed Species Forest Plantations

In the 1950s, when I was an undergraduate student in Forestry, we used F.S. Baker's "Principles of Silviculture" (Baker 1950) as a text book. In it he defined Forestry as "the scientific management of forests for the continuous production of goods and services". The key to continuous production was to harvest only the largest trees, and carefully leave the younger ones to grow and be ready for another harvest in a

Box 5.14

Paulownia spp. (Princess Tree) is a fast growing tree native to China, and has a high economic value in Japan. It is light and strong, and makes excellent furniture wood. *Paulownia tomentosa* was accidentally introduced to the U.S. in the 1800s when its seed pods were used as packing for China plates. In 1994, I experimented with another Paulownia species, *Paulownia fortunei*. It has a much straighter form than *P. tomentosa*. Its big advantage over pine is that it sprouts after being cut. It does not have to be replanted for a second rotation, and little site preparation is needed. One simply lops off all but the best sprout, that then grows into a straight trunk. *Paulownia* spp. is listed as an invasive species, because it colonizes abandoned fields in the Southeast (USDA 2012). However, it is not nearly as invasive as loblolly pine which is not listed. Also, in contrast to privet, a true invasive, it cannot compete with late stage successional species such as oaks and hickories.

few years. The structure of the forest and the soil organic matter remained basically intact. It was sustainable forestry.

In the 1960s, there was a revolution in forestry. Continuous production was abandoned, in favor of clear-cutting and replanting. The reason was that clear-cutting was more efficient, when new machinery such as the feller-buncher and the mechanical skidder was introduced. A bigger profit could be made more quickly by harvesting everything all at once. The problem with clear cutting is that it scars the land, destroys the soil organic matter, and renders the site prone to erosion.

Nevertheless, most managed forests in the South are single species plantations that are planted after a clear-cutting of the previous forest. As a result, they use resources inefficiently. At Spring Valley Ecofarms, we have been experimenting with mixed species plantations because they, like natural forests, have more opportunities to fully use the available resources. One of the best combinations was a fast growing species, princess tree (*Paulownia fortunei*) (Box 5.14) interplanted with various species of oaks and green ash. The Paulownias grow fast, and are ready for harvest in about 12 years. At the same time, the oaks and ash are putting on a lot of root growth. When the Paulownias are cut, the oaks are released from competition for light, and they begin a rapid growth. However, it takes several years for the oak canopy to close. Meanwhile, a second rotation of Paulownia springs up between the oaks.

On very compacted soils, we have used red cedar and pine, together with oak and ash.

5.5.3 Mixed Species Grazing

Various combinations of sheep, cattle and goats can sometimes be used to take better advantage of the plant species in a pasture. Sheep are selective foragers, preferring to eat immature grasses, forbs and weeds. Cattle, on the other hand, sometimes prefer to eat mature grasses and legumes and have been described as "luxury grazers" (Moses 2012). Goats will feast on woody plants that neither sheep not cattle will touch.

5.6 Improving Pastures

Continuous grazing of cattle on a single pasture leads to rapid degradation of the grasses. Cattle will graze favored species of grass right down to the root, while leaving other less palatable grasses, herbs, and woody perennials. This gives the competitive advantage to the unfavorable plants, and they spread rapidly throughout the pasture. Intensive grazing management is a remedy for this problem.

5.6.1 Intensive Grazing Management

The objective of intensive grazing management is to keep pasture plants within their stage of rapid growth, so that the rate of new herbage formation remains high (Murphy 1990). This often is the period when grasses are between 2 and 4 in. high. Grass elongates from the base, not from the apex as in woody plants. This means that the best, most succulent, and most rapidly growing portion is below 2 in. If the cattle eat that, the roots of the grass will starve and the plant will die. Above 4 in., the grass becomes less succulent, and the stems will begin to go to seed. This is a less productive stage.

The key to maintaining grass at its optimum stage of growth is to allow cattle to graze intensively in a paddock for 1 or 2 days – just enough so that they mow the grass to about 2 in. – and then move them to a new paddock. At Spring Valley Ecofarm, we have used paddocks of about 1/4 acre for 10 steers. Fencing was portable electric, connected to a solar charger. Moving the fence took one man less than an hour. Moving portable water troughs and shade is somewhat of a problem. Ideally, the paddocks should be in the shape of pieces of pie, with the shade and water at the center, but this is not always feasible (Box 5.15).

Box 5.15

Restaurants are now charging a premium price for beef from cattle that are grass fed.

A grass-fed cow eats from a pasture and is not "finished" on a diet of grains and supplements for rapid weight gain. It is said by its promoters to be better for the planet (less energy goes into growing grass than grain); better for the beef eater (less overall fat, and more omega-3s and other "good" fats); and better for the cow (critics decry feedlot practices as inhumane). Price may be the first thing to notice about grass-fed beef: In supermarkets, small-production, grass-fed meat can be a lot more expensive than average grain-fed beef, just as artisanal cheese costs more than industrial cheddar (Cross 2011).

5.6.2 Rotational Grazing

Intensive grazing management is worth the effort if you are raising cattle for beef production, where most of the carbohydrates stored in the grass goes toward increasing the rate of meat production. It is a lot of work though. At Spring Valley Ecofarm, we use rotational grazing for our three horses, because the grass is used only for maintenance, not for weight gain, so less is needed. We keep them in one pasture for several months, or for a whole growing season, and then move them to another, leaving the original pasture to recover.

5.7 Increasing Efficiency of Irrigation Systems

Three Southern states have been battling for years over water rights to the Chattahoochee river. It originates in Georgia, and then passes through Alabama and Florida before emptying into the Gulf of Mexico. Atlanta claims the right to use the Chattahoochee for its water supply, while downstream users claim Atlanta's excessive use threatens their source of irrigation water, and also the fresh water needed for the mussel fisheries in Florida.

Increasing the use of ground water also creates a sustainability problem for agriculture. A story in the July 9th 2012 Banner Herald, Athens, Georgia read: "When Chuck Ellis became the extension agent in Dooly County 31 years ago, he estimated less than 5 % of row crops were irrigated. Today he puts that number at over 60 %. 'The increase has been dramatic in the past few years,' he said." The farmers in Dooly County are now drilling wells for their irrigation water. Their cost for water will include drilling, and the cost of pumping up subsurface water. As the aquifer becomes depleted, costs will increase. The Ogallala Aquifer in Kansas and Nebraska that has enabled annual wheat and corn to be grown on the High Prairie is in even worse condition. It is rapidly declining, and the farmers there have no place toward which to migrate (Scanlon et al. 2012).

Scarcity of fresh water can be partially overcome by more efficient irrigation systems that reduce water waste through employing highly sensitive soil moisture indicators (Melancon 2012). Another approach is with drip irrigation systems in which water is delivered through plastic tubing with emitters that feed water one drop at a time, thereby minimizing loss due to evaporation, and also to drainage due to overwatering. It is extremely effective for many vegetable crops and fruit trees, but impractical for thousand-acre wheat and corn fields. For large scale applications, a low-energy precision device sprays water just a few inches above the crop canopy (SARE 2003). Evaporation loss is much less than from overhead center-pivot irrigation systems or water guns that spray water high above the crop canopy.

Growing drought adapted or drought tolerant species is strategy that takes advantage of the natural abilities of various species of crops. For example, where droughts are common, use species such as sudan grass instead of water-demanders such as corn to feed cattle. A recommendation to use perennial species instead of annual crops is one of the recommendations of the Ogallala Aquifer Initiative, a collaboration between

Box 5.16

In one sense, water has been the limiting factor in agricultural societies where cheap energy was not available. Declining availability of fresh water 5,000 years ago in Mesopotamia caused the inhabitants to seek new lands (Chap. 2). Decreasing water supplies are not critically important to survival when there are new lands to inhabit and cultivate. But today in most of the world, there are no new lands suitable for agriculture.

the Natural Resources Conservation Service and local organizations to help conserve the Ogallala water source (NRCS 2012). With perennials, the soil surface maintains a cover, thereby decreasing evaporation from bare soil (Box 5.16).

5.8 Farmscaping

Farmscaping is a new word. It has been defined by ATTRA (2012) as "a whole-farm, ecological approach to pest management. It means the use of hedgerows, insectary plants, cover crops, and water reservoirs to attract and support populations of beneficial organisms such as insects, bats, and birds of prey".

This definition is too restrictive for a term that seems to suggest the landscaping of all functions of a farm. Webster's Third New International Dictionary defines landscaping as "arranging and modifying the effects of natural scenery over a tract of land so as to produce the best aesthetic effect with regard to the use to which the tract is to be put." To use the term *farmscaping* in the same sense as *landscaping*, but of a farm we can define farmscaping as "agriculture adapted to the landscape." That is the sense in which Ecoagriculture partners (2012) defines their mission, which is "Landscapes for people food and nature". It means understanding the history of a site and its influence on the interaction of topography, soils, and water drainage, and then designing a farm in harmony with these interactions. It is landscaping of a farm that considers the environment, past and present. It means raising plants and animals where they do best. It is an old concept with a new definition. Farmscaping has transformed Spring Valley Ecofarm from a homogeneous cotton monoculture to a farm that is adapted to the varying landscape and the multiple niches that actually exist on its 100 acres (Box 5.17).

5.8.1 Farmscaping at Spring Valley Ecofarm

The topography of Spring Valley Ecofarm consists of rolling hills, ranging from an elevation of 690 ft above sea level in the creek bottom to 770 ft on the hill tops. As one walks down slope from a hill top, the habitat changes dramatically. Soil on top of the hills is highly eroded. It is pure red clay, and becomes like brick when it dries. Although the soil is poor, we have planted blueberries and grapes. Because

Box 5.17

For over a century, the land that is now Spring Valley Ecofarm was a cotton plantation owned by the descendents of a Civil War Veteran. Cotton farming in the nineteenth century was very destructive of the soil. Fields lay barren during the winter, and heavy rains washed away the good topsoil. To partially counteract the erosion down the slopes, the family built a series of terraces that ran along topographic contours. Those terraces, with a drop of several feet between each, are still in existence.

blueberries and grapes are perennial crops, their soil does not need tilling. We add mulch and compost to the base of each shrub and vine to ameliorate the poor soils.

Down slope begin a series of terraces where terrain was flattened to facilitate cultivation. At the lower edge of each terrace, soil was mounded up by the cotton farmers to slow the flow of water during rains. Along these bunds we have planted fruit trees – peaches, apples, pears, plums, apricots. The soil in the mounds is relatively permeable, allowing for better drainage and root growth of fruit trees. The bunds, and thus the rows of trees are widely spaced. Air drainage is good and as a result, the problem of plant disease is lessened. On the flat slopes between the mounds there is pasture for cattle and horses.

The lowest terrace is where most of topsoil eroded from higher elevations has accumulated, resulting in soils relatively high in organic matter and nutrients. This terrace is dedicated to vegetables, because most vegetables have high nutrient requirements. The organic matter in the soil also helps retain soil structure during the frequent cultivation required for annual vegetables. Within the terrace we have planted hedge rows of "false indigo", a shrub that contributes nitrogen to the soil and provided habitat for beneficial insects that prey upon insect pests. The hedgerows border an "alley" where vegetable crops are grown (Fig. 5.4).

Below the lowest terrace and along the edge of the creek there is bottom-land forest, a buffer to protect the stream. The soil is deep, and there is a thick layer of soil organic matter derived from the decaying litter of the forest. The soil has been covered by privet, a truly invasive shrub because it thrives in the shade of native tree species and covers the ground so completely that tree seedlings cannot establish. We cleared out the privet and dug a soil pit to get a picture of the soil profile (Fig 5.6). It provides an interesting chronosequence. At the bottom of the pit is coarse sand, laid down through centuries by the meandering creek. Between 7 and 9 in. from the pit bottom is a bed of red clay, probably formed between 1864 and 1930, when the bottom land was grazed with cattle, and sheet erosion from the cotton fields above the bottom land carried down the red clay. Above the clay is a layer about 10 in. thick, apparently formed since the establishment of forest cover after the cessation of grazing in the 1930s. It has a high content of organic matter mixed with sand and clay laid down when the creek floods over its bank. The oldest trees in the bottomland are about 80 years old, as determined by a count of annual growth rings. That suggests the top horizon formed at a rate of 1/8 of an inch per year.

Fig. 5.6 Soil pit in the bottomland forest at Spring Valley Ecofarm. Annual leaf litter fall contributed to the rapid buildup of soil on top of the red clay

Water drainage on the farm influences the farmscape. The farmhouse is located on upland that divides drainage between the East Branch of Trail Creek and Shoal Creek. Two hundred yards below the farmhouse, Trail Creek was dammed in the past century to form a pond for watering cattle. Past erosion partially filled it with sediment, and it is no longer usable. However the pond and the secondary forest that have grown up around it provide habitat for wetland species. Below the dam, the creek becomes permanent. In the lower reaches, a spring feeds into the creek which is now the source of our irrigation water and water for livestock.

Between the farmhouse and the pond is a three-acre stand of old growth oak and hickory, some of which are close to 150 years of age. Soil under the stand is a thick layer of topsoil, suggesting that the stand was never plowed or cultivated (Fig. 4.5). The area is being preserved as an example of what the original pioneers found when they settled the area.

Other upland areas of the farm are in forest. In some areas previously in pasture, we have established stands of mixed species, which begin to mimic the diversity of natural forests. In other areas there is secondary forest that originated when cotton plantations were abandoned in the 1930s. First to come into these areas was loblolly pine. They reached maturity in the early twenty-first century, and in 2009, the pines were logged to allow the release of the oak and hickory saplings in the understory.

In the area near the farmhouse we keep chickens, ducks, and geese. We line their pens with wood chips or straw that absorb their droppings. The resulting mixture is collected, piled, and made into compost. that will fertilize the vegetable garden.

Berry (2009) argues that small farms are the optimum size operation for the future, because farmers on small farms are better attuned to the environmental variables (services of nature), and can use his or her knowledge to take advantage of increased energy use efficiency offered by the services of nature that occur in different parts of the farm.

Art in the Farmscape. Art and beauty in the landscape of cities is justified for the aesthetic pleasure and spiritual uplifting that it gives to city dwellers. Art and beauty at Spring Valley farmscape is similarly justified for the experience it gives to the children, the college students, and the adults who visit Spring Valley Ecofarm.

5.8.2 Working with Nature

Farmscaping involves the understanding of how soil and water influence natural ecosystems, and then applying this understanding to managing agricultural ecosystems. What farmscaping does is to work with the forces of nature, rather than against them. It utilizes crops and animals at each site that are best adapted to that site. It takes advantage of the natural processes and resources within that system, and thereby achieves an ecosystem that is sustainable.

5.9 Organic Agriculture

Organic agriculture is agriculture that does not use inorganic chemical fertilizers, herbicides, nor pesticides that are synthesized industrially. It uses some or all of the practices that facilitate sustainable agriculture (Box 5.18).

Box 5.18

Critics of industrial agriculture argue that what is needed is a paradigm shift away from agriculture based on the premise that humans must conquer nature in order to survive to the premise that humans must learn to understand how nature works, and take advantage of the services of nature to produce food and fiber (Jordan 1998). One term for such agriculture is "organic", but there are other terms that capture the spirit of organic agriculture such as permaculture, biodynamic agriculture, alternative agriculture, ecological agriculture and regenerative agriculture. All incorporate components of sustainable agriculture.

5.9.1 Why Do People Buy Organic?

There are several popular beliefs that lead people to buy organic foods:

1. It tastes better.
   In my organic agriculture class, I had the students do a double blind test to compare the taste of organic fruit and vegetables with conventional fruit and vegetables. For most of the foods compared, the students said that organically produce tasted better. For the rest, they said there was no difference. The problem with the test was that produce always tastes better when it is fresh, which means locally grown. The organically grown produce might have been locally grown but not the conventionally grown. That variable was not controlled.
2. It is healthier.
   The increasing popularity of organically produced food comes from the belief that it is healthier. Critics of organic agriculture have found what they think is new evidence to debunk this idea. A recent study from Stanford University in which 237 organic and conventional foods were rigorously compared found that organic food may not be healthier for you than conventional food (Smith-Spangler et al. 2012). But once again, organic critics have raised a straw man and then proceeded to shoot it down. The issue is not whether there is something inside organic food – vitamins, minerals, enzymes – that makes it healthier than conventionally produced food. The issue is whether residual pesticides on conventional produced crops, and antibiotics in industrially raised animals are a health risk. Some of the most important evidence that counters the study's claims comes from the Bouchard et al. (2009) comprehensive study on pesticides and health impacts. The goal was to examine the association between urinary concentrations of dialkyl phosphate metabolites of organophosphates and attention-deficit/hyperactivity disorder (ADHD) in children 8–15 years of age. They found strong evidence that organophosphate exposure at levels common among U.S. children is correlated with ADHD prevalence.
3. It is better for the environment (more sustainable).

5.9.2 Is It Sustainable?

This book has suggested that sustainability be judged on the basis of energy use efficiency. Here we compare the energy use efficiency of organic agriculture to that of other systems.

The energy yield in calories of output per unit calorie of input subsidy for grains in industrial agriculture ranges from 1.4 to 3.84 (Pimentel and Pimentel 2008). Ratios for organic agriculture, or farming systems similar to organic agriculture are usually much higher. Swidden agriculture, when carried out in regions where farmers can move every few years and leave abandoned fields to fallow has many characteristics of organic agriculture, including a high EROI (Energy Returned on Energy Invested). Studies that compared organic agriculture to industrial agriculture also found a relatively high EROI for the organically grown crops.

- Swidden farming for ground crops in New Guinea had an output/input ratio of 15.4/1, and for corn in Mexico, a ratio of 12.6/1 (Pimentel and Pimentel 2008).
- In the Amazon region of Venezuela, Uhl and Murphy (1981) found that the energy ratio of swidden agriculture was 13.9/1.
- Alluvione et al. (2011) compared energy use efficiency in conventional agriculture with efficiency in low input integrated farming (LI) and integrated farming following European Regulations (IFS). Compared with conventional agriculture, energy use efficiency increased 31.4 % in IFS and 32.7 % in LI.
- Results from the Farming Systems Trials at the Rodale Institute in Pennsylvania showed that organic farming uses 45 % less energy than conventional systems (Rodale 2012).
- Schramski et al. (2011) developed several interactive research models of biointensive farms that use no fossil fuels. They demonstrated that a successfully designed farm can produce a positive energy-return-on-investment (EROI).
- Cox and Atkins (1979) reviewed publications giving energy ratios for a variety of non mechanized systems. For wetland rice, values were 37.7 and 22.7. Gajaseni (1995), working in wetland rice systems near Bankok Thailand, found that the output/input energy ratio for rice transplants was 4.5/1, a relatively low figure due to the heavy use of industrial equipment.

Just because a farm is certified organic does not mean that the practices used are sustainable. The organic standards allow many techniques such as plowing and rototilling that can cause a system to be unsustainable. Carroll Johnson, a USDA researcher in Georgia uses mechanical cultivation to control weeds in his organically certified peanut fields, but heavy rains prevent his tractors from getting in the fields (Cooper 2012). Schramski et al. (unpublished manuscript) showed that a highly mechanized, intensive organic vegetable farm in Kentucky had an energy returned on energy invested value of only 0.025. They used techniques that are highly energy intensive, such as plastic mulch to suppress weeds, organic granular fertilizer, pumping systems for irrigation, and a variety of heavy equipment to till the soil. Although this system has been certified organic under the USDA National Organic Program, it clearly is not sustainable.

Just because a system is ecologically sustainable does not mean it is economically profitable. It depends in part on the crop. Jacobsen et al. (2010) found that in the Georgia Piedmont, organic okra and hot pepper production had the highest net returns to management, although the harvest labor requirements for these crops were 10–15-fold higher than a corn/winter squash intercrop.

5.9.3 Are High Yields the Answer?

Proponents of "Green Revolution" agriculture argue that increasing yield of existing cropland, not conversion to organic agriculture, is the most important factor to increase sustainability, because this will take pressure off natural areas to be converted into agriculture to feed increasing populations (Avery 2000). Their mistake is comparing organic agriculture to green revolution agriculture only on the basis of yield. Yield is gross production that ignores the cost of production. The cost of energy used to produce the yield must be used in any calculation of agricultural sustainability.

Yield comparisons. de Ponti et al. (2012) compiled and analyzed a meta-dataset of 362 published organic–conventional comparative crop yields. Results showed that organic yields of individual crops were on average 80 % of conventional yields, but variation was substantial. Another analysis of 316 published studies comparing organic and conventional crops showed that on the average, organic yields were 25 % lower than yields from conventional agriculture (Seufert et al. 2012), but input costs were not compared. Without output/input calculations, comparisons of yields will show only that the more energy you put in, the more you get out (up to a certain point). Even if ratios were the same, it would not be surprising that in short-term studies, organic farming has lower yields because some of the energy input is used to feed the soil microorganisms that increase long-term nutrient cycling efficiency, and some is used to feed beneficial insects that help control insect pests. Badgley et al. (2007) compared yields of organic versus conventional food production for a global dataset of 293 examples and estimated the average yield ratio (organic/non-organic) of different food categories for the developed and the developing world. The average yield ratio for studies in the developed world was slightly less than 1.0, but greater than 1.0 for the developing world. Conventional agriculture in the developing world may use less fertilizers, thereby accounting for the lower non-organic yield in these countries (Stockdale et al. 2001).

Only a few studies have been carried out long enough to evaluate the potential of organic agriculture for sustainability. Mäder et al. (2002) compared organic and conventional (industrial) farmed plots over a period of 21 years. They found that while crop yields were 20 % lower in the organic trials, fertilizer and energy inputs were up to 53 % lower, and pesticide input was reduced by 97 %. This means that while gross income from the organic fields was lower, net income may have been higher. Pimentel et al. (2005) reviewed the 21-year study of industrial and two types of organic treatments at the Rodale Institute in Kutztown, Pennsylvania. They concluded that organically managed crop yields on a per-ha basis can equal those from conventional agriculture, although there was high variability depending on the crop, soil, and weather conditions.

To compare agricultural systems based only on yield is like comparing businesses based only on sales. What the investor needs to know, in order to invest wisely, is net, the money left over after all the bills are paid. To compare sustainability of agricultural systems, we need to know not only the energy yield, but the energy invested, that is, the energy output/energy input ratio.

While most farmers and agribusinesses construct balance sheets that show the difference between gross income and expenses to produce that income, most still focus on maximizing yield through intensive use of energy rather than on maximizing profit through efficient use of energy. They do this to outcompete other farmers, gain more research grants, and control more resources. To achieve these objectives, it is more important to grow fast than to conserve energy. In terms of systems analysis, this is using energy subsidies to maximize power rather than to use energy efficiently. While this strategy sometimes enables economic success in the short term, it is unsustainable in the long term because increasing scarcity results in a higher price of energy, and wasted energy becomes pollution (Box 5.19).

Box 5.19

In the past, Colleges of Agriculture have had an almost obsessive preoccupation with increasing yield. Why? Because that has been their mandate established by the Morrill Acts of 1862 and 1890. A greater focus on sustainability has recently arisen in some Universities as environmental awareness has increased.

Box 5.20

Cotton farmers have been some of the most intensive users of on-farm energy. Thus it was gratifying to read in a cotton farmer's bulletin the opinion that on-farm energy management has a huge potential for improving the environment, lowering farm and ranch production costs and decreasing reliance on foreign energy supplies. (Cotton Today 2012).

Box 5.21

Detailed information on the techniques and practices discussed in this chapter is available from ATTRA, a program developed and managed by the National Center for Appropriate Technology (https://attra.ncat.org/) and Rodale Institute (www.http://rodaleinstitute.org/). In the South, SAWG, the Southern Sustainable Agriculture Working Group (http://www.ssawg.org/) and Georgia Organics (the umbrella organization for organic agriculture in Georgia – http://georgiaorganics.org/) hold yearly conferences where practicing farmers give talks and exchange ideas. Georgia Organics also promotes workshops on various aspects of organic farming.

5.10 Future Directions

Norman Bourlag, a Nobel Prize winner for agriculture has been a leading proponent for increasing agricultural yields throughout the world through more intensive use of fertilizers applied to genetically modified crops. The justification for increasing yields has been to fight world hunger. A recent paper in the Medical Journal the Lancet (Lozano and 205 others 2012) has pointed out that obesity now is a bigger health problem globally than hunger, and the leading cause of disabilities around the world. Every country, with the exception of those in sub-Saharan Africa, has experienced an 82 % increase in obesity in the past two decades. Middle Eastern countries have seen a 100 % increase. This suggests that less emphasis should be placed on increasing yield – there already is enough – and more be placed on how that yield is produced (Box 5.20 and 5.21).

Currently, global ecosystems that support agriculture are approaching collapse due to various threats, including climate change, scarcity and diminishing quality of water, loss of biodiversity and habitat, and overfishing. However, if sustainable practices that maintain ecosystems or allow them to recover were put in place, environments would not be as stressed.

(United Nations Environment Program 2012).

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Chapter 6
An Economic, Ecological, and Cultural Evaluation of Agriculture in the American South

Abstract Economic theory predicts a free market will direct the activity of producers by giving the greatest rewards to those who produce goods most economically and efficiently. Producing crops economically means producing them by maximizing energy use efficiency through allocating land for production to the crops that are best adapted to that land. The theory has not held true in the South. Analysis of past and present agriculture shows that maximizing short term yield rather than using land efficiently has been the force guiding management decisions. Reasons include:

- The Colonial Imperative – The original English colonists were acting to maximize profit for British business through short-term exploitation.
- Ignorance – First settlers thought the soil was rich and could be exploited indefinitely.
- Subsistence farming – Many of the later immigrants were fighting for survival, and needed quick results.
- Slavery – This artificial energy subsidy allowed cotton and tobacco farming on land ill-suited to these crops.
- Market access – Access to markets (roads, railroads, canals) limited the exchange of products that could be grown efficiently.
- Costs – Even where access was developed, the cost of transportation and storage often outweighed the benefits of growing more energy efficient crops.
- Ineffective Communication – Lack of market information on the frontier limited ability for good economic decisions.
- Market distortions – Subsidies, tariffs, and embargoes restricted free trade, thereby interfering with the workings of Adam Smith's "invisible hand of the marketplace".

The theory that maximizing energy output, not energy efficiency will give the greatest success to producers has been the better predictor of agricultural strategy, at least in the short term.

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Keywords History of agriculture in the American South • Sustainability and Southern agriculture • Energy use efficiency in Southern agriculture • Economics and Southern agriculture • Southern agriculture and unsustainability • Maximum Power in Southern Agriculture

6.1 The Invisible Hand of the Marketplace

Adam Smith was a Scottish pioneer of political economy and the author of "An Inquiry into the Nature and Causes of the Wealth of Nations", published in 1776, and usually abbreviated as "The Wealth of Nations". It's most famous and enduring contribution to economics is an explanation of the "invisible hand of the market place" the underlying mechanism of capitalism. Milton Friedman, a Nobel Prize winner in economics, has interpreted Adam Smith's "invisible hand" of the market place as follows: "Efficient methods of production are adopted to maximize profits. Low prices are charged to maximize revenue through gain in market share by undercutting competitors. Investors invest in those industries most urgently needed to maximize returns, and withdraw capital from those less efficient in creating value. All these effects take place dynamically and automatically."

The concept was advanced by the English economist David Ricardo who coined the phrase "comparative advantage" to identify the activities that one nation can do better than most others. The concept in relation to agriculture means that the market will direct the activity of farmers by giving the greatest rewards to those who produce food and fiber most economically. For example, it will encourage farmers in Greece to grow olives, but discourage Scotch farmers from doing the same. In contrast, it will encourage Scotch farmers to raise sheep, but discourage sheep farming in Greece. Within the United States, it would encourage dairy cattle on the limestone-derived soils of Southern Indiana (lots of calcium for milk), but discourage production of annual grains in the Southeast where trees have an adaptive advantage.

The "invisible hand" means that crops or animals that are naturally adapted to a particular environment will be more sustainable and more economically successful than those that are not, because a lesser energy subsidy will be required to produce them. In other words, they are more efficiently produced. For purposes of sustainability, Smith's "invisible hand of the marketplace" is the "invisible hand of nature". The invisible hand of nature (otherwise known as evolution) allocates species to those soils and environments to which they are best adapted and produce most vigorously. Timber, vegetables, grains, cattle, pigs, and ducks will grow most vigorously and maximize profits most sustainably when they are grown in ecosystems whose structure and function resembles that where these species occur naturally, because this reduces the need for energy subsidies. Producing agricultural crops that are best adapted to the local environment will result both in lower market prices for all crops for the benefit of all people, and for increasing the sustainability of farming for the benefit of the environment.

This chapter first presents an agricultural history of the South, and then gives an evaluation in terms of economic theory.

6.2 Why Focus the South?

If you can learn to farm sustainably there, you can learn to farm sustainably anywhere.

In the first part of my career, I studied the impact of agriculture and forestry in the Amazon Basin. I wanted to test the idea of early explorers of the Amazon rain forest, that the size of the trees there indicated that the region had great agricultural potential. In Northern Europe, large trees meant good soil. For example, Wallace (1878, p 65) wrote: "The primeval forests of the equatorial zone are grand and overwhelming by their vastness and by the display of a force of development and vigour of growth rarely or never witnessed in temperate climates" (Box 6.1).

The most important thing that I learned was that the idea that big trees meant the soil was good for agriculture was completely false. It was the humus and soil organic matter on top of the soil which lent productivity to the region, but when this humus was destroyed by plowing, agriculture failed, because the soil beneath the humus was highly weathered and very low in nutrients (Jordan 1982). The fact of the matter is that central Amazonia is one of the most difficult places in the world to carry out agriculture, because of the highly weathered soils, and because the long, hot, humid growing season is an ideal breeding place for insect pests, fungal diseases, growth of weeds, and for rapid decomposition of soil organic matter. That rapid decomposition is the most critical factor. The soil organic matter lends productivity and sustainability to the undisturbed forest, but disappears under conventional agriculture (Montagnini and Jordan 2005).

After 20 years in the tropics, I had the opportunity in 1993 to buy a 100 acre farm in the Georgia Piedmont, and to look at agricultural problems there. A few years of trying to manage a farm in the humid environment of the Georgia Piedmont led me to see that the agricultural problems of the Southeast are very similar to those of the lowland wet tropics. Both regions are hot and humid. Both get lots of rain. The only difference is in the season when plants are dormant. Much of Amazonia has four or

Box 6.1

There is no strict definition of which states comprise the "South". The States included in this discussion include Virginia, the Carolinas, Tennessee, Kentucky, Georgia, Alabama, Mississippi and Northern Louisiana. The problem of highly weathered infertile soils is common throughout this region. These states are south of the geological moraines left by glaciers that covered the northern part of the U.S. until some 12,500 years ago, and so did not have mineral rich bedrock exposed by the scraping of the glaciers. Slavery also was an agricultural factor common factor in these States. Because of Spanish occupation, Florida had a different early cultural history, and so is not included here. Although Texas, Arkansas and Missouri were slave states and part of the Confederacy, their climate and soils are somewhat different.

so months of dry season when plants are dormant and 8 months of hot, wet, growing season. Georgia has 4 months of cool weather when plants are dormant, and 8 months of hot, wet growing season. In the Amazon Basin, the soils are red, highly weathered Oxisols, the remnants of millions of years of weathering of the Brazilian and Guyana Shields. In the Piedmont of North Georgia where the farm is located, the soils are red, highly weathered Ultisols, the remnants of millions of years of weathering of the rocks that form the Appalachian mountains.

Every region of the world has environmental problems that are unique. Because of my familiarity with the agricultural problems in regions having highly weathered and infertile subsoils overlain by a mantle of rich organic matter that when undisturbed, can sustain massive forests, I have chosen to write about agriculture in the South, where this situation poses a distinct challenge to agriculture.

6.3 An Agricultural History of the South

Except where specifically noted, sources for Sect. 6.3 were: Bonner 1964, Caruso 2003, Craven 1925, Range 1954, Reidy 1992.

6.3.1 The Cultural Context

Agriculture in the Southeast, as well as in the rest of the world, has been influenced by the specific characteristics of the soil, the topography of the region, climatic conditions, and availability of land. It is also influenced by a complex web of governmental policy, international trade agreements, traditions, customs and culture, moral choices and societal norms. Despite the fact that the sequence of conquering, exploiting, and abandoning has been the history of agriculture from time immemorial, it is the details of the story, the political, economic and social setting of agriculture in all regions of the world that helps shed light on the culture that emerged in each region, and how the culture and the agriculture have interacted. In the Southeast, the history of agriculture helps explain why the Southeast has culturally been the most conservative region of the United States, and why this conservatism has delayed the transition in agriculture from exploitation to sustainability, at least until very recently (Box 6.2).

6.3.2 The Colonial Period

In 1606, England's King James I authorized a charter granting land in what was then called Virginia (but stretched from modern-day Maine to North Carolina) to the Virginia Company of Plymouth and the Virginia Company of London. Colonists,

Box 6.2

One would think that those who nowadays consider themselves "Conservatives" would be most eager to promote "Conservation". For the most part however, conservatives of today put a higher priority on economic expansion than on limiting the environmental damage to resources caused by economic expansion.

Box 6.3

Groups such as the Pilgrims and Puritans came to the new World with their wives to work towards religious, moral, and societal reforms. They came to America to make it a permanent home where ideally they could live and worship as they saw fit (Staples 1988). In contrast, colonization in Virginia was for business purposes. England needed resources, particularly pitch tar, and tall, straight trees for ships' masts. The legacy of the difference between idealism and practicality is one of the factors that has caused the difference between cultures in today's "red" (conservative) states of the South, and "blue" (liberal) states of the Northeast. Another factor is the nature of the agriculture. Since no great staple crop like sugar or tobacco could be raised in New England, the people had to diversify, and keep their mind open to new economic ideas. "Any tramp kidnapped in the alleys of Portsmouth or the taverns of Plymouth could be sold as a indentured servant in America's tobacco and rice country, but in New England he had to know his business. Without a special skill or trade, there was no market for his services." (Jordan 1939).

considered employees of their respective companies, journeyed to America in 1607 to found settlements along the Atlantic seaboard. The Virginia Company of Plymouth failed, and its settlement at the mouth of the Kennebec River in present-day Maine was abandoned within 2 years. The Virginia Company of London was more successful.

6.3.2.1 Jamestown

The 105 original Jamestown colonists were all men. Jamestown was a business venture, not a place to raise a family (Box 6.3). The colonists took this goal to heart and focused all their efforts on staking claim to land with trees that could be used to build England's Navy. However, they neglected subsistence agriculture. As a result, more than half of the colonists died of malnourishment and starvation within the first year. Only 38 colonists remained when reinforcements arrived in 1608. Captain John Smith, one of the surviving original colonists, soon emerged as a prominent leader. In 1608, he organized work gangs to ensure the colony had food and shelter and made rules to control sanitation and hygiene. During the winter of 1608–1609, only twelve of 200 men died. Smith also excelled in diplomacy, and maintained friendly ties with the nearby Powhatan Confederacy, but when Smith was wounded in 1609 and returned to England, the colony staggered toward collapse. Out of a population of about 500 colonists in Jamestown in September 1609, 400 died by May 1610. Relations with the nearby Native Americans deteriorated, and in 1610 the first Anglo-Powhatan War erupted.

In the end, Jamestown was saved because it had the perfect climate for growing tobacco. John Rolfe, an Englishman who married the Powhatan leader's daughter, Pocahontas, introduced West Indian tobacco to the colony. From 1616 to 1619, Jamestown's tobacco exports grew nearly 20-fold. Sensing the possibility for great profit, the Virginia Company dispatched money and supplies and awarded land grants to anyone able to pay for his own passage to Jamestown, or for the passage of another laborer. The profits produced by tobacco saved Jamestown and ensured the settlement's success.

As the colony grew in size, its members began to desire a better system of government. In 1619, the colonists formed a general assembly, the House of Burgesses. This was the first representative government in the New World, though its power was limited because the Virginia Company could still overrule its actions. In 1622, things took a turn for the worse. A second war with the Powhatan tribe, a slump in tobacco prices, fraudulent practices by local officials, and high death rates from disease resulted in extremely hard times for the colonists. The joint-stock company collapsed and James I revoked its charter, and made Virginia a royal colony in 1624 (Sparknotes 2012).

The political and economic situation of the colonists led to the entrenchment of tobacco as a single crop staple. The colonists continued to expand production throughout the colonial era. Taxes, the English merchant middle men and government regulations that stipulated they could only trade with England kept colonists locked into producing this crop even through times when profits were so low as to impoverish the smaller planters, and to make other planters, large and small, debtors to the English brokers and merchants. These practices engendered a legacy of distrust for government, a root of Southern conservatism.

6.3.2.2 The Migration Westward

The difficulty of obtaining land with good soil resulted in new immigrants leaving, or skipping over the tidewater regions. Waves of colonists spread westward from the tidewater regions of the Atlantic Coast, through the outer and inner coastal plains, across the fall line, into the Piedmont, over the Blue Ridge, the hill and valley province, and into the Appalachian plateau.

Box 6.4

The soils of the outer coastal plain are podzols, that is, soils with a thick undecomposed humus layer, underlain by an "A" horizon of almost pure coarse sand, very low in nutrient content, and nutrient holding capacity. For my doctoral research, I studied the nutrient dynamics in the Pine Barrens, in the outer coastal plain of New Jersey (Jordan 1968). My hypothesis was that nutrient concentrations in the water that leached out of the humus layer would be high, and that from the A horizon would be low. Results turned out just the reverse. Leachate from the humus was low in major nutrients, because of the ability of the organic matter to retain them. Leachate moving through the A horizon was high in nutrients, because every rain that fell washed out all the nutrients that had accumulated. In addition to not retaining nutrients, the coarse sand does not bind the tannins leached from the humus. Instead, they are leached through and cause the rivers that drain the lower coastal plain to be dark tea colored. They are called "blackwater rivers".

6.3.2.3 The Coastal Plain

The first colonists settled in the Coastal Plain, a geographic province that extends from New Jersey through Georgia. It is comprised chiefly of sands, deposited millions of years ago when the region was under the ocean. Coarse sands dominate the outer coastal plain from the Pine Barrens of New Jersey to the Pine Flatwoods of Georgia. Because of the low potential for agriculture in the outer coastal plain, the region was usually left in pine forests. The tall pines were valuable to the British for masts for their ships, and the live oaks that grew in the coastal plain were used for planks. Turpentine and naval stores such as resin from pines were collected to seal England's wooden ships.. The barefoot workers that collected resin were called "tar heels", from the accumulation of pitch on their feet. The name became a nickname for the University of North Carolina (Box 6.4).

Further inland, the Coastal Plain Sands were finer and the soil more amenable to agriculture. In fact, the good physical properties of the inner coastal plain is the reason New Jersey is now called the "Garden State". Further south, the hot, humid climate was good for agriculture because the long growing season and (usually) ample rainfall initially resulted in high annual crop yields. But the climate was bad in another way, because the hot humid climate stimulated microbial activity and decomposition of soil organic matter, the lifeblood of sustainable agriculture. The early settlers in the South could see the good part. The reports of early explorers are filled with grandiose descriptions of luxuriant vegetation, and abundant game animals. What the explorers and settlers didn't understand was the bad part – the hot, humid climate promoted the growth of weeds and insects, and caused rapid decomposition of the soil organic matter, once the forests were cleared. It was this rapid deterioration of the soil organic matter that "exhausted" the soil (Box 6.5).

Box 6.5

The farming practices of the early colonists, especially the tobacco farmers, quickly "exhausted" the land. Although "exhaustion" clearly meant the loss of productive capacity, it was not clear exactly what caused the exhaustion. Today we know a major cause was the oxidation of carbon in the soil organic matter. It was the soil organic matter where nutrients were stored, and that gave energy to the community of soil organisms that maintained the permeability and fertility of the soils. The plow was the instrument of destruction. As the soil was loosened, oxygen could rapidly permeate the soil and stimulate bacteria that oxidized (burned) the carbon. All that was left was infertile sand and clay. Plowing also loosened the soil, and facilitated erosion during winter rains when the land was not covered.

The best economic alternative for new immigrants to the American South was not to try to farm over the worked-over land, but to forge westward, to new and virgin soils.

6.3.2.4 The Piedmont

In the first half of the eighteenth century, German and Scotch-Irish immigrants poured westward into the region above the Fall Line, the physiographic boundary that divides the eastern coastal plain from the Piedmont. The Fall Line represents the shore line of ancient oceans. Steamships could not pass beyond the fall line rapids, and this is where the overland journey of the settlers began. Inspired by explorer's tales of choice lands, settlers moved westward with their cows and sheep, which they grazed in the open meadows and cane breaks while they built cow pens, cleared fields, grew corn, and raised cabins for shelter."The rich soil, swift streams, mild climate, and boundless forests were irresistible attractions to the farm-loving Germans and to the adventurous, land-hungry Scotch-Irish" (Caruso 2003). However, much of the land in the Piedmont was already owned by Tidewater Planters through grants from the English crown. They were anxious to make a profit, and had agents distribute pamphlets that promoted the country as "the best, richest, and most healthy part" of America. Sometimes they made slight improvements in their properties to justify the prices asked, and had agents in the eastern ports to persuade new arrivals to buy sections of their grants. After farmers had cleared the land, agents sometimes forced them to repurchase the land, contending that they had settled in the wrong place. The unscrupulous practices of the English landowners further contributed to the Southern farmers distrust of government. These original landowners became rich, not through hard work, but because of political connections through which they gained ownership of huge tracts of land, and through their access to slave labor.

Piedmont Soils

The Piedmont physiographic province is a remnant of several ancient mountain chains that have since been eroded away. There the colonists encountered soils and topography quite different from that of the coastal plain, but on which it was equally difficult to establish permanent agriculture. The soils are typically red clay, the color being indicative of iron, left after intense weathering depleted the clay of all other nutrients. The northern end of this highly weathered soil in New Jersey is marked by glacial deposits from the Terminal Moraine, a line of rocks deposited at the furthest southern extent of the glaciers, 10,000 years or so ago. As the glaciers retreated, they left exposed bare rock, high in basic elements. As the rocks weathered, they left soil relatively rich in nutrients. As a result, agriculture in the North was easier in one way because the soil was richer, but it was harder in another, because the soil was full of rocks. In the South, the red clay soils of the Piedmont could not sustain agriculture for longer than the Coastal Plain soils. And because of the hilly terrain of the Piedmont, erosion occurred more quickly than in the Coastal Plain.

Agricultural practices based on utilizing land until it was exhausted were common in the Piedmont as well as the Coastal Plain, in part because tobacco growers chose methods that maximized short term returns rather that long term soil viability. The decision to plant crops until the soil was "exhausted" was an economic one. The choices made by tobacco planters were based not only on yield of the soil, but also on conditions reflective of the socio-economic order. Decisions to keep mining the soil, despite lower and lower yields might seem to be irrational, but in fact these were perfectly rational economic decisions. There already had been an investment in the land. What was of concern were yearly operating expenses. As long as 1 year's operating investment yielded a profit, however small, it would have been economically irrational to cease operating. Nevertheless, eventually yields became so low that the promise of better soils to the west was irresistible.

6.3.2.5 The Mountains

Quotations are from Caruso (2003).

In 1716, governor Alexander Spotswood of Virginia led an expedition across the Blue Ridge Mountains and into the valley of the Shenandoah River. "The valley abounded with wild turkeys, deer, cucumbers, currants and grapes", he said in his account. To encourage settlement in the valley, he described it as an "agricultural paradise". The reality was somewhat less, mostly because the pioneers did not have the tools to work the land. Some had to plow the land with sickles, grind corn in stone mills, and having neither horse nor cow, carried their belongings on their backs. Their impact on the soil probably was equal to the Indians, who had lived there for perhaps thousands of years.

By 1740, waves of migrants had moved into the Shenandoah Valley. "As they advanced, they converted a trackless wilderness into a continuous agricultural paradise." The Scotch-Irish were the most numerous of the settlers. Their ancestors had struggled to survive in the Old Country, and this pattern of life developed in the pioneers a self-reliance and physical endurance that enabled them to "respond with admirable effectiveness to the formidable challenge of the American frontier." They had a defiant, aggressive nature, and an indomitable spirit of personal independence which caused them to resist any encroachment on their individual rights. They were impatient of the slow process of the law, and resentful of governmental restraint imposed on them without their consent. They believed that the people themselves should be the ultimate repository of political power, and not some far-off government. This quality of self-reliance and independence from government is another factor in molding the conservative character of the South.

Caruso (2003) in his book "The Appalachian Frontier", relates many colorful stories illustrating how the Southern mountains became occupied. The book is useful in understanding the history of colonization, and how by 1740, waves of migration spread up the Shenandoah Valley, but his hyperbole about the heroic qualities of the settlers, and the land as a paradise is a reflection of the misunderstanding of the limitations of the land and the people that colonized it. He describes how immigrants trekked through the South Branch of the Potomac, and eventually to a Southern tributary of the Ohio River. While these descriptions of the Appalachian valleys, and of the pioneers that settled there seem almost like wild exaggerations, the enthusiasm of the first colonists is understandable. The soils there, with the deep rich organic A horizons never touched by a plow, were something they had never seen while farming the worked-out soils of Northern Europe.

For the most part, colonists settled and farmed the river valleys, where there was an accumulation of fertile sediments over the underlying poor subsoil. Once fields were cleared, it was necessary for them to use forests on the mountainside for lumber and firewood, but the amount of timber harvested was small and skidding the logs out by oxen or mule did little damage to the forest. Steepness limited the use of land in the Appalachian mountains. The mountainsides remained pretty much in forest, until the advent of commercial logging at the beginning of the 1900s (Box 6.6).

By 1775, settlers were moving into the territory known as Kentucky. These first settlements west of the Appalachian Mountains were founded, with settlers primarily from Virginia, North Carolina, and Pennsylvania who entered the region via the Cumberland Gap and the Ohio River. The most famous of these early explorers and settlers was Daniel Boone, one of the founders of the state. In Kentucky, the settlers found soil that lived up to exuberant claims. The soil in the region around what is now Lexington has been classified in recent soil surveys as an Alfisol. In contrast to the highly weathered, acid, and nutrient poor Ultisols to the East, Alfisols are considered by soil scientists to be highly productive (Brady 1974). The soils are derived from fossil limestone and dolomite, resulting in a moderate pH level (measure of acidity), and high phosphorus availability. The deep, well drained soils of this "Bluegrass" region are responsible even today for the high agricultural value of the region. By 1800, farmers noticed that horses that grazed there were more durable than those from other regions. Within decades, the herds of bison that had grazed there were replaced with thoroughbred horse farms. Other forms of agriculture also

Box 6.6

Scientists working in the Coweeta Basin, in western North Carolina, have provided the best record of the impact of commercial logging on the mountain forests. Before the first white settlement in this area, the Cherokee Indian Nation inhabited the mountainous land in western North Carolina. In 1838, they were forcibly removed and Europeans began to settle in the Coweeta Basin, using the land for agriculture and grazing livestock. From 1848 to 1900, white settlers cultivated less than 200 acres of the basin, primarily along the main streams. Lumber companies purchased the Coweeta Valley in 1900, and subsequently the land was logged (Butler 2006). Much of the timber was removed from the steep slopes. The denuded land suffered severe erosion due to clear cutting. In 1918, the Forest Service bought the tract and designated it part of the Nantahala National Forest in 1923. The site was set aside as the Coweeta Experimental Forest in 1934. By that time, there had been enough forest regrowth to study the effects of various logging techniques on stream runoff quantity and quality. The site consists of a series of "catchments" (small watersheds). The bottom of each catchment has a weir that records amount of water passing through, and an automatic sampler that takes water samples from the passing flow (Webster et al. 1992). The site now supports studies of the effect of climate change on ecological processes (Clark et al. 2011).

flourished, including grapes, hemp, and tobacco. Although erosion can be a problem in the rolling hills of Northern Kentucky, weeds rather than low soil quality is the main factor limiting sustainability.

6.3.3 Carolina and Georgia

As the land in the Virginia Coastal Plain became settled, English land scouts in the 1660s were sent to reconnoiter the Carolina Low country. They "ranged through very spacious tracts of rich Oake land" before declaring the region fit for colonial occupation. Alongside these commonplace European hardwoods, the scents and sights of peach, fig, and cedar trees stirred the first settlers' imaginations about its extraordinary potential. They scoured the Carolina landscape for signs that English agriculture might be practiced in the Low country. "Gallant Groves of Pines, delightful forests of Oake, and Cypress trees, innumerable, very tall and large, all proclaimed the richness of the soyle beneath them." The reports of explorers suggested that Carolina's settlers could take advantage of "good land enough for millions of people to live & worke on. Mellow in appearance and soapy to the touch, these deep deposits of black Earth scattered generally all of the countrey were just like the fine mould of our well order'd Gardens". The explorer Robert Sanford was so satisfied

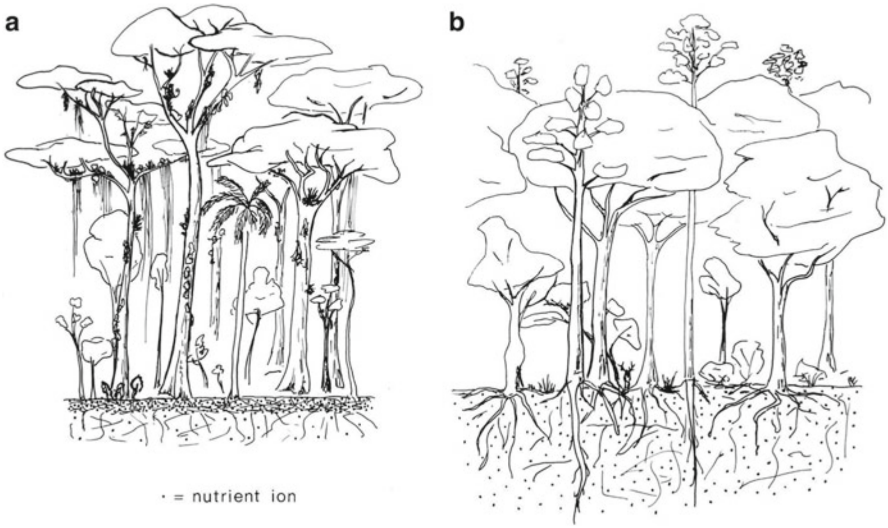

Fig. 6.1 Distribution of nutrient ions in a very old, highly weathered soil such as that of the Amazon lowlands or the Piedmont of Georgia (**a**), and in a relatively young soil that has formed in New England within the last 10,000 years after the retreat of the glaciers (**b**)

by the sorts of woods he saw on his 1666 expedition that he felt no need to venture into the forests. He was confident that trees he observed from afar captured the promise of the land (Phrases in quotes are from original sources in Edelson 2009).

The idea that tall trees indicate that the soil on which they grow is fertile derives from experience in Northern Europe, where indeed that is usually the case. There the soils are not as weathered as soils in the American Southeast, and the clays of the mineral soils have the ability not only to retain essential nutrient elements, but also to supply them. That is not so in the Southeast, where the clay minerals have little "ion exchange capacity" (ability to retain nutrients), and are principally iron, aluminum, and quartz, with little inherent nutrient supplying capacity. In the Southeast, it is the soil organic matter where nutrients are retained, and the organic matter there is concentrated on top of the soil, or in the upper soil horizon. When the topsoil is plowed, the carbon in the soil organic matter is oxidized, leaving nothing but the highly weathered nutrient-poor subsoil. The contrast between nutrient distribution in young and old soils is shown in Fig. 6.1 (Box 6.7).

Despite the peach, mulberry and fig trees that the first explorers found in the Carolinas, it did not take long for settlers there to become addicted to tobacco production. As in Virginia, tobacco provided such high returns that it soon supplanted all other crops. It was light weight, kept well, and shipped easily. In addition, the government played a large role in promoting tobacco. At first the British government sought to encourage colonists to diversify crop production. Once tobacco cultivation began, however, it generated such high revenues that the crown reversed its opinion, and for the latter half of the seventeenth century, tobacco was

Box 6.7

The idea that tall trees indicate rich soil is this same fallacy that is leading to the destruction of Amazon rain forests today. The huge biomass of the central Amazon forest exists not because the soil is rich, but because the nutrients are recycled directly from the humus and organic matter on top of the soil back into tree roots that penetrate the humus (Jordan 1982). The underlying soil is an Oxisol, even less productive than the Ultisols encountered in the Carolinas and Georgia. As a result, the nutrient recycling efficiency had to be high for the forest to survive, especially for limiting nutrients such as phosphorus. We found that the recycling efficiency of phosphorus from humus to roots in the Oxisol site was 99 %, (Herrera et al. 1978, Stark and Jordan 1978, Jordan 1982). Another fallacy is that trees in the rain forest grow fast. That is true only of early successional species, and means growth in volume, not biomass (Jordan and Farnworth 1980). In mature forests, accumulation of biomass is similar to, or even slower than that of trees in temperate forests (Jordan 1971, 1983).

promoted as a key crop. Nevertheless, there still was an interest in England of promoting exotic plants not grown elsewhere in the British possessions. Because of the milder climate along the Georgia coast, a "Trustee's Garden" was laid out at Savannah in 1770. It comprised a 10-acre experimental plot, having oranges, olives, apples, pears, figs, vines, pomegranates, coffee, tea bamboo and medicinal plants. Producing silk by raising silkworms on the leaves of mulberry trees seemed to offer the greatest promise. A bounty was placed by the English on silk production. In contrast to fruit production, silk production, dependent on caterpillars (silkworms) that eat the leaves of mulberry trees, flourished for a number of years. During the eighteenth century, when silk became the fashionable fabric for the upper classes in Europe, England hoped to compete with the thriving silk industries in France and Italy by encouraging its production in the American colonies. While the mulberry trees were well adapted to the Southern environment, seasonal temperature variables were detrimental to the sensitive silkworms. The Revolutionary war effectively ended silk production in the U.S.

6.3.3.1 The Rice Plantations

The first English and French Huguenot settlers arrived along the South Carolina coast in 1670. Rice cultivation appeared soon after that. The earliest reference to rice cultivation dates to 1690, when plantation manager John Stewart claimed to have successfully sown rice in many different locations. Carney (2009) hypothesized that African born slaves, whom the settlers brought with them, initiated rice planting in South Carolina. Rice cultivation quickly expanded. By 1695, South Carolina was exporting rice, and during the 1720s, rice emerged as the colony's leading trade item.

Box 6.8

In 1787 John Eatton LeConte, a native of New Jersey, became the sole owner of 3,356 acres of land in Liberty County, on the coast of Georgia. Known as the Woodmanston Plantation, the estate eventually passed to John Eatton's sons, Louis (1782–1838) and John Eatton (1784–1860). By 1810 Louis had settled permanently at Woodmanston, had acquired slaves, and was cultivating rice and cotton. His sons John, Luis and Joseph all become noted scientists. Mt. LeConte, in the Smoky Mountains reflect the esteem in which the family is held (New Georgia Encyclopedia 2012).

Rice was first grown in the uplands close to the coast. Upland rice production complimented the colony's early economic emphasis on stock raising and forest-product extraction. Cultivation of upland rice depended on rains, which were not always dependable, and on slaves which were often in short supply. With the dramatic increase in slave imports by 1720, rice cultivation shifted to the inland swamp system.

To ensure a more reliable water supply, farmers began planting in inland swamps where high groundwater tables kept the swamps saturated. They often constructed bunds, small earthen embankments, around the field to form a reservoir for capturing rainfall or stream runoff. They sometimes improved drainage and aeration in inland swamp plots by ridging the soil. Rice seedlings were either sown directly atop the ridges or transplanted. The high yielding inland swamp system demanded considerable labor for clearing the cypress and gum trees and developing the network of bunds and sluices necessary for converting a plot into a reservoir. The system impounded water from rainfall, subterranean springs, high water tables, or creeks. Water could be released on demand for controlled flooding at critical stages of the cropping cycle.

By the mid eighteenth century, rice production shifted to tidal river floodplains in South Carolina and Georgia. The system was dependent on tides to flood and drain the fields. Tidal rice cultivation depended on complex hydrological and land-management techniques. The water control system relied on proper placement of embankments and sluices. The lower embankment permanently blocked the inflow of saltwater at high tide, while opening the sluice at the low tide enabled water discharge from the plot. A sluice in the upper embankment delivered steam water as needed for desalination, irrigation, and weed control. The labor for transforming tidal swamps to rice fields proved staggering. The ecological damage caused by tidal rice plantations also has been considered significant. Rice plantations simplified the hydrography of the coastal plain in ways that made it more prone to unpredictable and destructive flooding (Edelson 2009) (Box 6.8).

Despite the large cost in establishing tidal rice culture, once the system is established, it is a very energy efficient system, dependent on the free services of the flowing rivers and the ebb and flow of tides to do all the work of weeding and irrigation. We can calculate the energy subsidy of this service by again using the data of Pimentel and Pimentel (2008). Irrigating with industrial methods such as overhead sprinkler consumes 320,000 kcal/ha/year. Killing weeds with herbicides consumes 620,000 kcal/ha/year. Using the same calculations as in Sect. 4.4, we get the value of flooding and tides to be $104.44/ ha, or $10,444.00 for a 100 ha plantation.

6.3.4 The Post-revolutionary War Period

6.3.4.1 Agricultural Decline

George Washington was a farmer who experimented with soil improvement. He fought erosion by filling gullies with old rails, leaf litter, and straw, and covered them with dirt and manure. He realized the difficulty of improving large units of land by manuring, so he cut his estate into smaller tracts, and insisted upon more intensive methods by his overseers or tenants. Other farmers tried crop rotations, and fallowing with grasses and clover. John Taylor, a farmer in Virginia and an author of articles and books on agriculture wrote that "The way to a restored fertility, lay in the return of manures of all kinds, animal, and vegetable, to the soil. Manure only can recover this capital".

Despite sporadic efforts to improve soils, agriculture throughout the colonies continued to decline after the American Revolution. In 1819, land in Maryland was described as "dreary and miserable in aspect – uncultivated wastes, a barren and exhausted soil, half clothed negroes, lean and hungry stock, a puny race of horses, a scarcity of provender, houses falling to decay, and fences wind shaken and dilapidating". There were some attempts at soil improvement, by adding manure, gypsum, and marl (derived from limestone rock), but in general, conditions continued to deteriorate. Impoverished soils, however, were not the only factor contributing to the difficulties of agriculture. Lack of capital was another handicap and cause for failure. Heavy investments were needed, and results were slow in coming. Many farmers could not furnish the required capital for investment without a reduction in their standard of living, This they were reluctant to do. They enjoyed too much their social stature established by hospitality, saddle horses, carriages and other so called luxuries.

A greater factor in the agricultural decline was the lack of steady and paying markets. Thomas Jefferson was caught by the embargoes and blockades of the War of 1812, and the loss of income checked his efforts at agricultural reform. There was also a feeling against perceived government policies that gave advantages to manufacturing interests of the North. Tariffs caused farmers to pay higher prices for manufactured goods, but there was no increase in prices for their products. Where there were markets for Southern tobacco and wheat, lack of road and railroad access to the markets stymied progress.

Loss of social capital also contributed to the decline. Many young men could see little hope in remaining, and emigrated west, in a quest for land where a farmer

Box 6.9

"Men may, because of force of habit or ignorance, ruin their soils, but more often, economic or social conditions, entirely outside their control, lead or force them to a treatment of their lands that can end, only in ruin". (Edmund Ruffin, a Maryland farmer in the early 1800s, quoted in Craven 1925)

could make a better living. It was often men of initiative and energy – the ones most willing and able to undertake new things – who went west. Those who already were established, and saw future fortunes decline with the loss of their younger generation, were then forced to look for new ways to make their farms productive again (Box 6.9).

6.3.4.2 The Agricultural Revival: A Reprieve from the Downward Spiral

Craven (1925) points to the year 1820 as the beginning of what he calls an agricultural revival of the South. The revival was prompted in part, by editorials in magazines such as Farmer and Gardener. "Ask those who have gone, or are going West, why they have left, or intend to leave their native hills, and they will tell you 'the soil is worn out'." Men saw clearly that the South was in transition from what the American Farmer called "large possessions, well disciplined and profitable slave labor, elegance of manners and luxury of living to a condition in which estates will all be cut up, slavery will disappear, and every mother's son, as in the country of New England, put his own hand to the axe and plough. Daughters were warned that they must give up their silks and satins and betake themselves to the churn and wheel."

Fundamental to any effort at improvement of the soil and the agriculture of the South was the establishment of markets and roads to markets. Before improvement could be permanent, agriculture had to be put on a paying basis. One of the first steps was the beginning of the Chesapeake and Ohio canal. By 1840, it was furnishing an outlet to regions along the Potomac, and was somewhat profitable for Maryland's farmers, despite the rise of the Baltimore and Ohio railroad. From its very beginning, the B&O was swamped with freight, most of which was agricultural products. By 1840, other lines were completed, and the trade that was made possible encouraged a more permanent system of farming.

Soil Amendments

The soils of the South are geologically very old, highly weathered, and the mineral soil that lies below the topsoil is low in nutrient content. These subsoils have a relatively strong natural acidity. Nevertheless, the native forests that were there not only survived, but showed evidence of a strong rate of growth. Why then did acidity appear to be the problem for crop production?

Box 6.10

The nutrient dynamics of Southern soils are similar to those found following slash and burn agriculture in the Amazon Basin, where soils also are acid and highly weathered (Jordan 1982). "Slash and burn" has achieved a negative connotation among development specialists, because it implies the soil has been wasted. However, slash and burn agriculture as practiced by indigenous tribes in the Amazon is a very sustainable approach to agriculture. It is better called "shifting cultivation", where a plot is cleared and cultivated for only a few years, and then abandoned before the nutrients are all leached out of the soil. The plot is left fallow and rapidly recovers because successional vegetation takes up nutrients before most of them are leached. Meanwhile the indigenous farmers move on to another area. This system, of course, is dependent on large areas of sparsely populated land. Whether inter-tribal warfare and/or disease kept population low and thus allowed this sustainable type of agriculture is a question about which anthropologists have fiercely divided opinions.

Every species has a range of acidity to which it is best adapted. Trees of the original forest were well adapted to the acid, low nutrient status soils. For example, rhododendron, a common species in the mountains of North Carolina, does so well in the acid soil that it often crowds out other species. A symbiotic relationship with mycorrhizae is part of this adaptation. In contrast, most economically important crop species have been bred for high yield but only when soil acidity is neutralized. Survival on acid soils is an energy consuming process that diminishes high yield.

If the soils that the first settlers encountered were acid, why were the yields so good when the soil was plowed the first time? Initial high yields were due to the nutrients incorporated in the organic topsoil of the original forest. These nutrients were released from the decomposing organic matter of the topsoil as the forests were cleared for agriculture. Plowing increased the oxygen supply to soil bacteria, and stimulated their burning up (decomposing) of the soil organic matter. This decomposition made nutrients available for crops, but it also destroyed the reservoir that held the nutrients.

Nutrient-rich ashes from trees that were burned as the land was cleared constituted another factor to account for high yield following cultivation of virgin forest soils. Paul Sutter, an environmental historian formerly at the University of Georgia, has argued that "slash and burn agriculture" is a good description of the agriculture practiced by early colonists in the South (Sutter 2009). As the forests were cleared, some of the wood was used to build cabins and barns, but much of the smaller branches and inferior trees was burned in place (Box 6.10).

Low levels of available nutrients also was caused by high acidity (low pH). At low levels of soil pH, toxic elements in the soil such as aluminum are highly soluble, and thus available for plant uptake. As soil pH rises, toxic elements become less available, and beneficial nutrients such as phosphorus become more soluble. When soil amendments such as marl (a calcium carbonate-rich mud)) are added to the soil, the calcium dissolves and percolates into the soil. It replaces the hydrogen, resulting in a decrease in acidity. With fewer hydrogen ions in the soils, the nutrients released from the decomposing manure become more available to the crop plants. Soil fertility is increased, and crop growth is stimulated. The effect of liming is particularly effective in releasing phosphorus from iron and aluminum compounds, common in highly weathered soils of the South.

Restoration of exhausted soils was a factor essential to the recovery of agriculture in the South. At first, some farmers tried to rejuvenate their soils by adding manures, but manures had little lasting impact, probably because of their rapid decomposition in the hot, humid climate. The amount needed to replace the original fertility was far beyond the capability of cattle herds to produce. In Chap. 4, I calculated the weight of soil organic matter under a mature forest in the Georgia Piedmont to be 0.04 mt/m^2. This would equal 400 metric tons of manure per hectare. That's what it would have taken to replace the original soil fertility.

Then shortly after the War of 1812, Edmund Ruffin, a farmer in Prince George County, Maryland, tried again the previously abandoned practice of adding calcareous marl to the fields, but with greater intensity and in combination with manures. His trials were so successful, and his yields increased so dramatically that he became one of the South's leading exponents of the value of marl. He theorized that the problem was not that the soil was exhausted, but that it was too acid (Craven 1925). Adding calcium and magnesium to the soil decreased its acidity, a prerequisite for good crop growth. If added to the soil, in combination with manure, he thought that farms in upper Virginia and Maryland could be restored to profitability.

Other amendments also improved the productivity of the soil in the years before the Civil War. Greensand, a layer of Coastal Plain sand rich in potassium was used as a supplement to marl and manure. Guano (sea bird excrement rich in phosphorus) imported from Peru proved to be an extremely effective fertilizer. These amendments, in combination with crop rotations such as wheat/ clover/ tobacco and rotational grazing of cattle brought not only improved soil fertility and greater crop growth, but also greater crop resistance to insects and disease. And while large plantations still survived, smaller, more intensified farms were better able to take advantage of improved management techniques. Slave labor also became more effective when their efforts were concentrated on smaller parcels of land instead of huge plantations.

"By 1860, soil exhaustion had ceased to be a problem in Virginia and Maryland, at least for the small farm and the small farmer. Even where the larger estate still persisted, extensive crops and methods began to give way to intensive cultivation of diversified production" (Craven 1925). The advances in agriculture in Virginia and Maryland did not, however, have much impact in the states further south.

6.3.5 King Cotton

The 1939 movie "Gone with the Wind" portrayed life on a cotton plantation in Georgia just before the Civil War. The movie was extremely popular, not only in the U.S., but also abroad. It projected an image of life in the South as elegant

Fig. 6.2 Lumpkin House in Athens Georgia, built in 1842, home of Joseph Henry Lumpkin, Chief Justice of the First Georgia Supreme Court. It is one of many Greek Revival style houses in Georgia from the nineteenth century

and prosperous. The past and the future of Tara, a magnificent ante-bellum mansion was the sub-plot to the romance of a young woman who inherited the plantation on which it occurred. Even today in the South there are dozens of Tara look-alikes catering weddings for romantic couples reminiscing the faded glory of the Confederacy. For important cultural buildings, such as the residence of Joseph Henry Lumpkin, Chief Justice of the First Georgia Supreme Court (Fig. 6.2), this Greek Revival style was often used. Ironically, many of the white columned structures of the 1850s were originally log houses that had been transformed, but with the original logs left underneath to betray the transformation to later generations.

The life style at Tara did exist among a very small proportion of the population for a short time in the mid nineteenth century. But even by the standards of the nineteenth century South, conditions on the frontier were primitive. Such roads as existed were generally old Indian trails. Most of the population consisted of small farmers called yeoman, with few or no slaves. They lived in log cabins (Fig. 6.3) that were simple, yet constructed with distinctive characteristics, such as dove-tail notching where one log lay across another at the corners.

6.3.5.1 Settlement of Central Georgia

Following the American Revolution, settlers moved into Central Georgia. Much of the region lies above the fall line in the gently rolling hills of the lower Piedmont. The humus from decaying hardwoods over millennia produced rich deposits of soil.

Fig. 6.3 Restored frontier cabin at Spring Hollow, Georgia, a gift from Dr. Eugene Odum to the School of Ecology

Fertile bottomlands along the Ocmulgee river alternated with sandier soils on the uplands. Both formations were ideally suited for crops, an irresistible lure to occupants of tired lands in older agricultural areas. In scarcely more than a generation, the area surrounding Macon developed into the heartland of Georgia's cotton kingdom. Cotton grew there as nowhere else in the state, and cotton growers prospered. In the early years of settlement, slave-less yeomen and small slaveholders predominated. Unlike smallholders in Georgia's upper Piedmont, where distance from markets made commercial agriculture difficult, small holders who settled in central Georgia integrated commercial cotton growing into a flexible pattern of subsistence agriculture.

Despite the numerical preponderance of yeoman during the settlement period, large plantation owners exerted influence far beyond their modest numbers. This power rested upon command over the premier resource of the southern agricultural economy-slaves. Slaves raised the cotton, the profits of which made possible the purchase of additional laborers, who in turn cleared more land for cultivation, raised more cotton, and generated more profits. The planters' monopoly on force gave them a decisive advantage in molding work routines of slaves to their liking. It facilitated the spread of the plantation system, which in turn, made for larger cotton crops, which brought new wealth to the planters. The gang system of labor, backed by the lash, proved an excellent mechanism for forcing large numbers of slaves to the will of a small number of masters.

A factor that originally slowed the expansion of the cotton market was the difficulty of separating the fiber from the seed. Because of the tenacity with which the lint clung to the seed, it was impossible to separate the two by any means except laborious hand cleaning. As a result only small quantities were grown and they were devoted largely to home use. To separate a pound of cotton from the seed required a day's work. The task usually was done during winter evenings in a family circle around the fireside. The commercial importance of cotton did not begin until Eli Whitney in 1793 devised an effective machine for separating the seed from the fiber. It was capable of cleaning 50 pound of lint in 1 day.

Between 1830 and 1835, cotton boomed and prices rose steeply. But the attendant prosperity was misleading. To the extent that small holders committed land and energy to cotton, they compromised their ability to subsist themselves, and subjected their livelihoods to market fluctuations. The lure of earning cash to purchase the growing array of consumer goods had long term consequences. Deteriorating soils cast a pall over the quest for large cotton crops, and heavy mortgages to purchase slaves created a real threat of foreclosure. But the commitment to commercial agriculture was difficult to reverse. By 1835, the land east of the Ocmulgee was ravaged, the topsoil gone, and deep gullies worn into the underlying red clay. When prices fell during the recession of the 1840s, the most successful planters expanded their holdings of land and slaves at the expense of their insolvent neighbors, thereby consolidating wealth, power and influence.

In the North, the increasing commercialization of agriculture undermined traditional social relations based upon landed proprietorship, household centered production, and the mutual exchange of goods and labor. This type of change was strongly resisted in the conservative South. Southern planters wielded power at the local, state, regional and national levels in such bodies as county courts, legislatures, and executive offices. They formed the core of southern agricultural societies and political parties. They served as trustees of churches, schools, and a host of public and fraternal groups and organizations. Their virtual monopoly over international cotton supplies guaranteed them powerful friends in the commercial and financial centers of the North and of Europe. The economic downturn of the 1840s only reinforced their commitment to the status quo.

As the recession of the 1840s began to recede, cotton fever again began to rage. On the eve of the Civil War, large-scale planters in Central Georgia owned most of the land, and averaged 35 slaves apiece. The richest 10 % of the landowners prospered beyond their wildest dreams. Cotton was so successful that the cotton culture spread into the upper Piedmont region (Box 6.11).

6.3.5.2 The Movement Westward

As Georgia soils became depleted, settlers moved westward across Alabama and Mississippi. The cheapness and abundance of land in new areas offered hope and expectation to those who found their soils impoverished by the frontier system of cultivation. With few exceptions however, the soils were as problematical as the red clay of Georgia. One exception was the Alabama Black Belt, where a thin layer of rich, black topsoil occurs atop the chalk parent material. For lack of a reliable source of water, the earliest settlers avoided farming the black soil until the discovery that deep artesian wells could be drilled to supply water for people, livestock, and crops.

Box 6.11

In 1864, a soldier in the Confederate army, during leave, came to Athens and purchased the Piedmont land that now is Spring Valley Ecofarm. He chose that land for cotton, rather than land closer to Athens, because he believed that the soil was better. In the years after the war, a farm was established, called Great Oaks. A farmhouse was built in 1878. To facilitate plowing on the rolling hills, terraces were constructed by flattening the land into a series of gentle steps. At the base of each terrace, a bund (low embankment) was built to lessen erosion. On some farms, rocks were used to buttress the bunds, but we have found that a shrub, Ebbing's Silveberry (*Elaeagnus ebbingei*), works better than rocks. One of the initiatives at Spring Valley Ecofarm was to plant fruit trees along these bunds because the soil there is better due to the accumulation of eroded topsoil. The original farmer and his crew also dug out a farm pond to capture water from a spring at the top of the property. To prevent floods from washing out the pond, a complex water diversion system was engineered. It required an incredible amount of hand digging.

Beginning in the 1830s, cotton plantations in the Black Belt became Alabama's greatest source of wealth. Before the American Civil War, these plantations were worked by thousands of African American slaves.

The Mississippi Delta region is another exception. It lies in northwest Mississippi between the Mississippi and Yazoo Rivers. The area is not a the same as the delta at the mouth of the Mississippi River, but is part of an alluvial plain, created by regular flooding over thousands of years. This region is remarkably flat and contains some of the most fertile soil in the world. It was one of the richest cotton growing areas before the Civil War.

Slavery as a Subsidy

The adaptability of cotton and corn to simple tools and the widespread use of slaves contributed much to the backwardness of field culture in the South. Slavery was the foundation of Southern society. Slavery was the subsidy that made cotton agricultural economically profitable. It represented the energy input over and above that of the sun that enabled economic production to continue for a generation or two. But like all artificial subsidies, it was not sustainable.

6.3.6 The Civil War

The South's agricultural wealth was its greatest military asset. It provided food and forage for its men at arms, but it was also its most vulnerable resource. A strike

Box 6.12

Frances Butler Leigh described the impact of the War on plantation owners of the South. She was the daughter of a planter who owned a rice plantation on Little St. Simon's Island, Georgia before the Civil War. She began an account of her observations there as follows: "The year after the war between the North and the South, I went to the South with my father to look after our property in Georgia and see what could be done with it. The whole country had of course undergone a complete revolution. The changes that a four years' war must bring about in any country would alone have been enough to give a different aspect to everything: but at the South, beside the changes brought about by the war, our slaves had been freed; the white population was conquered, ruined, and disheartened, unable for the moment to see anything but ruin before as well as behind, too wedded to the fancied prosperity of the old system to believe in any possible success under the new" (Leigh 1883).

against these resources by the North was an indirect means of accomplishing the destruction of the Confederate army. An attack against an enemy's resources goes beyond the simple destruction of material products. It destroys the enemy's social and economic systems as well. In targeting the South's agricultural section, the Union strategy undermined the region's most basic relationship to the natural world, destroyed the Confederacy's ecological foundations and assured Federal victory.

General Grant initiated this strategy during his march to Vicksburg in 1862, when his supply lines from the North were cut off by the Confederate army. Rather than retreat, Grant seized the animals and crops of Mississippi farmers, used what he could to supply his troops, and killed or burned the rest. The strategy worked so well, that in 1863, General Sheridan used it to take the rich farming region in the Shenandoah valley of Virginia by destroying its agricultural base. Robert Barton, owner of Springdale farm, recalled that "two columns flanked the road skirting his property, marched in the fields and destroying everything before them. Hogs, sheep, cattle etc. were shot down and left to rot and horses were taken and carried away, whether needed by the army or not." (Brady 2009). Then in November, 1864, General Sherman left behind his supply lines, and set out on his infamous "March to the Sea", from Atlanta to Savannah. Cotton fields, as well corn were destroyed to undermine the Confederacy's ability to finance its war. Stocks of food were quickly consumed or destroyed, and the Union army had to move continuously or risk the same fate as those left starving in its wake.

Sherman laid waste to the economic foundation of the Confederacy. Agriculture based on slavery was the cornerstone of the southern economic prosperity. Its success relied on a system of power based on the oppression of black Americans. It was an energy subsidy that was not politically sustainable (Box 6.12).

6.3.7 Reconstruction: 1865–1900

General Robert E. Lee's surrender on April 9, 1865 left the Confederate agricultural establishment destitute. All Confederate money held by farmers and planter was worthless. Confederate banking capital that had been invested during the war in bonds and securities also was worthless, and banks were nearly ruined. The life savings of farmers and planters were mostly gone. What remained for them however, was their land, and their determination to rebuild a cotton empire. The problem was to find the man-power to weed and harvest the cotton. The hope was that former slaves, now proclaimed "Freedmen" could be hired back onto the farms and plantations. Although many returned as tenant farmers or share croppers, the results were less than satisfactory for the planters. For one thing, the former slaves, without the threat of the whip, were not inclined to work as hard. They preferred to devote time to their own personal subsistence plots, from which they harvested vegetables, fruits, and chickens, and to spend time hunting and fishing, or visiting relatives. Secondly, the planters did not have the capital to invest in guano, marl, and other amendments to fertilize the soil, nor to buy deep-cutting steel plows, cultivators, and grain drills that made farming more productive. Many of the white yeoman who lost their farms also became tenant farmers, but they were no more inclined to work assiduously than the former slaves.

An even greater factor in the decline of agriculture in Georgia was the psychological mind-set of a tenant farmer. Although a tenant farmer or share cropper could keep some of the cotton yield for himself, he had little motivation to spend time or effort improving the soil, in as much as the land on which he worked did not belong to him. The motivation to mine the soil was even greater for the tenant farmer than for the planter or farmer. The result was lack of winter cover crops, and erosion that scoured out gullies that still exist today. Providence Canyon State Park in west-central Georgia contains Providence Canyon, the "Little Grand Canyon" of Georgia (Fig. 6.4). The park was established as a dramatic reminder of the effect that erosion has had on the soils of Georgia.

Some farmers tried, with little success, to produce something other than cotton. They often found their new crops were beset by diseases and insects to a greater extent than cotton. There were no entomologists to develop controls, nor veterinarians to help with the diseases that killed off cattle and hogs. To remedy the situation, in 1862 Congress passed the Morrill Act, which provided each state with land it might sell to establish agricultural and mechanical schools and colleges. In 1866, the Georgia State College of Agriculture and Mechanic Arts was established within the existing University at Athens. In 1891, a similar institution was established specifically for Black Americans. For the rest of the 1800s however, the Colleges of Agriculture had limited success. "American boys seemed to want to get away from farming rather than learn more about it." (Range 1954). A few experimental farms were established, but these efforts did little to help farmers extricate themselves from the Long Depression of 1865–1900.

Fig. 6.4 Providence Canyon, a network of gorges in southwest Georgia. Historical accounts indicate that the canyon began forming in the early 1800s as a result of poor soil- management practices (Photo Credit: J. Kelley. http://SoilScience.info)

6.3.7.1 Pharsalia

"Pharsalia: An Environmental Biography of a Southern Plantation – 1780–1880" (Nelson 2007) is a counterpoint to "Gone with the Wind", which portrayed a romantic vision of life in the Antebellum South. Pharsalia portrays life on a Southern Plantation as it really was, through notes and diaries meticulously kept by the plantation master, with particular emphasis on agriculture.

In 1803, Major Thomas Massie purchased 3,111 acres of land in the Virginia Piedmont at the foot of the Blue Ridge chain of the Appalachian mountains. The land had been farmed for tobacco and corn since before the American Revolution, and had lost some of its fertility. In 1815, he deeded part of the land to his youngest son William, who named the estate Pharsalia, after the Roman epic poem telling of the civil war between Julius Caesar and the forces of the Roman Senate. William Massie had two goals: To keep his family in the ranks of the aristocratic Virginia gentry; to restore Pharsalia's soils and turn it into an efficient sustainable agricultural ecosystem (Box 6.13).

Massie began by trying to make Pharsalia self-sufficient, by minimizing commercial inputs from outside the farm, and by managing the land to maintain its fertility. In ecosystem terminology, he was "striving for sustainability by minimizing energy subsidies from beyond the farm boundaries." In other words, Energy Independence. He did have horses and oxen, but they grazed on pastures within the farm. He also had slaves, but he kept them isolated on the plantation, for fear they

Box 6.13

Eighteenth-century planters figured tobacco yields in pounds per worker, revealing the greater value of labor over land. Farmers that intensified reversed the calculation and began measuring yields per acre. Massie was perhaps the first to use ecological energetics to evaluate his system of agriculture. He calculated a ratio of grain harvested to the amount sown – the productivity of the seed was an even greater concern to him that that of the land or the labor. Even in the early 1800s, Massie recognized the importance of energy efficiency

$$\frac{Energy\ out - grain\ yield}{Energy\ in - seed\ to\ produce\ the\ grain}$$

Box 6.14

Massie's slaves began using something they called "new milk" to stimulate crop growth. The diaries gave no indication of what this was. In recent years, there have been anecdotal accounts of how unpasteurized milk sprayed over a field can increase plant vigor. One possible explanation is that the microbes in the milk are able to mobilize the nutrients sequestered in the passive portion of the soil organic matter, making them available to the crops.

would run away. Since the slaves fed on home gardens and game within the plantation, they too were subsidies internal to the farm.

Massie began with crop rotations, which stabilized to some extent, the decline of soil nutrients that occurred with continuous corn and tobacco farming. The first attempt was with short-term fallow. The slaves plowed the remains of harvested plants back into the soil of cropped fields. Then they allowed the weeds and wild grasses to colonize the clearings. These plants checked the advance of soil erosion and added more nutrients and biotic material to the soil when they were plowed back under. Massie then began allowing livestock to graze in the fallow fields for a year, where their manure added a spike of nutrients to the soil. When animals were penned in the barn during the winter, the manure was collected and hauled out into the fields (Box 6.14). He also began experimenting with planting clovers which appeared to have an ability to enrich the soil (Box 6.15). By selectively breeding and culling the half-feral hogs that roamed the forests, Massie began to satisfy a demand for high quality meat in Richmond. Pharsalia became noted for his smoked and salt-cured hams.

Despite his efforts, success was evasive. Rainstorms, weeds, fungal blight, and wildlife that invaded and dug up his crops, all contributed to his difficulties.

Box 6.15

Only in 1888 was it discovered that the nodules in the roots of clover housed rhizobial bacteria that fixed nitrogen from the atmosphere (Hirsch 2009). It was this nitrogen that enriched the soil at Pharsalia.

Transients that stole his corn, or plowed up a remote corner of the plantation for a few months worth of food degraded the soil. But the biggest obstacle that Massie faced was the practices of other planters, who used slash and burn techniques to gain a year of corn and tobacco, and then moved on and cleared new areas. These planters undercut the prices that Massie needed to maintain his operation. We could say that they were exploiting, but not replacing, the services of nature. As a result, Massie was forced to do what other planters nearer the roads and rail lines were already doing – intensifying. He first tried using gypsum, to decrease the acidity of the soil, but with mixed results. Much more successful was the application of guano. Massie struggled with the fact that such outside sources of agricultural inputs was replacing the old virtue of local ecological adaptation, but he had little choice.

Problems arose when the Peruvians realized that they had a valuable monopoly on guano, and rapidly raised prices, much to the consternation of Southern Planters. Nevertheless, Massie survived. In fact, Pharsalia was in its prime in the years leading up the Civil War. Capitalist intensification had helped the plantation escape its ecological crisis and achieve a measure of profit and stability. Yet he still faced challenges. The most serious did not come from outside his fences, as he had always expected. His problem was that capitalist intensification could not deliver on the aristocratic ambitions of the Massie family. They wanted to assert their status by spending heavily on luxury consumer goods. They also believed that a rural plantation was the proper way to earn the wealth for those purchases and the proper place to display them. While Massie fought to reinvest his resources in intensive agriculture, his children badgered him for money, land, and slaves that they needed to establish themselves in the southern gentry.

After William Massie's death, his widow tried to manage Pharsalia for profit while still keeping the family's home place secure for the next generation. Her efforts though, resulted in slowly diminishing returns. In her final will before her death in 1889, she gave up the battle to keep the plantation intact. Pharsalia died with her (Nelson 2007).

6.3.8 Southern Agriculture Since 1900

The beginning of the twentieth century marked a gradual emergence of the South from its long depression. The change away from King Cotton was gradual, but as the University of Georgia College of Agriculture established various experiment stations and trained young extension agents to teach better ways of farming, many new crops were tried. Diversification was hailed as the road to profitability. A new strain of tobacco, bright leaf, was tried. While cattle, chickens, and hogs had always been kept around the farm yard, farmers at the beginning of the twentieth century began to see economic potential in them. Grains such as corn, wheat, oats, barley and sorghum (all annual grasses) were planted, but these had little impact on the Georgia economy.

6.3.8.1 Corn

Corn had never shown itself able to compete as a cash crop with the corn from other parts of the nation (Range 1954). The reason is that grain crops are better adapted to the deeper and more fertile soils of the Midwest, where grass covered prairies had been the naturally occurring vegetation. But even in the Midwest, annual grains are not the best environmental fit. In the South and Midwest, periodic drought is a threat to the shallow rooted annuals. The Prairie grasses are deep rooted perennials, and are much better adapted to surviving extended droughts than are the annual grain crops (Brasher 2012).

6.3.8.2 Tobacco

Tobacco, like corn and other grains, suffers during drought. It feeds heavily on soil nutrients, and needs rich soil to prosper. Except perhaps for farmers on the richer soils of Kentucky, few Southern farmers became prosperous trying to grow tobacco. Tobacco Road, a 1932 novel by Erskine Caldwell has depicted the desperate cycle of poverty faced by sharecroppers trying to survive on barren Georgia soils.

6.3.8.3 Cotton

In 1898, the long-depressed prices of cotton began moving upward. In 1900, the Moultrie (Georgia) Observer declared "cotton is up – God is surely smiling on this country." (Range 1954). After 35 years of depression, farmers were convinced that prosperity had returned. By 1905, the president of the State Agricultural Society insisted that "today's cotton agriculture stands upon the highest pinnacle yet reached." Cotton production, and the income to cotton farmers increased steadily until 1918, when the crop was worth three times that in 1900. Little attention was paid to the impact that cotton cultivation was having on the soil. Erosion was taking a terrible toll.

With the increase of cotton plantings throughout the state came an increase in the boll weevil. These insects feed on bolls, the fruit of cotton. They drill holes into the bolls with their chewing mouthparts at the tip of their "snout". Infested cotton bolls turn yellow and fall off the plant. By 1919, boll weevil damage became serious, and by 1923 it was disastrous. Cotton production dropped more rapidly than it had increased. By 1925, Georgia's farm population declined by about 375,000 and nearly 3,500,000 acres of land were taken out of farming. Several factors contributed to the explosion of the boll weevil population. Georgia was a huge monoculture of cotton, just the ideal situation for a pest to spread. The beetle faced an unlimited resource with nothing to stop its exponential population growth. Another factor was depleted soil, both through erosion and through lack of fertilization. Cotton, like any other living organism, is more susceptible to insects and disease when it is lacking in adequate nutrition. Soil degradation led to cotton's decrease in insect resistance, and so the weevil had not only an unlimited resource, it was a resource lacking in defenses. Finally, the economic depression that began in 1929 put an end to cotton as an economic crop in the Southeastern United States.

6.3.8.4 Legumes

Herbaceous legumes did better environmentally, if not economically than cotton and grains, because they are symbiotic nitrogen fixers, a characteristic that helps them to overcome the low fertility of most Southeastern soils. Cow peas and velvet bean grew well, but they are annuals, and need a plowed seed bed to grow. They were fed to the cattle on small farms, but did not match cotton in economic importance. Perennial forage crops such as lespedeza were better adapted because of their deeper roots. Peanuts, in contrast to other annual legumes, became a commercially important crop, because of the demand for peanut oil, and the success of the marketing of peanuts and peanut butter. The economic demand for peanuts resulted in a price high enough that farmers could afford to cover that costs of production and still make a profit. Soybeans, a recent leguminous addition to Georgia agriculture, also has been commercially important but is now threatened by the Kudzu bug (*Megacopta cribraria*), a new potentially devastating pest of soybeans.

6.3.8.5 Vegetable Crops

The recent interest in organic and locally grown foods has stimulated the growth of local farmers markets, and cooperatives called CSAs (Community Supported Agriculture). Fresh vegetables are the predominant crop. Most vegetables, like grains, are annuals, and thus suffer the scourge of annual cultivation. Soil disturbance is the primary negative factor. Even though vegetable crops are grown on a much smaller scale than commodity crops, the problems of monocultures still affect them. Insect pests and fungal diseases that attack vegetables also thrive in the hot, humid climate of the Southeast. There are now many organically approved pesticides and fungicides on the market that can help control vegetable pests, but they are expensive. Cultivation of several species such as corn, beans, and squash in close proximity, as was practiced by the indigenous inhabitants of the South theoretically should make the trio more resistant to insects and disease, but planting and harvesting such combinations on a large scale with modern machinery is not economically practical.

Box 6.16

Fruit trees take several years to bear fruit. To realize an early economic benefit from the land on which the fruit trees are planted, the farmer can plant annual crops between rows of newly planted fruit trees. This is the basis of taungya agriculture in Thailand, where farmers plant rice between teak seedlings (Jordan et al. 1992).

6.3.8.6 Fruit Trees

Trees are the natural vegetative cover over most of the Georgia. Trees are well adapted to the environmental conditions of the South because their deep roots. Their roots are able to recycle nutrients and acquire water from soil horizons that are inaccessible to annuals. Tree crops should be one of the most sustainable crops in the South. Peaches did become economically important, and the growth of peach orchards led Georgia to take on the name "The Peach State". However, peach orchards, like all monocultures, are susceptible to rapid pest outbreaks, especially in a hot, humid climate. Peach trees themselves often do well, but a variety of insects and diseases attack the fruit. It is almost impossible to produce fruit without using industrial pesticides and fungicides. Pecan orchards also are important in Georgia and throughout the Southeast. Like peaches, pecan nuts attract insect pests and disease, but for pecans, the modern approaches of integrated pest management have proven more economically viable (Box 6.16). Perennial Shrubs and vines also are well adapted to the Southern environment. In recent years, blueberries have become commercially important because they do well and require little maintenance. But like all things that are easy, everybody does them and market competition quickly drives down the price. Muscadine grapes are native to the Southeast and were often used by early settlers. The market for them is limited however, but they can be used as rootstocks for European grapes. In recent years, there have been numerous vineyards with European grapes started in the South, but competition is fierce. One of our favorites had to go out of business.

6.3.8.7 Timber Trees

The best and most sustainable crop for the Coastal Plain of the South is Longleaf Pine. Because its evergreen leaves help conserve nutrients, it does better than many other species on the infertile sands. Unlike most conifers, the first 3–7 years of longleaf pine growth do not involve stem elongation. Rather, it remains a fire resistant, dense cluster of needles lacking a stem, and resembling a tuft of grass. During this stage, seedlings are developing a deep taproot system below the ground and are

Fig. 6.5 Foreground: Loblolly pine saplings in an abandoned field near Athens in the Georgia Piedmont. *Background*: Mature pines

capable of sprouting from the root collar if the top is damaged. Once the root system is thoroughly established, the tree begins normal stem elongation. When the pines reach 8 ft in height, it can usually withstand periodic low-intensity fires that often are set by humans to clear out tangled underbrush.

Loblolly pine is well adapted to Piedmont soils that have been cropped for many years and then abandoned (Fig. 6.5). It is able to do well on these poor soils in part because of symbiotic mycorrhizae that help extract nutrients, especially phosphorus from the red clay. However, it is an early successional species, and has a lifetime of about 60 years, at which time a pure pine stand is replaced by hardwoods through the process of natural succession. Because loblolly has a commercial value for pulp and lumber, land owners often try to replace a harvested stand with new pine seedlings. This only works if the cutover stand is plowed and "root-raked" by energy intensive bulldozers to eliminate later successional hardwoods such as sweetgum.

There are about 20 native species of oaks in Georgia. Live oak, does well along the coast, and was highly valued as timber for shipbuilding. Ship builders would sometimes scout the forests and look for trees with a shape that was needed for a particular part of a ship. At Spring Valley Ecofarm, there is a plantation of white oak that is doing exceptionally well. The problem with planting oak as a commercial crop for furniture or flooring is the long time between planting and harvest, often 30 years or more.

6.3.8.8 Cattle

Beef and dairy cattle were of limited success in the early 1900s. Grazing animals, adapted to forage grass, are best raised where grass is the natural ground cover, as in the arid West, although burning of the Georgia prairies by native Indians maintained a grass cover in those regions. But now that burning is severely restricted, intensive use of selective herbicides is the only way to keep trees and perennial shrubs from invading pastures and out-competing grasses. Goats would be a good solution, if fencing them in were not such a problem.

6.3.8.9 Poultry

Poultry raised around the farmyard provided some income for farmers beginning in the 1920s. Most chickens are well adapted to the barnyard. If their coop is opened in the morning, they can scavenge for insects and loose grains, and in the evening, they will return to roost and the door can be closed to keep out predators. However, as demand grew, chicken production evolved to the "putting out" system, whereby agricultural businesses supplied credit, chicks, feed, and marketing services to hundreds of relatively small operating farmers. It took away the farmer's independence. It made farmers into errand boys for agricultural corporations by making them completely dependent on the company for a market, and subservient to corporate demands on how the chickens are to be raised. Chicken farms of today are an example of extreme unsustainability. The chickens are crowded together in long coops, kept ventilated and lit to encourage production throughout the day and night, and are fed grain imported from the Midwest where recent droughts are making the feed expensive.

6.3.8.10 Hogs

Since the Civil War, pork production in the South has played a role in the economy. Razor back hogs are descendents of pigs brought by the Spanish in the sixteenth century. These hogs were wild, and difficult to control, and gradually they were replaced by Northern European pigs that were more economically profitable when raised in concentrated animal feeding operations, mostly in North Carolina.

Wild hogs are one of the biggest pests in Southeastern Georgia, where their rooting habits are destroying many plants, both wild and cultivated. They obviously are well adapted to the environment, but their survival instincts prevent them from being economically attractive, except for hunting.

6.3.9 Agriculture in Georgia: 2012

Timber is Georgia's number one crop, and Georgia is at the top of pulp and paper states in the nation (Georgia Agriculture Education Curriculum Office 2002). Georgia's top five agricultural (non forest) products are broilers (young chickens), followed by cotton, cattle, chicken eggs and peanuts (Georgia Economy 2012). Other products include barley, canola, oats, rye, wheat, sorghum, tobacco, corn, sweet potatoes, cabbage, onions, tomatoes, and other vegetables, hogs, sheep and forage.. Blueberries are a rapidly emerging product that is easy to grow (a perennial shrub) and few diseases have yet emerged.

Cotton can be profitable now in the South because of insertion of a gene that provides the plant with resistance to herbicides. This means that herbicides can be used to control weeds without affecting the cotton plant. However, some weeds, particularly pigweed (*Amaranthus* sp.) have already evolved resistance to most herbicides.

Georgia is a leading producer of peaches, pecans, and apples. These can be grown with a relatively small energy subsidy (over the life of the tree) in the Georgia environment where trees are the natural vegetation. Because they are grown in monocultures however, the fruits are susceptible to disease and insect attack.

6.4 Southern Conservatism

This chapter suggested that the poor quality of soils over most of the South was an important influence on Southern agriculture. But does the poor quality of soils in the South have anything to do with the tendency of many Southerners to be conservative? Farmers in Midwestern States with fertile soil also tend to be conservative so it could not have been the quality of the soil alone that resulted in the Conservative South. More likely, the poor quality of the Southern soils resulted in much poverty, which made evangelical religions more appealing. Evangelical religions, emphasize traditional, thus conservative, values. Evangelical religions in the old South were especially appealing to poor farmers, because the promise of a life hereafter in heaven could make poverty bearable. Infertile soils over most of the South may have *indirectly* influenced conservatism.

Another factor is that the people who settled the South were conservative to start with. Early English colonists were primarily employees of British corporations, and so reflected the conservative business ethic of their employers. Later Scotch-Irish settlers were fiercely independent and distrustful of all government and authority, a trait that resulted from life in their home country.

Perhaps the biggest reason for Southern Conservatism is antagonism toward the "Liberal North" over the fact that the North took away what Southern whites believed was their God-given right – to own slaves. The plantation South is remembered fondly (if erroneously) as a glorious era, when times were providential and cotton fields bountiful. Belief that times and values of the past were better than present day times and values has been a basic characteristic of many Conservatives in the South.

Oh I wish I was in the land of cotton
Old times they are not forgotten
Look away, look away, look away
*Dixie Land**

*Dixie, The Anthem of the Confederacy, played until very recently at football games of some Southern Universities.

6.5 An Economic Evaluation of Agriculture in the Old South

6.5.1 The Colonial Period

When the English set out to colonize the American Southeast in the 1600s, one of their objectives was to use the native forests to supply timber and naval stores for the British fleet. Their approach was to exploit the forests, but not to replenish them. It was 200 years later that the importance of reforestation was realized, when the British began experimenting with teak plantations in Burma to replace the teak forests that had been ravaged by logging (Takeda 1992). But in the seventeenth century, sustainable wood production was an unfamiliar concept in the American colonies (Box 6.17).

6.5.1.1 Tobacco

Tobacco quickly became the principal agricultural crop in the Colonial Period. Was tobacco well adapted to the sandy Coastal Plain and the red clay of the Piedmont? When first planted, it seemed that the region was well adapted for tobacco farming, but that was only because the tobacco received its nutrients from the decaying soil organic matter of the original forest (Box 6.18). Once the rich topsoil was plowed, erosion and oxidation of the soil organic matter depleted the nutrients in just a few years, and the remaining subsoil had little productive capacity. Tobacco was ill-adapted to that condition.

6.5.1.2 Subsistence Agriculture

The pioneers that moved across the Blue Ridge encountered soils in river valleys, where the accumulation of sediments and the higher water table were more suited to

Box 6.17

By the 1800s, the English Colonial System finally began to realize that forest exploitation was not a sustainable way of replenish wood supplies for their Navy. To try to ensure greater sustainability in the teak forests of Burma, (Now Myanmar), they instituted a system called "Taungya", in which teak plantations were established (Takeda 1992). It was successful for a while, but then disease and labor problems caused a decline. In modern taungya in Southeast Asia, landless peasants are allowed to grow agricultural crops among teak seedlings for the first few years of the plantation (Watanabe 1992).

Box 6.18

We can get an idea of the energy yielded per calorie subsidy in the colonial days on virgin soils by looking at the energy efficiency of "primitive" peoples who carry out "swidden" farming, because what the Southern colonists did was basically a type of swidden farming. In swidden farming, farmers clear a patch of forest, and plant their crops in "virgin" soil, soil that has never been cultivated and is rich in soil organic matter, and then move on when productivity declines. In the tropics, this is called "shifting cultivation". Corn production in Mexico using swidden agriculture produced 12.6 cal of output per calorie of input. For root crops in New Guinea, the gain was 15.4 These outputs per unit input are dramatically higher than those for modern industrial agriculture, 3.8 or less (Pimentel and Pimentel 2008). Certainly then, it was the energy subsidy from the soil organic matter that produced the good yields for colonists in the South for the first few years. Only a small energy subsidy of human labor produced this substantial but short-term yield.

grain and vegetable production, and pastures. The environment was better adapted to production of annuals than was the upland Piedmont and the sandy Coastal Plain. Nevertheless, for most of the non-English settlers in the South, the philosophy toward land was the same as that of the planters: lay claim to as many resources as possible as fast as possible and exploit it as quickly as energy permitted. For most of the small pioneer farmers, short term exploitation of the soil for survival was all they knew. There were exceptions, such as the Moravians whose ideas of social welfare also extended to agricultural welfare of the land (Caruso 2003). But for the most part, colonists, as they settled and moved westward across the physiographic provinces of the South – the Coastal Plain, the Piedmont, and the Appalachian Mountains- , it was a race to exploit the soil and all that it produced.

6.5.1.3 Rice

Construction of the dams and reservoirs for rice production required a huge energy input in the form of slavery. The finished product altered the coastal landscape, but rice was well adapted to the system, once it was completed. The regulation of fresh water flow into the rice fields was similar to the system of paddy rice in Asia, a system that has been sustainable for centuries. Both systems took advantage of a free service of nature, the supply of fresh water that could be regulated as needed. However, paddy rice production, both in the Southeast and in Asia required considerable energy subsidies to plant and harvest the rice, to maintain the reservoirs, and to regulate the water flow. When the Civil War ended slavery in the South, cheap energy disappeared.

6.5.2 Settlement of the Georgia Colony

6.5.2.1 Early Settlers

By the first half of the eighteenth century, the Trustees of British Corporations faced the difficult task of bringing settlers to occupy the Georgia Colony. Indentured white servants were to compose the principal source, and in time, they were to become freeholders and masters of their own farms. The English settlers represented a wide variety of urban trades and occupations, including writers, potash makers, wig makers, and upholsterers, with only a sprinkling of skill related to the cultivation of the soil. The German Salzburgers were the most successful farmers of the Colonial period. The Scotch were highly regarded by the English Generals for their fighting qualities and their sturdy habits rather than for their agrarian skills. As a result they were settled on the southern frontier where their main function was to do garrison duty in the colony's defense against the Spaniards (Bonner 1964).

To attract new settlers to the Carolinas and Georgia, English authorities publicized the fact that many fruit trees grew naturally in the region: peach, mulberry and fig trees, apples, pears, figs, fox grapes, pomegranates. These species are woody perennials, and thus well adapted to the climate and soil of the Southeast, and therefore should have conferred a "comparative advantage" to farmers that cultivated them. Nevertheless, in the eighteenth century, fruit trees had little commercial impact.

6.5.2.2 The Cotton Era

Of all the possible crops that could have been chosen for the South on the basis of adaptability, cotton was the least likely. It is an annual, trying to grow in a region with an environment to which trees are naturally adapted. Cotton is a heavy nutrient feeder, that is, it needs soil rich in nutrients, but most Southern soils, once the topsoil has eroded, is exceptionally nutrient poor. It is grown in monocultures, and thus is highly susceptible to the rapid spread of disease and insect pests. It requires high energy inputs for planting, weeding, and processing. Why then did it have such an economic advantage over fruit tree crops that are better adapted ecologically? Why was Adam Smith wrong?

- There was so much new land to be cleared for cultivation that virgin soils could be wasted.
- Cotton could be stored for long periods of time, and transported to markets when convenient, thus obviating the undeveloped transportation facilities. Fruit crops, in contrast, area easily damaged and spoil quickly.
- Tariffs helped to protect the Southern producers from producers overseas that could grow cotton more efficiently.

- The energy subsidy – slavery – was cheap. Even after the end of slavery, large landowners through a monopoly on land, could keep the cost of share croppers or tenant farmers low.
- The demand for cotton was so great that the short-term economic advantage of producing them seemed greater than the long-term ecological damage to the soil. In the end however, this was not the case. Ecological factors – soil depletion, the boll weevil – overcame the economic advantage.

6.5.2.3 Alabama and Mississippi Territories

After the Revolutionary War, the region that became Alabama and Mississippi was a territory of the new United States of America. With two exceptions, the soils, like those of Georgia, were highly weathered and of low fertility. The exceptions:

1. The Alabama Black Belt Region. Beginning in the 1830s, cotton plantations in the Black Belt became Alabama's greatest source of wealth. The high fertility of the soil, and the availability of water from wells gave the region a big competitive advantage. For a century, the availability of soil nutrients gave the region huge energy subsidy that made cotton farming appear sustainable. In the end though, the boll weevil proved the ecological maxim true – monocultures are not sustainable despite good soils.

   Since the end of cotton, much of the once-good soils of the Alabama Black Belt Region have been depleted due to erosion of poorly cultivated cotton fields. Most of the area continues to be rural, with a diverse agricultural economy, including peanut and soybean production. Some people have considered the Black Belt as a kind of "national territory" for African Americans within the United States. Due to the rural economies, the Black Belt remains one of the nation's poorest and most distressed areas. The invisible hand did not work here. Residents of the region were not able to capitalize on the soil resource, for a variety of sociological, economic, and cultural reasons.
2. The Mississippi Delta Region. Because the Mississippi delta region is remarkably flat and contains some of the most fertile soil in the world, it is highly suited to large scale, mechanized agriculture. Since the late twentieth century, lower Delta agriculture has been dominated by families and corporations that own large landholdings. Hundreds and thousands of acres are used to produce commodity crops such as cotton, sugar, rice, and soybeans. The invisible hand has worked well economically, by allocating fertile soils to crops that require fertile soils. The ecological problem of monocultures has been avoided by the heavy use of pesticides and herbicides. As long as these subsidies remain cheap and effective, these crops can be sustained. Even if fossil fuel energy becomes more expensive, the region will still have a competitive advantage over other agricultural areas. As in the rich soils of Kentucky to the North, the invisible hand has been working, if only temporarily.

6.5.3 "How Well did the Invisible Hand Work in the Old South?"

Not very well. With few exceptions, the invisible hand of the market place did not allocate land for production to crops that were best adapted to that land.

6.6 An Economic Evaluation of Agriculture in the New South

6.6.1 Agricultural Crops

How well do current agricultural crops in the South do when judged by the EROI (Energy returned on energy invested) scale?

- **Chickens**. Thousands of chickens are raised in a single crowded structure where they are fed corn grown in the mid west and imported thousands of miles. Growing corn and transporting it thousands of miles are energy intensive activities. Disposal of chicken manure requires intensive pollution control, also energy intensive. Verdict – The Chicken industry in the South has low sustainability.
- **Tobacco and Annual Grains**. Tobacco, soybeans, corn, oats, sorghum grain and wheat all are annuals, and their fields must be plowed every year to bury weeds and prepare a new seedbed. Loss of soil organic matter through plowing is an energy depleting process. The crops are grown in monocultures, so insects and disease are a continual problem. Pesticides and fungicides require energy, both for synthesis and for application. Verdict – low sustainability.
- **Vegetables**. Most vegetables are annuals, and yearly cultivation disturbs the soil. Sweet potatoes and onions are even worse. Not only do they suffer the same energy consuming problems as grains, their harvest disrupts the soil even more, since they must be dug up. Verdict – very low sustainability.
- **Peanuts**. Peanuts are native to South America, and most varieties do better in warmer climates. Since they are legumes, they have a symbiotic relation with nitrogen fixing bacteria. This gives them an advantage over other crops on the nutrient poor soils of the South. For peanuts, Ricardo's comparative advantage in the market place seems to have been more effective. Verdict – more sustainable than most annuals.
- **Cattle**. Keeping pastures satisfactory for beef and dairy cattle requires intensive use of herbicides to keep woody successional species at bay. Verdict – moderate sustainability.

6.6.2 Fruit Tree Crops

Since fruit tree crops are woody perennials, they are better suited to the Southern environment where the hot, humid climate results in intensive nutrient leaching from soils that do not harbor an extensive network of tree roots. Because the plantations are monocultures, there are insect and pest problems, but these problems are outweighed by the comparative advantage of trees being adapted to the Southern environment. A more serious problem is over-supply, especially for pecans. Verdict – above average sustainability

6.6.3 *Forest Products*

The prediction by the invisible hand of the marketplace that forest products should be the principal crop in Georgia seems at first to have held true. In Georgia, forest products are the most important land-use resource. In 2004, 131 out 159 counties were greater than 50 % forested. Georgia is home to nearly 1,400 forest products manufacturers. The state is consistently ranked near the top in pulp and paper production and in the top ten lumber-producing states (Forestry 2012).

Longleaf pine in the outer coastal plain is a good example of the success of the comparative advantage of trees in the Georgia landscape. However, loblolly and short-leaf pine, which comprise most of the trees harvested, are well adapted only in fields that have recently been abandoned from agriculture, and it is from these areas that that most of the trees used for forest products are harvested. Much of the pine that grows in Georgia became established in cotton fields when they were abandoned during the great Depression. When landowners wish to reestablish these pines after an initial clear-cut harvest, they must get rid of the hardwood competition that became established under the canopy of the first rotation. This usually involves root-raking with bulldozers, an energy-intensive operation that deliberately destroys the soil organic matter that has begun to develop. Root-raked fields are devastated fields. A better ecological strategy would be to simply let the hardwoods grow, because there is a good market in the furniture and flooring industries for these trees. The economic problem is that it takes 30 years or more for the oaks and hickories to reach a merchantable size.

Verdict – long leaf pine – highly sustainable; loblolly pine – sustainable only in abandoned fields (Box 6.19).

6.7 How Well Is the Invisible Hand Working in the New South?

Not very well.

Why isn't the Invisible hand of the market place doing better at directing the activities of farmers in the South? Some of the excuses given for its failure in the frontier South are not valid for the modern South. Roads and railroads now facilitate efficient exchange of products. Costs of transportation now are low compared to costs of production. Also, market information now is readily available.

There are other reasons however, that are relevant to the South (and all of the U.S.) today.

Box 6.19

One summer as a boy, I watched the old-time loggers at work in the woods of Northern Maine. Two men with a cross-cut saw would take down a big spruce, and then use a draft horse to skid the log out of the woods. The method is rarely used anymore, because it is "inefficient". Today, loggers can make a lot more money operating big machinery that gets trees out of the woods fast. To get the tree down, they sometimes (depending on the terrain) use something called a feller-buncher, a machine with hydraulic arms that grips the trunk of a tree while a powerful blade near the ground slices through a tree in less than 30 seconds. Then they use a skidder that binds six or more trunks together and drags them to the loading dock.

Who is more productive, the operator that operates a feller-buncher, or an old time logger with a cross-cut saw? "Economists define productivity as output per worker hour" (Kessler 2012). If we use the economists definition, the feller-buncher operator obviously is the more productive. The old-time loggers were more energy efficient. There still are many loggers who prefer to use draft horses to skid logs out of the woods to minimize damage to the remaining trees and soil. However, they rely on chain saws to fell the trees.

Subsidies. The most obvious distortion to the efficient market place is the subsidy given to cotton farmers to protect them from foreign competition. In other parts of the South, production of sugar cane also is subsidized. Elimination of the subsidies would put some American farmers out of business, but would benefit consumers.

The subsidies given to tobacco farmers were the result of the very effective lobbying of the tobacco industry. Although subsidies have been ended, the new overseas markets in China, Russia, and Mexico have rejuvenated tobacco farming.

Local advantage – Even though vegetable production is less energy efficient than in other parts of the country, freshness is a factor that commands a higher price, because freshness means better tasting. It is not clear whether organically grown vegetables are more nutritious, but in farmer's markets, organically grown means locally grown, and locally grown means fresher. Certain niche vegetables, such as Vidalia sweet onions command a premium price because they cannot be grown anywhere else but in Southeast Georgia.

Factory farming – Since chickens are produced in energy-inefficient factory farms, they can be produced with equal energy inefficiency anywhere in the country. For factory farms, what matters is who gets started first with the biggest capital investment. It has nothing to do with comparative advantage of the environment.

Logistics – For dairy farmers, logistics gives local producers an advantage. Long distance shipping of milk is usually not economical. Price supports for milk also help distort the market.

Box 6.20

Technology has increased the productive capacity of our farms, forests, and rangelands. It also has increased the standard of living in those regions able to afford modern technology. But technology has drawbacks as well as advantages, and the disadvantages often do not become apparent until the technology has become deeply integrated into our economy. By then, the technology has allowed the population to expand and increase its standard of living. These are trends that are difficult to reverse, and so we have a *ratchet effect*.

The ratchet analogy refers to a spring that is wound tighter and tighter, but prevented from releasing its energy by a ratchet. Just as the ratchet only allows the spring to tighten, our increasing dependence upon technology forecloses our options to survive without technology and like the spring whose potential energy increases with each notch of the ratchet, the potential for calamity increases with growing dependence upon fallible technology.

Box 6.21

Is the recent movement toward organic farming in the South a move toward agricultural sustainability? Not necessarily. Most organic vegetable farms in the South are on upland soils, that demand heavy loads of compost to maintain production. Organic vegetable production is best suited to environments such as the Central Valley of California. There the drier climate inhibits soil organic matter decomposition and proliferation of insect pests. But if people in Atlanta want organically produced food, doesn't the cost of shipping it from California to Georgia compensate for the higher energy costs in Georgia? Not necessarily. Some estimates have shown that the cost of shipping canned organic foods from California is negligible compared to costs of canning the food. Better arguments for organic farms in Georgia are that locally produced vegetables taste better because they are fresher, and they also help support the local economy.

Climate – Although most soils in the South are not well suited for pasture, the warm climate gives cattle farmers an advantage. Beef cattle can be kept on pasture throughout most of the year in the south. This gives an additional advantage to cattle producers who advertise their product as "grass-fed beef".

Low Cost of Energy – Throughout the U.S. the biggest reason that crops are not grown in environments to which they are best suited has been the low cost of energy. Energy overcomes ecological and physical barriers (Box 6.20). Only when the cost of industrial energy subsidies become higher than the energy supplied by the services of nature will agriculture begin to conform to Adam Smith's predictions (Box 6.21).

Box 6.22

The South is not the worst place to grow annual crops. With sufficient energy subsidies, agriculture can be practiced in the most inhospitable places, such as the rain forests of the Amazon Basin. In 1982, a group of North American scientists proved that intensive fertilization and pesticide application in the lowlands of Peru could compensate for the nutrient recycling services of the intact forest so that grain crops could be cultivated (Sanchez et al. 1982). Because of increasing costs of energy, buying and transporting subsidies into remote regions of rain forests has not been widely practiced. Likewise, converting rain forest to pasture is not energetically rational. Nevertheless, some North American non-governmental organizations are subsidizing cattle for peasant farmers in rain forest areas where cattle are poorly adapted and pasture maintenance requires energy to combat competition from woody plants. Much more appropriate for meat production would be wetland-living capybaras (*Hydrochoerus hydrochaeris*) that are well adapted to the hot, wet environment.

6.8 An Ecological Evaluation of Agriculture in the South

The native peoples living in the Americas before the arrival of Europeans are sometimes described as "living in harmony with the land", and are imbued by writers as having an awareness of how to live sustainably, and not destroying the resources on which they relied (Edelson 2009). There is some evidence for this in the South, where Indians burned grasses to stimulate growth, and keep the fields open from trees that would shade out the food for elk, bison, and deer. But did Native Americans really have an environmental consciousness, or did they merely lack the tools to plunder the land? The only tools available to the native Americans were stone axes, and bows and arrows. While they may have stampeded wooly mammoths to extinction, it was the European colonists when they came to the Americas, who introduced the tools and techniques to exploit the natural capital which they found and consequently, although unwittingly, destroyed (Box 6.22).

It is tempting to ascribe to pre-colonial American Indians an environmental awareness, when Hollywood movies, such as Dancing with Wolves, portray their life so romantically. In reality, however, there has never been a population anywhere in the world and at any time that did not exploit available resources when they had the tools to do so. Exploitation always was followed by an increase in population and betterment of living conditions, until the resource became limiting. Then followed wars over the resource, and a migration of populations to a new frontier and a new unexploited resource. While oil, gold, and other metals have precipitated conflicts in recent centuries, and other resources such as salt in earlier times, the most common resource over which wars have been fought was land. In some civilizations, now and in the past, water rights have been the cause of wars between

Box 6.23

An exception to the maxim that bigger is better because bigger is stronger might be modern children, when those who are smarter rather than bigger will often win out in life's race for resources. But they win only if they combine aggressiveness with intelligence.

farmers, fishermen, and cities that need a water supply. But throughout history, it has been the need for new land that precipitated a conflict between those who were already there, and those who wanted it for themselves. What was it about land that was so desirable as to cause a war? It was soil, soil that had the capacity to produce wood for an Armada, and food and shelter for the populations that supported Tribal Leaders, Caesars, Emperors, Kings, and Dictators!

With few exceptions, wherever land was settled, it was used in a way to produce as much yield as possible in as short a time as possible, with little or no thought to sustainability. For the most part, farmers did not know how to treat the land to prevent exhaustion and desertification. And even when there was the knowledge as to how to steward the land, the decision to "mine" the soil was a rational economic one. It was more profitable to abandon worn out soil and move on to a new frontier than to make the effort to preserve the productivity of the land already cleared. This has been the narrative since early human beings moved out of Africa, and migrated to Asia, Europe, and the Americas.

There is another reason that colonists in the American South did not use resources "wisely", that is, conserve them. The reason is that those who got biggest fastest won the competition for new land. Competition for resources is as true for groups of colonists as it is for nations, corporations, cities, athletic teams, and the 8 baby ducks recently hatched at Spring Valley Ecofarm, where only the five biggest survived. When groups of colonial farmers enter a region, there is competition between individuals for the best soil in a valley, between groups of farmers for the best valley in the region, and between colonial powers for the best region on the frontier. This competition mandates that farmers, villages, states, and nations use resources as quickly as possible in order to grow and win the competition. Those who were careful stewards of the resource grew more slowly, and were more likely to lose the competition for additional resources (Box 6.23).

The story of how Europeans came to the Americas and settled what is now the Southeast is merely a repeat of the sequence that occurred throughout the world whenever humans moved into a new "wilderness". It has been called "progress". It is a re-statement of Gunderson and Holling's (2002) "Panarchy", a renewal, Phoenix-like, from the ashes of the old resource.

1. Discovering a new resource
2. Exploiting the resource
3. Exhausting the resource
4. Searching for a new resource
5. Repeating step 1.

Land was not the only resource to be exploited. The American Indians were another, at least at first. When possible, the colonists used the Indian's knowledge of plants for medicines and other purposes. They were also useful trading partners, who supplied fur pelts in exchange for trinkets. But for the most part, they were an impediment, and either had to be killed, or moved to Western Territories where they would be out of the way. For the Europeans, the native Americans already living in the Southeast were part of the "wilderness", and were subject to subjugation, because they had no more right to the land than the alligators that were living there.

6.9 Maximum Power vs. The Invisible Hand (H.T. Odum vs. Adam Smith)

6.9.1 Verdict at the Frontier

Adam Smith, in his 1776 book "An Inquiry into the Nature and Causes of the Wealth of Nations" theorized that the "invisible hand of the market place" will direct the activity of producers by giving the greatest rewards to those who produce goods most economically. The theory would predict that farmers will manage farms to maximize energy use efficiency, determined by the energy output/energy input ratio. Clearly the theory has not been successful in predicting resource use in the Southeast, at least so far.

H.T. Odum in the paper "The optimum efficiency for maximum power output in physical and biological systems" (Odum and Pinkerton 1955) theorized that operating at the point of optimum efficiency for maximum power output, not where energy efficiency is greatest, will give the greatest success to producers. The theory would predict that farmers will manage farms at an energy input rate higher than that for maximum energy use efficiency in order to beat the competition and attain dominance in the marketplace. Because the optimum efficiency for maximum power output in biological systems results in a sub-optimum efficiency of energy use, agricultural management tends to use energy inefficiently, in other words, unsustainably. But history in the South is still short-term.

To get a longer-term view of energy use in biological systems, let's look at short-term vs. long term in ecological succession in abandoned cotton fields of the South. The first tree species to invade are fast growing pines, species that maximize yield (optimizing power, not efficiency). But pine forests are not sustainable over most of the better soils. After half a century, they are replaced with oaks and hickories, and eventually beech and magnolia. The energy output of these communities is greater than that of the pine, but most of that output goes in to maintaining the system, not expanding it. Thus they are longer lived than the pines, and in this sense, more sustainable. Do natural systems have a lesson for human managed systems? Shouldn't a greater proportion of the energy input into agricultural systems be devoted to maintenance ?

Perhaps we need to wait another 100 years to see whether Odum or Smith is the better long-term predictor of agriculture in the South.

6.9.2 Verdict Beyond the Frontier

According to the classification of Colby (1990), Southern agriculture is barely out of the "Frontier Economics" stage, the stage where systems are managed for power output, not efficiency. Colby has recognized a series of stages that occur in economic and agricultural development. They are:

- Frontier economics
- Environmental protection
- Resource management
- Ecodevelopment

Agriculture in the South has passed through the frontier stage, and is now entering the environmental protection stage. The Environmental Protection Agency and the U.S. Dept. of Agriculture are two agencies established to regulate environmental protection. For example, there are now rules regarding pollution discharges from Concentrated Animal Feeding Operations, and levels of pesticide residues on crops.

The Resource Management Principle (Jordan 1998) states that resource production systems (farms, forests, etc.), which resemble the natural ecosystems of a region, require fewer subsidies from outside the system than systems that are quite different. In some ways, the U.S. Dept. of Agriculture is already ushering the South into the resource management stage. For example, SARE, the Sustainable Agriculture Research and Education Program promotes sustainable farming practices that encourage taking advantage of the services of nature, such as building the soil organic matter. The USDA Environmental Quality Incentives Program (EQIP) subsidizes farmers to employ sustainable management techniques.

The Ecodevelopment stage is still in the future. It requires a holistic view of agriculture. The increasing cost of energy due to technical difficulties in extracting new energy sources is the factor most likely to cause agronomists to take the view that crops which should be grown in a region are those that are *ecologically* the best adapted. This is the stage that would vindicate Adam Smith.

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Chapter 7
Case Studies of Contemporary, Sustainable Farms in the South

Abstract Many farmers in the South have adopted sustainable (energy saving) agricultural practices. Some of the practices include:

- Free Ranging Livestock – Energy is saved when they feed themselves
- Heritage Breeds – Breeds adapted to survive without energy subsidies
- Draft Animals – Powered by the sun; no petroleum subsidies needed
- Organic Vegetables – Nutrients recycled by energy of micro-organisms
- Cover Crops and Conservation Tillage – Conserves energy of the soil organic matter
- Composting and Manuring – Energetically expensive nitrogen fertilizer not needed
- Integrated Pest Management – Uses energy supplied by beneficial insects
- Adding Value – On-farm processing of produce yields energy gain
- Teaching and Research – Producing and teaching energy-saving techniques for future farmers

These are techniques that increase sustainability, but a single farmer cannot do them all. To maintain a closed nutrient cycle, for example, a farm should include both livestock and field crops. But to succeed economically, a farmer needs to specialize and raising livestock requires a different set of farming equipment and marketing skills than producing vegetables, fruits or grains. A community of farms that integrates many specialized individual farms is more feasible than single farmers trying to optimize energy efficiency in all aspects of farming.

Keywords Case studies of sustainable farms • Farming sustainably in the American South • Case studies of sustainable agriculture • Sustainable agriculture in the American South • Examples of Southern sustainable agriculture • Sustainable Southern farms

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7.1 Sustainable Specialties

An ideal sustainable farm would include livestock, poultry, grains, fruit, and vegetables, just as a sustainable natural ecosystem contains birds and mammals, and the leaves, nuts and fruits that make the system energy efficient (no waste, no pollution) and nutrient use efficient (tight cycles reduce losses). The integration of a farm into a similar system would increase energy use efficiency and increase efficiency of nutrient cycling. However, to compete in the marketplace, most farmers specialize in one or a few types of crops or livestock. All farmers, including organic ones have to devote time and energy to perfecting the details of one type of production. We begin here with case studies of individual sustainable practices.

7.1.1 Free Ranging Livestock

7.1.1.1 White Oak Pastures, Bluffton, Georgia

"Cows were born to roam and graze. Hogs were born to root and wallow. Chickens were born to scratch and peck. These are natural instinctive animal behaviors." So says Will Harris, President of White Oak Farms (www.whiteoakpastures.com). He and his family now manage their farm in a way that allows their livestock and poultry to live in a way to which they are naturally adapted, a way that is energy efficient. But for many years, they raised angus cattle using pesticides, herbicides, hormones and antibiotics. They also fed their herd a high-carbohydrate diet of corn and soy. But he became disillusioned with the artificial methods of stock raising that he learned in College, and in 1995, made the decision to return to the farming methods his great-grandfather had used 130 years before. Today, White Oak Pastures employs 65 people and produces grass-fed beef and lamb and free-range pastured poultry. Harris is a leader in humane animal husbandry and environmental sustainability.

7.1.1.2 Polyface Farm, Shenandoah Valley, Virginia

Polyface farm, run by the Salatin family, is one of the nation's largest non-industrial farms. Their website (www.polyfacefarms.com), suggests the farm is deeply rooted in religious principles, but interestingly, their beliefs coincide remarkably well with the secular, ecological vision of sustainability. "*Believing that the Creator's design*" they say, " *is still the best pattern for the biological world, the Salatin family invites like-minded folks to join in the farm's mission: to develop emotionally, economically, environmentally enhancing agricultural enterprises and facilitate their duplication throughout the world.*"

The "best pattern for the biological world" means that plants and animals do best in environments to which they are adapted, regardless of whether that adaptation occurs through evolution or through design. It means that farmers should not try to impose the demands of an economic system onto the natural instincts of animals or the physiology of plants, but rather take advantage of the plants' or animals' abilities that have come to exist through natural selection (secular belief), or through divine creation (religious belief). We can see the convergence of Polyface management principles listed below in bold with ecological vision shown in italics.

- **Livestock and poultry should be moved frequently to new "salad bars"**. *(Animals should be periodically moved so they graze in pastures that are in the optimum stage of production where energy use efficiency is optimized).*
- **Plants and animals should be provided a habitat that allows them to express their physiological distinctiveness**. *(Plants and animals should be raised in habitats to which they are ecologically adapted, thus requiring fewer energy subsidies).*
- **Farmers should not ship food. Consumers should seek food closer to home**. *(Shipping food burns energy).*
- **Mimicking natural patterns on a commercial farm scale insures moral and ethical boundaries to human cleverness**. (*Raising hot house tomatoes in January is energetically wasteful).*
- **Stimulating soil biota is the most important priority**. *(The community of soil micro organisms, powered only by the sun, is the greatest agricultural energy saver).*

7.1.1.3 Grass Roots Farm, Walton County, Georgia

Grass Roots Farm is located on 20 acres, the small end of the farm size spectrum. The farm is dedicated to raising "Pastured Poultry". The owner, Brandon Chonko, says "*Our farm is based on principles of animal welfare and organic agriculture. We treat our animals with dignity and respect. They, in turn, provide us with great tasting meat and eggs that we can all feel good about eating*." The birds are kept outside, where they have constant access to fresh-growing palatable clovers, grasses insects and worms. They are sheltered in a movable chicken house, the "chicken tractor" shown in Fig. 5.5. They are hormone free and antibiotic free. The meat chickens are French label rouge, a variety that is adapted to foraging on pasture. They are unlike the industrial Cornish cross chickens used in conventional chicken houses. Chonko's pastured quail is the first commercially produced pasture raised quail in the state of Gerogia.

His layers are a mix of Rhode Island Reds and Dominique chickens. They are heritage breeds and produce brown eggs. Both are hardy breeds and forage exceptionally well. "It is a lot of work" they say, "but it is all well worth it and we are very grateful" (http://www.gapasturedpoultry.com) (Box 7.1).

Box 7.1

"Midwest drought costs Georgia poultry producers big bucks" was the headline in the August 24, 2012 bulletin of the University of Georgia College of Agriculture (Lacy 2012). Even in normal times, grain must be bagged and shipped in from the Midwest, then put in feeders daily. With pastured poultry, the birds do all the work.

7.1.2 Heritage Breeds

7.1.2.1 Grove Creek Farm, Crawford Georgia

Danielle and James Adams of Grove Creek Farm raise "Pineywoods" cattle, longhorn cattle that are descendents of the cattle first brought to North America by the Spanish in the 1500s, and later escaped or were abandoned. From their ancient bloodlines they retained the characteristics of scrubland animals – disease resistance, easy births, low metabolism, low impact to watering areas. The ability to browse among brush and scrub and eating much more than just grass gives their meat a unique flavor.

"*Grove Creek Farm is dedicated to the preservation of agrarian landscapes and lifeways*", say Danielle and James on their website http://www.grovecreekfarm.org/ "*Its philosophy is that we learn from the past to guide us in principles of sustainable living for the future*."

Their approach to raising livestock contrasts sharply with White Oak Pastures. Nevertheless, while yield is lower, it requires fewer energy subsidies. Grazing cattle in pastures, after all, requires energy inputs to maintain the pasture.

7.1.2.2 Broad River Pastures, Elberton, Georgia

Jon and Cathy Payne have instituted several sustainable practices in their Broad River Pastures farm. They raise silver fox rabbits, Khaki Campbell ducks, and a variety of chickens, but most notable is their sustainable sheep operation, for three reasons:

1. The breed- "Gulf Coast" sheep. These sheep are descendents of the flocks that the Spanish brought to the Gulf Coast area in the 1500s. Many became feral, and the breed was shaped by natural selection to the Southeastern environment. The lack of wool on their faces, legs and bellies is an adaptation to the heat and humidity. Their high resistance to gut parasites, foot rot, and other sheep diseases makes them a low input, and therefore more sustainable variety.
2. Their rotational grazing system. The sheep are kept in quarter-acre paddocks surrounded by an electric fence. To keep the grass in the paddocks from being

overgrazed, the sheep are moved every week. The portable shelters are moved between paddocks by tractor.
3. Protection from coyotes. The Paynes use a pair of English Shepherd farm collies to ward away predators from the sheep, as well as their chickens and ducks. The dogs are taught where things belong, which is good, but not always good. When Jon moved some of the chickens to another part of the farm, the dogs tried to chase them back.

7.1.3 Animal Power

Use of draft animals for farm work is more energy efficient than use of tractors. Pimentel and Pimentel (2008) estimate that a team of oxen expends 297,525 kcal of energy to plow 1 ha of land, while a 50-hp tractor burns 553,531 kcal. So why have most farmers abandoned draft animals and switched to tractors? Because harnessing and driving a team of draft animals requires a lot more human energy than driving a tractor. It's hard work. Nevertheless, there are some farmers that use animal power. Why?

As a boy, my family had friends in Lancaster County Pennsylvania, near an Amish community, and I became aware of their customs of not using electricity, and using draft horses on their farms. I couldn't understand why they chose to live that way, or rather, why their religion mandated them to live that way. As a scientist, I now can see the reason for maintaining the knowledge of how to farm with draft animals. It is similar to the reason for the Svalbard Global Seed Vault in Norway. That facility preserves a wide variety of plant seeds in an underground cavern. The seeds are duplicate samples, or "spare" copies, of seeds held in gene banks worldwide. The seed vault is an attempt to provide insurance against the loss of seeds in gene banks, as well as a refuge for seeds in the case of large-scale regional or global crises. Draft horses would be insurance for farmers, in the event that diesel fuel reached $40/gal.

7.1.3.1 The Amish Community at Ethridge, Tennessee

The Amish are a religious sect that have attempted to preserve the elements of late seventeenth century European rural culture. They try to avoid many of the features of modern society, by developing practices and behaviors which isolate them from American culture. Many old Amish farmers have strict rules against using motorized farm tractors, but ironically, their church does allow them to use motors for certain tasks. Welsch (1998), in his book on the transition from draft horses to tractors, posts a picture of a farmer in Lancaster Pennsylvania using a team to pull a forecart with a gas motor that powers a mower trailing behind. This saves the horses energy, but does it save the farm energy?

7.1.3.2 Nacoochee Valley Farm, Sautee Georgia

Nacoochee Valley Farm is located in a Valley of the Chattahoochee River in the mountains of North Georgia. It is owned by Scott Hancock, a veterinarian who has spent his life working with his passion, draft horses. Once a year Scott hosts a field day where he invites draft horse owners from throughout the region to congregate and present a show to the public. Nacoochee Valley Farm raises a variety of vegetables, as well as poultry, hogs, and chickens. It is one of the few farms in the South that combines plants and animals on the same farm. That enables Scott and his family to tighten the nutrient cycle by using compost made from the animal manure to fertilize the vegetable garden.

7.1.3.3 Mills Farm, Athens, Georgia

Mills Farm, home of “Red Mule Grits”, supplies grits and polenta (finely ground corn) to many of the best restaurants in the Athens Area. The small mill where the corn is ground is powered by Luke, a red mule. “*The mill is certified by the State Department of Agriculture and there*’*s not another one like it*”, says Tim Mills, owner of the farm and driver of the mule. Actually the mule doesn’t have to be driven, just started. I often bring my class to the farm to see this phenomena. One time I asked Tim why he used a mule to power his mill, when a diesel engine would be so much easier. “I farm the way God wants me to farm” he answered, very sincerely.

7.1.3.4 EWE-Niversally Green Sheep Rental Service, Dunwoody Georgia

Sheep and goats that clear out unwanted brush is a different kind of animal power. It is called targeted grazing, and many government agencies, municipalities and private landowners are using it to keep vacant lots, steep back yards, parks and right-of-ways clear of brush. Targeted grazing is a suitable option, whether a landowner is dealing with acres of stream bank, a retention pond or a small back yard, but it’s not meant to replace basic maintenance, said Brian Cash, owner of EWE-niversally Green sheep rental service in Dunwoody.

Cash often works with new homeowners in and around downtown Atlanta who have purchased foreclosed homes with overgrown lawns and local government agencies needing to clear brush from public lands. Sheep and goats are most useful when an area is so overgrown that no one else wants to clear it out. Even if it’s just a small yard, most homeowners, and many landscapers, don’t want to work in an area that’s choked with poison ivy, poison oak and briars, he said. Sheep and goats are also useful in areas that are too steep or too wooded to use a tractor to clear out brush. Sheep usually can clear an area up to about a five-foot height, but goats can climb and take care of plants up to 7 feet off the ground. Because of their climbing ability, goats can take care of larger plants. However, that skill and natural curiosity, makes them more likely to escape and antagonize neighborhood dogs. Cash usually sends a few goats along with his sheep herd to get the best of both worlds, but for such tasks he's careful to select his best-behaved goats. (Melancon 2012)

7.1.4 Organic Vegetables

7.1.4.1 Walker Farms, Sylvania Georgia

It takes a long time and a lot of money to turn an organic farm into a commercial success. There have been many organic farms that have grown into a thriving business, but the effort to get there is hard. When an offer comes from a major agribusiness corporation to buy out a struggling farmer, many farmers are tempted. But Relinda Walker, of Walker Farms in Sylvania Georgia, has never given up the fight. The farm was purchased by Relinda's grandfather, Frank Lafayette Walker, in 1925, the year Relinda's dad was born. Frank Alston Walker farmed the land from the time he returned from World War II in 1947 until his health forced him to retire from active farm management in 2002. Relinda grew up on this farm, exploring its woods and fields without ever imagining herself as a farmer. That came later as she developed a passion for food, an interest in agriculture, and a desire to be part of a healthier food system. The evolution of Walker Farms to an organic enterprise began when Relinda returned to the farm to start growing specialty produce such as sweet onions for restaurants, stores and local customers. The process was one of intensive learning: from her father about the basics of growing and from a remarkably generous network of farmers, researchers, and extension folks willing to share experiences and work together to find more sustainable ways of farming. The farm was certified organic in 2005 and now is an important local employer.

7.1.5 Intercropping

Intercropping means planting two different species with different structures together in the same field. Resource use efficiency on a field basis is greater when two crops with structures that complement each other are alternated in rows, because the competition for light, nutrients, and water is less, and less of the resources go unused.

7.1.5.1 William Dillard, Tift County Georgia

Dillard plants cantaloupe and cotton in the same field. "You prep your land one time for the melons. All you're doing is going in and seeding so you don't have as much cost as far as re-prepping you land," Dillard said. "Intercropping also saves valuable time during the growing season. Once you get through with the melons, it's very hard to get a second crop and get it to where you can get it to grow before frost.

This way you're able to get it planted in a timely manner." One of Dillard's intercropped field produced 1,200 lb of cotton without affecting the cantaloupe yields, and the other produced 800 lb of cotton without affecting the melon yield.

"Intercropping allows farmers to make better use of what could be limited resources," said Brian Tankersley, extension agent for Tift County. "Cotton fertilizer costs are reduced because the crop shares the same fertile soil used earlier in the season by cantaloupes or watermelons. The young cotton plants and the melon crop also share the same irrigation systems, so the cost of having to irrigate a second field is eliminated. Also, because the land is already tilled the for melon crop, land preparation costs for the cotton are eliminated." (Thompson 2013).

7.1.6 Cover Crops and Conservation Tillage

Cover crops and conservation tillage work together to build up soil organic matter. Most farmers that employ conservation tillage also plant winter cover crops. In the spring, the cover crops are rolled flat, and a no-till planter is used to inject seeds through the weed-suppressing cover crop residue.

7.1.6.1 Cotton Farmers, Perry Georgia

The bulk of Georgia's conservation-tillage farming is being practiced in the southern portion of the state, says Andy Page, district conservationist from Perry, Ga. (Hollis 2012). It is being done in cotton, corn, peanuts, soybeans, tobacco, corn and vegetables." *The long-term benefits of conservation-tillage*", Page says, "*include carbon being stored in the soil. Through straight conservation-tillage, with no actual turning of the soil, we've been able to raise the residue level in our soils 3 percent to 3.5 percent in a three to four-year period.*" "*Conservation-tillage*", says Page, " *must be a systems approach, with many equally important parts. You must utilize nutrient management, pest management, and crop rotation in such a system. All of these factors come into play to make you effective in a conservation-tillage system.*"

7.1.7 Composting and Manuring

7.1.7.1 Poultry Farmers, South Georgia

Poultry production is the biggest agricultural business in the state of Georgia. The heaviest concentration is in the Southern part of the state. Poultry producers there have found a ready market for the litter from their poultry houses. Over half of the peanut, cotton, corn and tobacco farmers buy poultry litter to fertilize their crop. Poultry litter is a mixture of bedding material (sawdust, wood shavings, peanut hulls, rice hulls paper pulps), manure, spilled feed, and water. Because of the manure content, litter is a rich source of nutrients for crops. Most poultry producers apply the litter directly to the fields. It must be done before crops emerge, because of pathogens in the litter. A few farmers compost it to reduce pathogenic bacteria (Dunkley et al. 2012).

7.1.7.2 Poultry Farmers, North Georgia

Chicken litter is also good for pastures. The Helton brothers run a poultry and cattle farm in White County, Georgia. They regularly clean out their chicken houses to make room for a new flock of birds, but storing the litter is a problem when the fields are too wet for a tractor. With the help of a Natural Resource Conservation Program called the Environmental Quality Incentive Program (EQIP), they were able to build a stack house in which to store the litter until they could get it into the field. Depending on the design of a stack house, it can be used to compost the litter. Through the EQIP program, the Heltons developed a resource management plan which included nutrient management, pest management, and prescribed grazing on their pastureland (NRCS 2012).

7.1.7.3 Athens/Clarke County, Georgia

Athens/Clarke County, Georgia, has developed a county-wide system of composting (Athens Clarke County Unified Government 2012). They recycle municipal sludge to make compost for local farmers and gardeners. Sewage from the community is filtered and dewatered. The water is treated, and released back into the Oconee River. The sludge is carted to a special facility near the landfill, where it is mixed with wood chips from the cities suburban limb and branch pickup service. The mixture is piled in big windrows and turned regularly over a period of months, until it is certified pathogen free. Because of the large size of the windrows, the pile generates its own heat, and on cool days, the steam rises up like from a giant tea kettle.

7.1.8 Integrated Pest Management

7.1.8.1 Arkansas Dairy Cooperative Association, Damascus, Arkansas

The house fly and the stable fly are the major fly pests in and around dairy housing systems in the Southern United States. Lower milk production, reduced feed conversion efficiency, community nuisance problems and public health concerns about unsanitary milk handling conditions are among the problems caused by these pests. Dairy producers can no longer rely solely on pesticides for control of flies. There are high levels of pesticide resistance in filth fly populations. Relying on an integrated fly management approach including manure management that is augmented with biological control by relying on parasitoids is necessary. Preliminary data on two family farms in Arkansas in 2000 showed that the use of parasitoids (parasitic insects that live in or on and eventually kill a larger host insect) coupled with restricted chemical use in an IPM program resulted in satisfactory fly control. The use of parasitoids was comparable in costs to more conventional methods of fly control, allowing dairies to maintain a sustainable fly management system (SARE 2008).

7.1.8.2 Green Cay Farms, Boynton Beach, Florida

Green Cay Farms raises 225 acres of green peppers each year along with 100 acres of squash and cucumbers. Thrips can be a major problem for peppers. In 1993 Glades Crop Care had tested an introduced beneficial nematode, *Steinernema carpocapsae*, at a pepper growing site in Charlotte County, Florida. Results from that test showed significant reductions in emerging adult thrips. Predator nematodes turned out to be more economical than a mass release of predatory insects purchased from a commercial insectary. Emergence traps were sampled for thrips in both treated and untreated areas at 7 and 14 days after treatment. In all cases, the areas treated with Biovector showed reduced numbers of emerging thrips (SARE 1994). Nearly any insect that spends a part of its lifecycle in the soil is likely prey for predator nematodes.

7.1.9 Adding Value

Adding value to a crop at the farm level means processing it or refining it so that the product can be sold at a higher price than the raw material. In some cases, a farmer will retail the value added product himself, and in other cases, sell it to a wholesaler or distributor. In many cases, adding value enables a farmer to distinguish himself by producing something unique which can be branded and sold at a higher price. Adding value helps avoid the competition inherent in farming where everyone is producing the same thing.

7.1.9.1 Decimal Place Farm, Atlanta, Georgia

Mary Rigdon founded Decimal Place farm on about 18 acres not far from Atlanta. According to Decimal Place website, Mary is a self-taught cheesemaker who has won awards nationally and who is always experimenting with new varieties, usually with terrific results." *We founded Decimal Place Farm*," says Mary, "*with the dream of providing healthy, tasty goat milk and cheese for our family. For 15 years we have selected goats primarily for milk production and secondarily for the structural features that score well in the show ring*."

Goat cheese is a healthy alternative to cream cheese, with almost twice as much protein and half the fat and cholesterol. The aficionados of artisan goat cheese have made it into a profitable value added product (Box 7.2).

Box 7.2

Goats are better adapted than cattle to the Georgia environment, because goats browse on shrubs and vines that grow well in Georgia without any energy subsidy. In addition, Goats are of a more manageable size than cattle. The largest animals, adult males may reach 200 lb, but even mature females are likely to be closer to 100–140 lb. These animals won't overwhelm their handlers or overburden the land. On the other hand, goats must be enclosed with a sturdy woven fence, while cattle can be contained with a single strand of shock wire.

Box 7.3

Alpacas are native to the Andes of Peru, Bolivia, Ecuador, and Chile, at an altitude above 11,000 ft. It would seem unlikely then that alpacas should be a good fit for the American South. Nevertheless, there are a number of Alpaca farms in the South, where they have several advantages over cattle. They are efficient digesters and therefore need to eat less than other livestock and they produce less manure; they have soft feet that do not tear up turf or compact soils the way hooves can; they have incisors only on their bottom jaw so they graze by trapping grass between their lower teeth and a hard upper palate, which makes them gentle grazers, rarely pulling the roots from the soil. In addition, alpacas are very clean animals The herd concentrates its waste, along with urine in common dung piles thus leaving more pasture clean for grazing. An advantage of this behavior on an integrated plant/animal farm is that it makes it easy to gather the manure to make compost.

7.1.9.2 Walnut Knoll, Alpaca Farm

Alpacas are considerably smaller than llamas, and unlike llamas, they were not bred to be beasts of burden, but were bred specifically for their fiber. Alpaca fiber is used for making knitted and woven items, similar to wool. These items include blankets, sweaters, hats, gloves, scarves, a wide variety of textiles and ponchos in South America, and sweaters, socks, coats and bedding in the U.S.

Judy and George Dick have been raising alpacas at Walnut Knoll in Northeast Georgia since 2000. "*We would like people to see alpaca farming as it should be seen – as an agricultural effort to build another avenue for economic growth*", they said in an interview for the Georgia Farmers and Consumers Market Bulletin. That is a perfect way to rationalize a new niche market – what you need to do to make a profit. To process the fiber from their Huacaya and Suri breeds, they use a family owned and operated fiber mill. Huacayas are fluffy, with fine, crimpy fiber; the Suris have fiber that curls in a spiral to form lustrous locks, almost like dreadlocks. The Dicks believe alpaca farming and the production of a fiber with very unique and special characteristics should be recognized as part of Georgia's well rounded agricultural community (Box 7.3).

7.1.9.3 Nature's Harmony Farm, Elberton, Georgia

Does raw milk have any health benefits over pasteurized milk? The question is unsettled, with believers claiming that it has certain anti-microbial activity, and also is more digestible by lactose-intolerant humans. Nature's Harmony Farm, near Elberton Georgia does not sell raw milk from its grass fed organic dairy cows, but it does make raw milk cheese that is available in upscale restaurants and retailers in Athens and Atlanta. Farmstead varieties include Harmony Encore which has the mildness of a brie because of the softness of the texture, but it is actually rather sharp in flavor like a cheddar. What's does "farmstead" mean and how is it different from "artisanal"? Farmstead means "from the farm" and in the case of cheese it means that the cheese is made on farm from cows owned and milked on farm.

7.1.9.4 Covenant Valley Farm, Colbert Georgia

"At Covenant Valley Farm, we use organic principles, and raise our animals without the use of chemicals, hormones or antibiotics," says owner Nolan Kennedy and his wife Annie. The pastures for our cattle are free of pesticides/ herbicides, and free of synthetic fertilizers. "We currently offer Certified Naturally Grown honey, which our Honeybees produce without the aid of chemicals or antibiotics. Added value products include handcrafted lip balms and beeswax candles." In early summer, Nolan brings his hives to the mountains of North Georgia to take advantage of blooms of sourwood trees, to produce certified Naturally Grown Sourwood Honey. In the fall, he likes to take advantage of the goldenrod at Spring Valley Ecofarm, to let his bees stock up on pollen for the winter.

7.1.10 Teaching and Research

7.1.10.1 Spring Valley Ecofarms, Athens, Georgia

Spring Valley Ecofarms is a 100 acre farm dedicated to research and education in sustainable farming. There have been two main research goals.

1. Soil Restoration. Fig. 4.5 showed the soil profile encountered by the first colonists in the Georgia Piedmont. It had a topsoil rich in organic matter. Fig. 4.6 showed the soil profile after a 100 years of cotton farming. There is no topsoil. The subsoil is impermeable and low in nutrient content. The first major goal of Spring Valley Ecofarms has been developing management techniques to restore soil quality to improve the potential for sustainable agriculture (Box 7.4).

Box 7.4

The topsoil in Fig. 4.5 has a relatively high proportion of its carbon in a passive or sequestered form, due to the high levels of tannins and other secondary plant metabolites in the humus. When building up the topsoil for use in agriculture, carbon from manure is more desirable, because the carbon is in the active form and thus the energy in it is more available to the micro-organisms that render nutrients available.

2. Increasing nutrient cycling efficiency. At the time I obtained Spring Valley Ecofarm, it was being farmed for wheat and sorghum, using conventional inorganic fertilizers. The second major goal has been to use organic fertilizers derived from green manures and animal manures to decrease nutrient leaching and to increase the community of soil micro-organisms that recycle nutrients.

A Brief History

Buying Spring Valley Ecofarm in 1993 (then called Great Oaks – est. 1864) resulted in a big transition in my career, from a theoretical ecologist to an applied agronomist. The first thing I did after acquiring Spring Valley Ecofarm in 1993 was to go on farm tours with Georgia Organics, an umbrella organization for organic farms in Georgia. My work in the Amazon Basin taught me that conserving soil organic matter was the key to sustaining agriculture in hot, humid environments, and I thought that organic farmers would have much to teach me about the practical aspects of organic matter conservation in Georgia, where the long summers have a climate much like the Amazon, and the highly weathered soils also are similar. Much to my surprise, I found that most of the farmers plowed or rototilled their soils. I couldn't understand why these organic farmers were destroying, through plowing, the very resource that they should be conserving – soil organic matter. Didn't they know any better? Then I realized that they probably did, but didn't know how to cultivate their crops without disturbing the soil.

That set me off in a promising direction – developing no- till and strip-till seed planters and seedling transplanters that could be used to plant crops through the residue of cover crops in small organic farms, thereby eliminating the need for plowing or tilling (16-row no-till planters already were in use in South Georgia). At the same time, I took on Rodrigo Matta Machado, a Brazilian who wanted to do graduate work in agroforestry. He had read that alley cropping between hedgerows of leguminous shrubs was often used in the tropics as a way to enrich the soil without commercial fertilizers, and he wanted to test the system. The idea was to periodically trim the nitrogen-rich leaves and twigs of the hedgerows and let them fall in the alley. The first hedgerow species we tried was mimosa (*Albizia julibrissin*). However it became too woody too fast, and so we switched to false indigo (*Amorpha fruticosa*), a more succulent species. Another graduate student, Yolima Carrillo,

Box 7.5

In Community Supported Agriculture, share-holders buy up front a share of the season's production, so that the farmer has capital upon which to work. Then every week the share-holders stop by to pick up their weekly share of whatever is in season.

Box 7.6

Because of its fast growth and desirable characteristics for furniture, tradition in Japan was for a father to plant a Paulownia tree when a baby daughter was born. At the time of her marriage, the father had a chest built from its wood for her to keep her valuables.

found that the nitrogen from this species entered the soil primarily through sloughing of the roots, not from leaf litter, but the fertilizing effect was limited to the root zone of the plants. A bigger benefit of the hedges is that it is habitat for beneficial insects and spiders that prey upon insect pests in the alleys. We then combined the use of alley cropping with cover crops and no-till or strip till cultivation (Fig. 5.4) to take advantage of both systems.

In 2002, an experienced organic farmer, Jason Mann joined Spring Valley, and began growing organic vegetables. He introduced the use of a spader (Fig. 5.3) which presents an alternative way to utilize cover crop residue. A spader improves the conservation of cover crop residue by pushing it into the soil instead of exposing it. Production was excellent using a combination of alley cropping, winter cover crops, and chicken litter compost spaded into the soil. A video by Kathleen Raven showing the procedure now appears at the Spring Valley website (www.spring-valleyecofarms.org). Jason also demonstrated the economic benefit of direct farm-to restaurant sales, and sales through Community Supported Agriculture (Box 7.5).

There were several other initiatives occurring simultaneously. In the 1980s, I had been a visiting professor at the Central South Forestry University, Changsha, Hunan China. There I met a forest researcher, Xingquiang Huo, from Guangdong Province, where soils and climate are similar to that of Georgia. We arranged for him to be a visiting researcher at the State Botanical Garden in Athens. He brought over a number of species thought to have conservation value. Of those, there were two that had potential commercial value. One was the princess tree, *Paulownia fortunei*, a fast growing tree species that is highly valued in Japan (Box 7.6). The other was *Loropetalum chinense*, a decorative landscaping plant. We had a lot of commercial success with Loropetalum, and within a few years, it appeared all over the University of Georgia campus, around private homes, and in business landscapes. *Paulownia fortunei* was interesting for another reason. It has a much straighter trunk than

Box 7.7

Sometimes plows are necessary, even for sustainable farmers. Using conservation tillage works well for annual vegetables, once a system of cover crops has been established. However, I have found that to convert a fallow pasture into a system using no-till or strip till cultivation, it is first necessary to break the soil with a plow. Once the soil has been loosened and a cover crop established, then plowing or roto-tilling is no longer necessary.

Paulownia tomentosa, the common wild species in Georgia. I decided to try it in combination with other tree species in mixed species forest plantations. The best combination has been Paulownia with slower growing species such as oaks. I alternated species within each row. The Paulownia grows quickly can be ready for harvest in 12–14 years. Meanwhile the oaks are developing a substantial root network, and when the Paulownia is cut, the oaks have access to full sunlight and begin a more rapid vertical growth. After the cut, the Paulownia sends up five or six sprouts from the stump. We select the best one, and lop off the rest. Because of the root reserves, the sprout shoots up sometimes 10 or 12 ft the next season. In many cases, this is fast enough to get up between the canopies of the oaks, and so we get a second rotation of Paulownia.

My observations in the tropics of how shade grown coffee is a sustainable practice and how it improves the taste of the coffee beans compared to coffee grown in full sunlight led me to try Paulownia as an overstory tree with blueberries. The thin canopy of Paulownia lets plenty of light through for the berries. I am not sure whether the slower growth of shade grown blueberries improves the taste, but it turned out that the Paulownia was a great trap crop for deer. When they wander up to the berry patch, most of the time they prefer to graze on the succulent bark of Paulownia, and leave the blueberries alone.

Oaks and Paulownia growing together to increase resource use efficiency is intercropping of trees. We also experiment with intercropping of vegetables, by planting together species with different life forms. Root crops such as carrots, turnips, and radishes are planted alternately with annuals such as lettuce and arugula, and with strawberries. Intercropping can also be done with species that have different times to maturity, such as broccoli that may take more than 2 months to flower, and lettuce varieties that are ready for harvest in 45 days.

The animal component has been an important part of Spring Valley Ecofarms. Shortly after I got the farm, a neighbor gave me Sally, a quarterhorse. She was lonely for a year, when Thor, a Belgian draft horse found his way into our pasture and took up with Sally. A year later Marlon was born, and the next year Dookie. That cross has the intelligence of a quarter horse and the strength, endurance, and calm demeanor of a Belgian. We trained them to pull a wagon that we use for tours of the farm. We also tried them with a plow, but it was a lot of work (Box 7.7). Draft horses may save fossil fuel energy, but using a tractor saves a lot more human energy. During winter months, we feed them bales of hay, and their manure mixed with loose hay makes a great compost. We also raise chickens, ducks and geese for eggs and meat. The hay used for bedding in their coop also is turned into compost, used on the vegetable gardens. We tried free ranging chickens, but hawks proved a problem, and coyotes caught a few of our free ranging ducks. The geese however, are big enough to fend off predators (so far). We keep them in a yard surrounded by an electric fence, where they can graze on grass. We also raise a few hogs on about an acre of land, where they love to root in the soil. Three strands of electric wire are enough to contain them.

For a number of years, Josh Egenolf raised Black Angus and Hereford steers at Spring Valley. He used intensive grazing management, whereby the cattle are moved every day or two to a new paddock of about a half acre. The portable electric wire that surrounds the paddock can be moved in less than an hour. The system worked very well. The pasture was not overgrazed, and was kept in the stage of maximum growth. But raising the steers, bringing them to a slaughterhouse, and marketing the meat is a full time job for one person, and so when Josh left, we had to exit the cattle business. We kept his rabbits though, as entertainment for children that visit the farm.

The soil along the terraces that were built during the cotton era are relatively nutrient rich, because the eroded topsoil tended to accumulate there. It seemed like a good place to grow peaches and plums. We tried to do it organically for a number of years, but without success. The trees grew well, but we could not control the Plum curculio (*Conotrachelus nenuphar*) with organically permitted insecticides. In 2011, we sprayed the fruit with malathion and achieved a bumper crop. The apples and pears that we planted on the terraces suffer from fire blight, due to the presence of many red cedars on the farm. Red cedar is an alternate host for the disease.

We planted muscadine and scuppernong grapes on a hill slope where the soil is too poor to raise annual vegetables. Our thinking was that a perennial would do better there than annual vegetables since the soil need not be disturbed after planting. Around the base of each vine, we placed old hay as mulch, and kept it in place with a quadrat of wood cut from downed trees. The mulch conserves moisture, and adds carbon to the soil. We irrigate with a drip irrigation system.

I was aware that early settles often planted their crops in floodplains where accumulated silt made the soil rich. Trail Creek runs along the edge of our farm for about a quarter mile, but it was so grown up with privet that it seemed hopeless to try to grow anything there. However, the Natural Resource Conservation Service had a program to pay farmers to eliminate privet, so we took advantage of that program to clear some of the floodplain (leaving sufficient vegetation along the stream bank to prevent erosion). In Dec. 2012 we planted raspberries, blackberries and elderberries there, and hope to benefit from the rich, moist soils.

Education. Beginning in 2002 we taught an intensive 3-week course in organic agriculture at Spring Valley Ecofarm. It was for 4 hours of University of Georgia credit, and it met every day in May for 6 h. Then in 2011 I tried a different model. One of my most worthwhile undergraduate learning experiences was practical

Box 7.8

The conflict between diversity and specialization presents a dilemma for agriculture. Diversity is a cornerstone of ecological sustainability. Specialization is the cornerstone of economics. Specialization is emphasized in research and teaching at most of the Land Grant Universities. There are departments of crops, horticulture (fruits and vegetables), poultry, beef cattle, dairy cattle, small ruminants (sheep and goats), and swine. Each department has its own fiefdom, and animals are not allowed on any farm where crops are raised, and vice versa. A diverse farm such as Spring Valley Ecofarms is ideal for teaching sustainability, where students can get an overview of all the factors involved. It is not good for making money.

experience at the 12-week summer camp of the University of Michigan Forestry School. I thought that a full-summer course would be a great experience for Georgia students, especially those who had never taken a field course. The students really enjoyed the course because for many it was their first opportunity for hands-on work outside the classroom. Some of the students even thought they might like to go into organic agriculture. I gave them a warning however. “If you want to make money in agriculture” I told them, “do not follow the model that you see here. We are doing too many things to make money at any one of them.” To make money, you have to specialize, carve out a marketing niche, and become the best practitioner of whatever you specialize in, be it raising hogs or preserving strawberries (Box 7.8).

7.2 A Sustainable Model

Environmentally conscious farmers are caught between economics and ecology. Economics demands specialization. Ecology requires diversification. Can a farm be diversified and still make money? Perhaps a diverse community of specialized farms would be more feasible.

In the 1980s, I spent a week at a community called Tomé-Açu, Brazil, about 115 km south of Belém in the state of Pará. A notable aspect of the community is the integrated cooperation between farms (Jordan 1987). Several farms concentrate on animal production. In one, some 13,000 chickens produce 30 t of organic fertilizer per year. Husks from rice grown on another farm are spread on the floor of the chicken houses. Every few months the husk-manure is bagged and used to fertilize plantations of fruit trees on other farms. At neighboring farms, pigs are fed corn, rice, and manioc grown in adjacent areas and supplemented with minerals. Organic waste from the pigs is used to fertilize black pepper plantations. The pepper plantations are interplanted with palms that become productive about the time that the pepper plants decline. Fallow fields are planted with high value hardwoods. The integrated system of farms provide enough profit to hire organizers that coordinate farm production with demand from restaurants and markets in Belém, and arrange for weekly deliveries.

Tomé-Açu is a mix of traditional Japanese culture and rain forest environment which has resulted in an apparently sustainable production system. The farming is labor intensive and tedious. A great deal of cooperation and self-sacrifice is required. The form that exists in Brazil is not possible in the United States. But it would seem that the model is transferrable. A community of farms that integrates many of the specialized individual farms such as those mentioned here would be a goal worth pursuing.

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Chapter 8
Holism vs. Reductionism in Environmental Science

Abstract There are various scientific approaches to agricultural sustainability. Research can be holistic, reductionistic, statistical, or systematic. Philosophical beliefs often guide the choice. Each approach has strengths and weaknesses, and solutions are often gained by a combination. Nevertheless, the reductionistic approach is the one most favored by scientists, granting agencies, and journal editors, because in the past, reductionistic science was the driving force for the tremendous gains in farm yield that improved the lives and economy of farmers and city dwellers alike. However, the critical goal now is not increasing yield, but producing yield sustainably, that is, in a manner that does not pollute the environment and at a price that is affordable. There is enough yield to feed everyone in the world (but getting the yield to the people who need it is another matter). Reductionistic science can propose mechanisms for increasing sustainability, but the holistic approach can determine which mechanisms will solve the problem.

Keywords Holism in agriculture • Holism in agricultural research • Holism in agricultural management • Holism in environmental science • Reductionism in agricultural research

8.1 Holism vs. Reductionism

Holism is looking at the properties of a system in its entirety, properties such as energy use efficiency, nutrient cycling efficiency, productivity, and nutrient discharge. These are properties that have direct relevance to management questions such as sustainability. Reductionism is looking at mechanisms that influence these properties. In an agricultural ecosystem, nutrient cycling efficiency is a property of the entire system. Reductionism is looking at the mechanisms that contribute to nutrient cycling efficiency. For example, reductionism tells us that phosphorus solubilization by the soil organic matter sub-system can contribute to nutrient cycling efficiency of the entire ecosystem.

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Holism and reductionism exist at all hierarchical levels of biological organization. An ecosystem scientist considers physiology to be reductionistic. A physiologist considers cell biology to be reductionistic. A cell biologist considers a molecular biology to be reductionistic. A molecular biologist considers biochemistry to be reductionistic. Going the other direction, a biochemist considers molecular biology to be holistic, a molecular biologist considers cell biology be holistic, and so forth. A reductionistic scientist helps explain properties of the next higher level in the biological hierarchy.

8.1.1 Holism

Holism is necessary for solving management problems. It helps frame the question that managers need to answer, and directs the research to answer those questions. The question for agriculture today is, "How do we manage for sustainability?" Research that is funded to answer this question must, in fact, answer this question. Answering a reductionist question about a phenomena that may contribute to sustainability may be helpful, but in the end, reductionism alone cannot answer sustainability questions.

I have often reviewed manuscripts by authors trying to test an ecosystem hypothesis by looking only at one sub-system of an ecosystem, a type of reductionistic approach. For example, I reviewed a manuscript dealing with the effect of reforestation on the nutrient stocks of abandoned agricultural fields. The author wanted to test the hypothesis that reforestation is a good tool to increase stocks of nutrients in a degraded ecosystem. His data showed that the nutrient content of the soil in the reforested plot was actually lower than that in adjacent plots that had not been reforested, and as a result, he rejected the hypothesis that trees increase the nutrient stocks of ecosystems. I pointed out to the author that what probably happened was that much of the nutrients in the soil were transferred to the biomass of the growing trees and the nutrient stocks of the <u>entire ecosystem</u> probably increased. Trees will not enrich the soil during succession or reforestation because the growing trees take up more nutrients from the soil than they return in litter fall. Soil enrichment will only begin when the forest becomes mature and the biomass is at an approximate steady state. At that point, trees help prevent nutrient loss through leaching and erosion, and ecosystem input of nutrients through atmospheric deposition and weathering of rocks in the subsoil begin to increase the stock of nutrients in the ecosystem.

Until the advent of computer modeling and an increased knowledge of the mechanisms that influence ecosystem properties, an holistic approach was merely an adaptive approach – "lets throw on another ton of fertilizer and see what happens." Now it is possible to construct mathematical models of ecological systems and experiment with many different management strategies much more quickly and efficiently than would be possible with the adaptive approach.

One of the first attempts at holistic ecosystem studies was the International Biological Program. This project began in 1964 to help scientists world-wide to better understand the ecosystems upon which life depends. There were two overarching goals (National Academies 2012):

- to explore how changes in the natural environment effect biological communities
- to focus on the conservation and growth of natural resources for human benefit

The United States became involved in 1968, with five biome studies, the largest of which was the Grassland Biome project centered in Colorado. It took a modeling approach to simulate various management strategies for bison on the Great Plains (Coleman 2010). A major problem was that the models were too complicated for the available computer technology. For example, there was a problem of integrating sub-models into the overall synthesis model. A bison grazing sub- model predicted the rate at which bison produced dung, and a microbial decomposer sub-model predicted the rate at which that bison dung would decompose. An early synthesis model predicted a build-up of undecomposed dung that overtopped the bison. We learned that in a hierarchical organization of ecosystems, species interactions that tend to be unstable, non-equilibrium, or even chaotic must be constrained by the slower interactions that characterize systems of a higher hierarchical level.

8.1.1.1 Populations as Subsystems

At one time in the recent past, there occurred fierce arguments between population ecologists and ecosystem ecologists as to which approach represents “real” ecology. While population ecologists argued that ecosystems do not exist (Jordan 1981), ecosystem ecologists categorized populations as sub-systems of ecosystems. As an example, take the view of energy flow through a farm ecosystem, and the flow through insect populations of the farm as a sub-system. Depending on the time of year, the weather, and whether the farmer uses insecticides, insect pests can divert a substantial portion of the energy flux as it moves from crop to farmer. Any predictive model of the farm must consider this flux because it represents an important loss. The insect population is a difficult sub-system to model, because it fluctuates much more rapidly than other compartments, and reacts differently depending on the time of year, the time of day, the presence or absence of predator insects or birds, the weather, or the proximity to the source of the populations. The population dynamics of insect pests and the factors that cause them may be of primary interest to many entomologists, but for ecosystem ecologists, insect populations are only part of the sustainability picture. Populations are a mechanism that helps explain the variability of energy flow in an holistic ecosystem model of sustainability.

8.1.1.2 Participatory Action Research (PAR)

Source for this section is Castellanet and Jordan (2002).

When scientists try to solve a complex management problem, they need to use two types of knowledge. The first type is derived from traditional academic science.

It concerns laws and regularities that can serve as a guide for achieving certain objectives under certain conditions. But researchers also need to know the specific character of the situation at hand. Therefore, they must conduct a diagnosis of this situation (the other type of knowledge). One can also say they need a model of the complex object on which they want to intervene. But no diagnosis can be perfect the first time. Action research is a way of testing this model and gradually improving it. It also is the best way to test any proposed method of intervention because it evaluates results against original hypotheses. By this means, errors can be observed and corrected, and new questions and hypotheses can be formulated.

The work of researchers from LAET (Laboratorio Agro Ecologico da Transamazônica) at the town of Porto de Moz, in the state of Pará, Brazil provides an example. Porto de Moz lies along the Xingú river, a tributary of the Amazon. The main activity was traditional extractivism (rubber, Brazil nuts, and fishing), but in the 1960s large-scale logging by commercial companies began. There was concern that large quantities of trees were exported from the district, and that returns to the district were low compared to returns that could be obtained for locally sawed lumber. In 1995, LAET convened a series of meetings that included stakeholders from the village including the local rural people's organizations, technicians, and the government. It became evident that the most accessible forests would be exhausted in 10–15 years if nothing was done to curb indiscriminant logging. Another problem that emerged was that fishing was becoming increasingly difficult due to severe competition from commercial fishing boats from Belém. After a series of meetings, a municipal committee was formed to develop a natural resources management program. Some important results of the program were:

- Start of a discussion of community forest reserves and demarcation of the boundaries.
- Support from the local Public Land Office to grant access to records of land ownership.
- Organization of a program of environmental awareness, and production of a booklet that explained existing laws and gave names of authorities that could be approached.
- Establishment of rules restricting fishing, and gaining control of the commercial fishing in the local areas.
- Support from the Federal Environment Agency that confiscated fish from illegal commercial boats.
- Creation of a protected area in a local seasonal lake

The PAR dynamic forced interdisciplinarity and helped to produce a diagnosis of natural resource management which analyzed the agronomic, economic, social and ecological aspects of the region, and integrated them more fully than is possible with most other specialized approaches. It produced results that were truly holistic for the local situation, but not necessarily applicable to other towns or regions. Because PAR does not produce results that are replicable in other locations, some people believe that PAR is not really "Science", but others contend that it is systematic gathering of knowledge, and thus is as scientific as other fields such as anthropology or other social sciences.

8.1.2 Reductionism

The analytic, reductionist approach in agriculture, has in the past, been very successful. It has been an important part of raising the living standard to millions of people. It pointed the way toward the green revolution – increasing yield through synthetic fertilizers, synthetic pesticides, and the genetic alteration of plants and animals. Reductionist thinking still dominates much of the news media. For example, former Secretary of Agriculture, Block (2012) said in a recent editorial in the Wall Street Journal that "Modern farming methods offer the best hope to feed the world's billions". However, no mention was made of the high energy cost of what Block considers "modern farming methods", and how the world's billions are going to pay for that energy. No mention was made either of the environmental and social costs of high energy farming methods that actually decrease net agricultural yield.

Reductionism looks at a phenomena and inquires into underlying mechanisms that produce that phenomena. If a scientist finds that applying chicken compost to farmer's fields results in greater yield than applying inorganic fertilizer with similar amount of nutrients, the reductionistic question is, "What is the mechanism that causes this effect?" That question was answered by a laboratory study that showed microbial activity in organic matter such as chicken compost liberates phosphorus that is bound in the soil and makes it more available to plants (Lee et al. 1990). This would suggest that improvement in yield could be brought about by using compost instead of inorganic fertilizers. However, this reductionistic study will not tell if using compost instead of inorganic fertilizer is the more sustainable approach. Farmers must take a holistic view before deciding to haul in compost. Phosphorus may be a limiting factor in a farmer's field, but the energy cost of preparing, delivering and applying compost to the field may be greater than the increase in energy yield from applying compost. Or maybe not. Other studies have shown that the critical factor for a farmer trying to decide whether to add chicken compost is the distance that it has to be hauled from the chicken houses to his field. In certain situations, if the distance is greater than 30 miles, the cost of fuel to haul the compost is prohibitive.

8.1.2.1 Reductionism in Agricultural Colleges

The research of many professors and scientists in agricultural colleges is reductionistic. This is ironic because colleges of agriculture were established to help farmers, who, by nature of their situation, must take a holistic view. How did scientists lose sight of the farmer? When an organization is established to solve a particular problem, the organizational structure is top-down. The mission is clearly stated, and then the individual tasks involved in carrying out the mission are delegated to departments who then report to the mission chief. Colleges of Agriculture were established to solve a particular problem – feed the growing population of the United States by increasing agricultural yield. The organization of the Colleges followed a logical scenario – create separate departments to address the various aspects of high-yield

Box 8.1

The Soil Science classification of the soil at Spring Valley Ecofarms is "Fine, kaolinitic, thermic Typic Kanhapludult."

Box 8.2

The U.S. Dept. of Agriculture has a similar problem. Their original mission was to ensure that everyone in the U.S. had enough to eat. They, along with the Colleges of Agriculture and their Experiment Stations did an excellent job in solving that problem. The new problem became the pollution generated by energy intensive agriculture. Certainly the Department of Agriculture has recognized this problem, and has begun numerous initiatives to control agricultural pollution. Nevertheless, the underlying philosophy is that energy intensive agriculture is still the best approach. Now we just have to clean up the mess that it makes.

The problem is analogous to that facing the medical profession. What is the best way to improve the health of Americans – through the use of increasingly expensive technologies to treat diseases (the reductionistic "band aid" approach), or by encouraging people to live a healthy life style by exercising more and eating nutritious foods (the holistic approach).

agriculture: crop science, soil science, entomology, weed control, erosion control, plant pathology, marketing, poultry science, animal and dairy science, agricultural economics, and so forth. The problem with this structure is that each department gradually develops its own agenda that supersedes the goal of helping farmers. A "paradigm" is developed among similar departments at Land Grant Colleges, and researchers become experts at sub-specialties so that they can get grants and publish papers in scientific journals. They become preoccupied with ever finer details of their sub-specialty and neglect the overall mission of the College (After all, who wants to be "Cow College" professor? Being a "Soil Physicist" has much more prestige.). Jargon is developed that is incomprehensible to anyone outside the initiated (Box 8.1). Criteria for research grants and publications becomes entrenched and codified, and those who do not conform are denied promotion and tenure. Just as in the Church, only the most conservative are promoted to positions of authority. The problem becomes more extreme when the challenge facing Colleges of Agriculture changes from increasing yield to optimizing sustainability (Box 8.2).

Can Academia ever extricate itself from this predicament? Some land grant universities, such as Iowa State University (Iowa 2013) are taking the first steps toward overcoming boundaries, and establishing an interdisciplinary curriculum. For example, their course "Integrated Crop and Livestock Production Systems" takes a big step in looking at nutrient cycles on a farm-wide basis, and this could lead to increases in sustainability through more efficient nutrient cycling. Iowa is a good place to start practicing sustainable agriculture. A 1981 paper reported that one-half of the fertile topsoil of Iowa was lost during the last 150 years of farming because of erosion (Risser 1981). A more recent study conducted by researchers at Iowa State University shows that the growth of sediment deposits at the bottom of Iowa's natural lakes is accelerating despite widespread soil conservation efforts (Heathcote et al. 2013).

8.1.2.2 Reductionism in Ecology

Ecologists thought that they could overcome barriers of academic reductionism by putting together a group of scientists in the same location at the same time over a period of years, and then bringing groups from the different sites together to develop insights resulting from ecosystem comparisons. Thus in 1980 they established the Long Term Ecosystem Research program. The objective was to "provide a context to evaluate the nature and pace of ecological change, to interpret its effects, and to forecast the range of future biological responses to change" (LTER 2013). Comparison of sites was a major priority.

A look at the LTER output suggests difficulties in overcoming academic barriers. In 2013, the Network Research Website said: "At each of the Network's 26 sites there is an extraordinary amount of knowledge about the organisms and processes important at the site, about the way the site's ecosystems respond to disturbance, and about long-term environmental change. A growing number of cross-site observations and experiments also have revealed much about the way that key processes, organisms, and ecological attributes are organized and behave across major environmental gradients." Not that the results are not good science – they are. It is just that they don't differ very much from independent ecological studies.

Consider the insights that could have been obtained by comparing holistic properties such as nutrient cycling efficiency, energy use efficiency and pollution discharge at some of the LTER sites such as: a montane forest at the Coweeta site in the Southern Appalachians (a natural ecosystem); the Kellog Biological Station in Michigan (an agricultural research station); the Konza Prairie (a natural grassland ecosystem); the Baltimore Ecosystem Study (a metropolitan ecosystem). Questions that I would have liked to seen answered are: Do Appalachian forests retain a pulse of pollution longer than a farm in Michigan, and if so, why? Does Baltimore use energy more efficiently than a farm in Michigan, and if so, what does this mean for agricultural research? Are some natural ecosystems more stable than others, and if they are, what is the reason? (Box 8.3). Can an understanding of how natural systems recycle nutrients help increase the recycling of nutrients in farmland and cities? Would improved recycling be energetically and economically feasible? Can a model of sustainable natural systems help guide sustainability in human dominated systems? Can cross systems comparisons yield insights into sustainability?

Box 8.3

At one time, it was speculated than tropical ecosystems are more "fragile" than temperate ones. (Farnworth and Golley 1973). "Fragile" would be an ecosystem property, the opposite of "sustainable". The speculation was never resolved, because fragility was never quantitatively defined.

Cross systems comparisons of ecosystem characteristics can lead to many interesting evolutionary hypothesis that have management implications. In 1971, I summarized 39 published studies that compared data on net primary leaf production and wood production in moist forest ecosystems from the tundra to the tropics (Jordan 1971a, b). I thought the data would show that production of both leaves and wood would be higher in the tropics, because of the longer growing season. However, the data showed that while leaf production was higher in the tropics, wood production did not differ on average between the tropics and the temperate zone. Why was this? Was it because many tropical soils are highly weathered and lower in nutrient content than temperate soils? Was it because tropical trees devote more energy in the form of secondary compounds to protect the wood against insects and microbial decomposition? Did it have anything to do with the density of the wood in tropical vs. temperate trees? The results certainly have implications regarding the belief that tree plantations in the tropics can be more productive than those at higher latitudes. It was just that belief that led to the establishment in 1967 of Jari, a Connecticut-sized plantation in the Brazilian Amazon. Hundreds of square miles of Amazon rain forest were cut and burned, and replaced with monocultures of *Gmelina arborea*, that was supposed to grow so fast that Jari would become a major pulp supplier to the world. To process the pulp, a mill was built in Japan and floated halfway around the world to the Amazon, and up the Jari river. The project cost hundreds of millions of dollars to establish, but it sold in 1982 to a consortium of 27 Brazilian companies for a $720 million loss because wood production fell far below expectations. (Jordan and Russell 1989). Problems continued to mount, and Saga Holding Company later bought the plantation, then in 1999 sold it to the Orsa Group for $1.00.

8.2 Management Problems Need Both Holism and Reductionism

Farmers need to be both holistic and reductionistic. They need to understand how fertilizers and insecticides affect sub-systems such as soils and insect populations that contribute to short-term economics (National Research Council 1989). But in the end, it is long term economics, translated as energy use efficiency, that determines sustainability.

There are also other factors that influence a farmer's management decisions. Perhaps he likes hunting, and wants to preserve part of the farm for game management, or simply for a nature preserve. Perhaps his daughter likes horseback riding, and wants to keep a path around the farm for trail riding. Perhaps the farmer plants a stand of oaks and chestnuts, knowing full well he will never live to see them through to harvest, but knowing that his grand-daughter will. These are all part of a farmer's long-term decisions.

8.2.1 A Case Study: Shifting Cultivation

The San Carlos Project in the Amazon region of Venezuela (Jordan 1989) is a case study of how holism and reductionism can complement each other, and lead to a better understanding of management for sustainability. The project stemmed from the belief of early explorers in the tropics that shifting cultivation as practiced by indigenous peoples was an extremely wasteful and inefficient way to practice agriculture. They observed that native farmers cleared and burned forest, planted crops for 3 years, and then abandoned the site due to rapidly declining yields of crops. Their explanation was that burning of the forest caused mineralization of nutrients that then were rapidly leached into streams and groundwater by frequent rainstorms (Nye and Greenland 1960). It was hypothesized that declining soil fertility caused the decrease in crop growth.

Because of the increasing deforestation in the Amazon region, scientists in the 1970s became concerned about the implications of cutting and burning the Amazon forest for agriculture (Farnworth and Golley 1973). In 1974, a team of scientists including myself began an holistic nutrient cycling project on an Oxisol (lateritic type soil) near San Carlos, Venezuela, to test the theory that shifting cultivation resulted in the loss of soil fertility. We measured the stocks of nutrients in the leaves and trunks of trees, and humus and mineral soil, and fluxes between the stocks in two adjacent plots of a mature rain forest. After a year, we had local indigenous farmers cut and burn one of the plots, and cultivate it in their customary fashion ("conuco agriculture"). Measurements of nutrient stocks and dynamics were continued in both the experimental and control plots. One of the results was that the total phosphorus in the soil water was much lower than might be expected considering the phosphorus concentrations in the biomass of the rain forest trees. We also found that the production of manioc and plantain did decrease during the first 3 years. However, the nutrient content of the soil in the experimental conuco did not decrease, but increased dramatically following burning due to nutrients lost from the felled trees, and most significantly, stayed high for 3 years. Nevertheless, the crop production declined. Nutrients had not been lost, nevertheless yield declined. As yield declined, we observed that the farmers collected leaves from the surrounding forest and heaped them around the base of the manioc plants. The result was a resurgence in plant growth (Box 8.4).

Box 8.4

After the manioc was harvested and the conuco abandoned, successional trees invaded the site and the nutrient content of the soil decreased due to uptake by the new vegetation. In other regions of the Amazon, where rain forests are converted to pastures that are grazed for longer periods of time, there is a different dynamic. As in the conuco, nutrients increase in the pasture soils immediately after cutting, and as a result, there is a flush of grass, but that growth lasts less than 3 years. Grazing reduces root biomass, and as a result, nutrient leaching increases. When grass productivity becomes too low, pastures are abandoned. However there are not enough nutrients to support the usual successional trees, and the sites are taken over by scrubby shrubs.

The resurgence of manioc called for a reductionistic explanation. Perhaps the organic matter of the forest leaves had some effect on the soil nutrients, possibly phosphorus. We speculated that organic acids in the leaf litter were released by microbial activity. These organic acids re-solubilized phosphorus bound by iron and aluminum in the soil (Montagnini and Jordan 2005). Although we were not able to prove the reductionist hypothesis during the course of the San Carlos project, Lee et al. (1990) were able to show the effect in the highly weathered soils of the Georgia Piedmont, which, like those of the Amazon, are high in iron and aluminum in forms that bind phosphorus in an insoluble state.

The management conclusion for Amazonian soils, as well as for soils in Georgia – conserve the soil organic matter because, among other benefits, it solubilizes phosphorus locked in the soil.

8.3 The Statistical Approach vs. The Systems Approach

8.3.1 The Statistical Approach

The statistical approach to environmental problems is similar to the approach taken by the medical profession when testing a new drug for its effectiveness in combating a particular health condition or disease. To test a new drug "A" against health problem "B", medical researchers will divide a population that suffers from condition B into two groups. To one group, randomly selected in a population, they administer the drug "A", to the control, the give a placebo. If 95 % of the group given drug "A" recovers or improves, the drug is considered effective (Box 8.5). The critical key is that the population receiving treatment is homogeneous. Thus depending on the medical problem, the researcher might have to select a population that consists only of female Asian Americans older than 50. If the condition exists in both mice and elderly Asian women, genetically identically white mice are

Box 8.5

However, the observation that drug "A" cures health problem "B" is not a "fact", but merely a statistical probability. There is no such thing as a "scientific fact" or a scientific "law" (except for the first law of thermodynamics). For example, statistical tests seem to confirm Newton's laws of motion, the basis for classical mechanics. Newton's laws predict that a pencil (or any other body) at rest will stay at rest unless acted upon by an external force. However, that is only because physical objects have such a good statistical base. A physical body is composed of billions of atoms vibrating in random directions. The net result is that the body does not move. However there is a very remote possibility that that for an instant, they all would move in the same direction, and the pencil would lift off. This means that Newton's laws are not really "laws", but merely probabilities. Newton had a much better statistical base than agronomists or ecologists who are laying out plots in a field, or even doctors experimenting with white mice. So not only are there no such things as "scientific facts" in physics, there are none in ecology or agronomy either. There are only probabilities (Jordan and Miller 1995).

preferable as a subject matter. The statistical approach is similar to the reductionistic approach, in that it seeks to determine the effect of a reductionistic treatment in the overall health of a population, an holistic property.

8.3.1.1 A Case Study – Bioenergy

In 2007, the Department of Energy began a 5-year program to determine the yield of various grasslands in different regions of the U.S. The reason for the studies was to determine the potential of herbaceous plants to produce biofuels to replace fossil fuels. I was involved in the program on a "Conservation Reserve" (National Sustainable Agriculture Coalition 2013) site on the Georgia Piedmont. The study compared the growth of pasture grasses in plots fertilized with inorganic fertilizers with plots treated with chicken compost. The study took place in a 24 acre field that had not been grazed for many years, but it had been mowed. The study site had gently rolling topography, but was as uniform as was possible to get in the Georgia Piedmont. Plots were laid out randomly in the field, and were treated once a year for 5 years. Program administrators gave detailed instructions as to what parameters were to be measured, namely soil characteristics, grass yield, and quality of the grass. An analysis of the data showed that average plant growth in the plots fertilized with chicken compost was higher than that of those fertilized with inorganic fertilizer, but the difference was not statistically significant. The conclusion had to be that there was no difference.

But a farmer looking at a pair of plots near the top of a rise, a pair at mid-slope, and a pair at the bottom of a slope could easily see that there *was* a difference between the plots at each elevation. The problem was that the standard deviations around the averages for the whole field were large because of innate differences in productivity at the three levels, due perhaps to differences in soil moisture. Couldn't the researcher have simply laid out more plots at each position on the slope? He could have, but then the problem becomes logistically very difficult. A paired plot test could have been used, but that test is much weaker statistically. The preferable statistical approach demands that the population sampled (in this case all the field plots) be completely homogeneous.

Sometimes with a statistical approach, the opposite situation occurs. A researcher sees a statistical difference between treatments at the 95 % level of confidence, but to the farmer, they look the same. The differences are so slight that they are not discernible to the naked eye, but because the field is so homogeneous, the differences are significant. In such a situation, the farmer might comment, "If you have to use statistics to prove your point, it can't be very important".

The weakness of the Georgia Piedmont study was that it did not attempt to answer the question that was relevant to the reason for existence of the program that sponsored it, that is, the potential of biomass for energy production. The question that should have been asked was, "what is the EROI (Energy Returned on Investment) resulting from the two treatments? " The answers that were obtained – yield per acre- did not indicate whether the yield in terms of energy was greater or less than the energy expended through the use of subsidies (fertilizer, chicken compost). The study did not ask, "what was the cost of hauling fertilizer and compost to the field and applying it to the plots?" It did not ask " What was the output of energy per unit of energy input? " If the ratio was positive, it would mean the treatment is worthwhile, if negative, not worthwhile. It was the holistic question that was necessary to justify the program, but that was never asked.

The statistical approach has been very powerful when used by agribusiness, where a 5 % difference in yield resulting from a new fertilizer makes it worthwhile to adopt this new subsidy. To ensure that the fertilizer really increases yield, it is necessary for researchers to go to great effort and expense to ensure that the test plots are homogeneous with regard to elevation, soil quality, and exposure to environmental variables. Ecologists have long admired the success of this approach. They suffer from "agronomy envy". For an ecological study to be published in most scientific journals, the agronomic statistical approach must be taken. The problem is that most ecological studies are carried out in systems that are not homogeneous, even when appearing uniform to the naked eye (after a year, it is hard to tell where the dog died) (Box 8.6).

8.3.2 The Systems Approach

In contrast to the statistical approach, the systems approach looks at ecosystem properties from a "top down" view, and thus is more holistic in nature. It focuses on a particular management question by constructing a model of the system and then

Box 8.6

Whenever I encountered a student who was taking the statistical approach to look at the effects of different treatments on an ecosystem, I would inform him or her about the $1,000 "Jordan prize in ecosystem uniformity". It was to go to the student who after finishing the study, would come to me and remark about how uniform the study site was, and that the variance was so small that it was easy to prove differences. What always happened, of course, was that the student would inevitably complain about the lack of homogeneity in a site, despite carful preliminary surveys to ensure uniformity throughout the site. And this has occurred at study sites that had areas ranging from a square mile to a square meter. I suspect it would also occur if a student were studying the microbial population in a square millimeter under a microscope. The Jordan prize is yet unclaimed.

Box 8.7

The first step in a systems model is to create a conceptual model of the important compartments of the system and the transfers between the compartments. Next, field measurements are made to quantify compartments and transfers, which are then incorporated into the model. Predictions are then made, followed by new field measurements to validate the model's predictions. Discrepancies between predictions and validation measurements are then used to focus on research that refines the model. The cycle of modeling, validation and refinement continues as long as time and money allow.

determining how different management strategies affect a desired outcome. The advantage of the systems approach is that you are not trying to *prove* the effect of an independent variable on a dependent variable. The objective is to see how an ecosystem responds under a variety of conditions that could occur at the study site, not just those that existed at the time of the study. You experiment with the model, changing one variable at a time, to see how changing them affects the range of outcomes that could occur at the study site. It also tells you what variable affects the prediction most, and what research must be taken next to improve your understanding. It is didactic. Most important, it keeps the researcher focused on the question that prompted the study in the first place. It is holistic in nature (Box 8.7).

A weakness of the systems approach is that it does not tell the researcher about the underlying mechanisms that are causing the different predictions. However, it guides the researcher in planning reductionist studies or collecting additional data that can help improve the performance of the model. Two case studies illustrate the point.

Box 8.8

An ecosystem model has to have a common currency. It could be energy, calcium, carbon, water, a particular chemical or pollutant in the environment, or dollars. But an ecosystem model cannot make anything meaningful from studies that only have in common the fact they were made in the same place at the same time. Energy is the common currency in H.T. Odum's (1988) system models of landscapes, cities, and the ecosystems that comprise them. Energy is sometimes difficult to measure, so in the studies cited here, biomass and carbon were used as surrogates for energy. Biomass is approximately 50 % carbon. Carbon follows energy through the ecosystem – when it is reduced through photosynthesis into biomass, and when it is oxidized through respiration by the living organisms in the ecosystem.

8.3.2.1 A Case Study – Farming to Build Soil Organic Matter

A systems modeling approach to predict the effect of different management schemes on soil organic matter was used in an alley cropped organic vegetable system at Spring Valley Ecofarm in the Georgia Piedmont (Jacobsen 2008). Alley cropping is when economic crops are grown between perennial hedges that prevent erosion, and that enrich the soil with nitrogen when the hedge is a leguminous species. Carbon was the currency used in the model (Box 8.8). The pools of carbon in the organic matter of the soil and the interactions of the pools are shown in Fig. 8.1. Active or labile carbon is material of high energy value, and is not physically protected. It is the pool most likely to participate in biological reactions. Slow carbon is composed of partially decomposed residues that is slow to enter the labile pool. Passive or recalcitrant carbon is made of material that may take a century to decompose into simpler compounds (Wander 2005). Surface litter is organic matter on the soil surface such as dead leaves. Soil litter is undecomposed organic matter within the soil, such as the roots of a plant that has recently died.

Build-up of soil carbon in three pools as a function of time under different management strategies is shown in Fig. 8.2a, b. The models predicted that carbon which was slowly available to microbes for respiration would build up with increasing amount of organic matter to the soil, but active carbon would decrease, possibly because of increased microbial respiration. or transfer to the slow carbon pool (Fig. 8.2a -AC1 through AC4) The models predicted that the active and slow carbon would build up faster in the plots conventionally tilled and fertilized (CT) than in the organic and ally cropped plots (Fig. 8.2b). This is contrary to observations made in long term studies, and could be the result of the stocks being measured for only 3 years. Transfer rates are not linear over time. As active carbon builds up in the conventional till plot, decomposition rates should increase and stocks should decline (Olson 1963). This is experimentally testable and would provide input for a second iteration of the model.

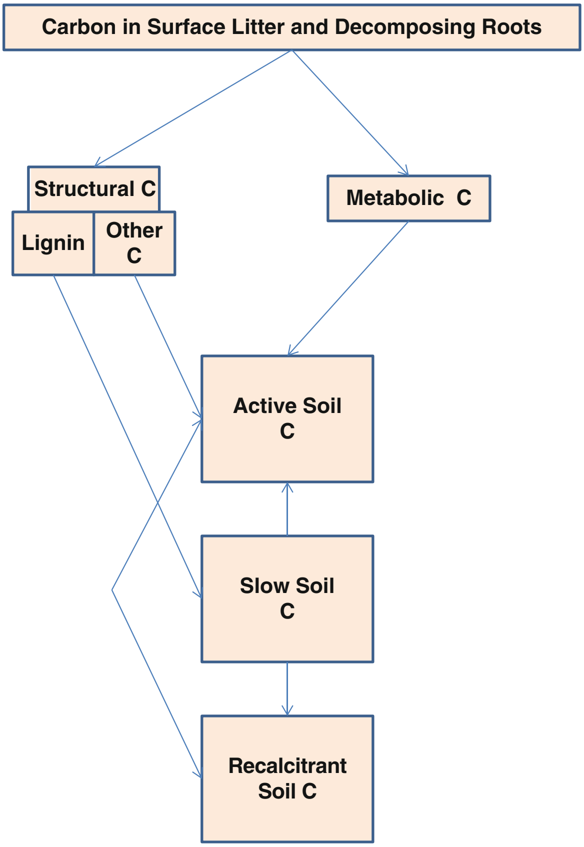

Fig. 8.1 Soil carbon pools and carbon fluxes between pools in an organic alley cropping system. Carbon is labeled as "C". Drawing constructed from data in Wander (2005, Table 3.2)

8.3.2.2 A Case Study – Pollutant Discharge

In the 1960s, I worked for the Atomic Energy Commission (now Dept. of Energy), looking at the impact of radioactive fallout on the rain forest in Puerto Rico. It was a time of atmospheric tests of nuclear weapons, and there was international concern about radioactive nuclides in the environment. An important product of these tests was radioactive strontium, Sr^{90}, and we began seeing it in the rainfall about 5 days after there was a test in China. The question that we set out to answer was, "What is the environmental half life of Sr^{90} in the rainforest?" Although H.T. Odum (1951) showed that the global cycle of strontium was stable, we did not know the dynamics of its radioactive isotope within a rain forest. Was it flushed out during the first rainfall, or did it remain locked in the system for a year, 10 years, a 100 years, or a 1,000 years.

Because the fluxes of stable strontium through an ecosystem are almost exactly the same as those of radioactive strontium, we began by making a conceptual model of stable strontium in the forest, using the same compartments and fluxes used in the

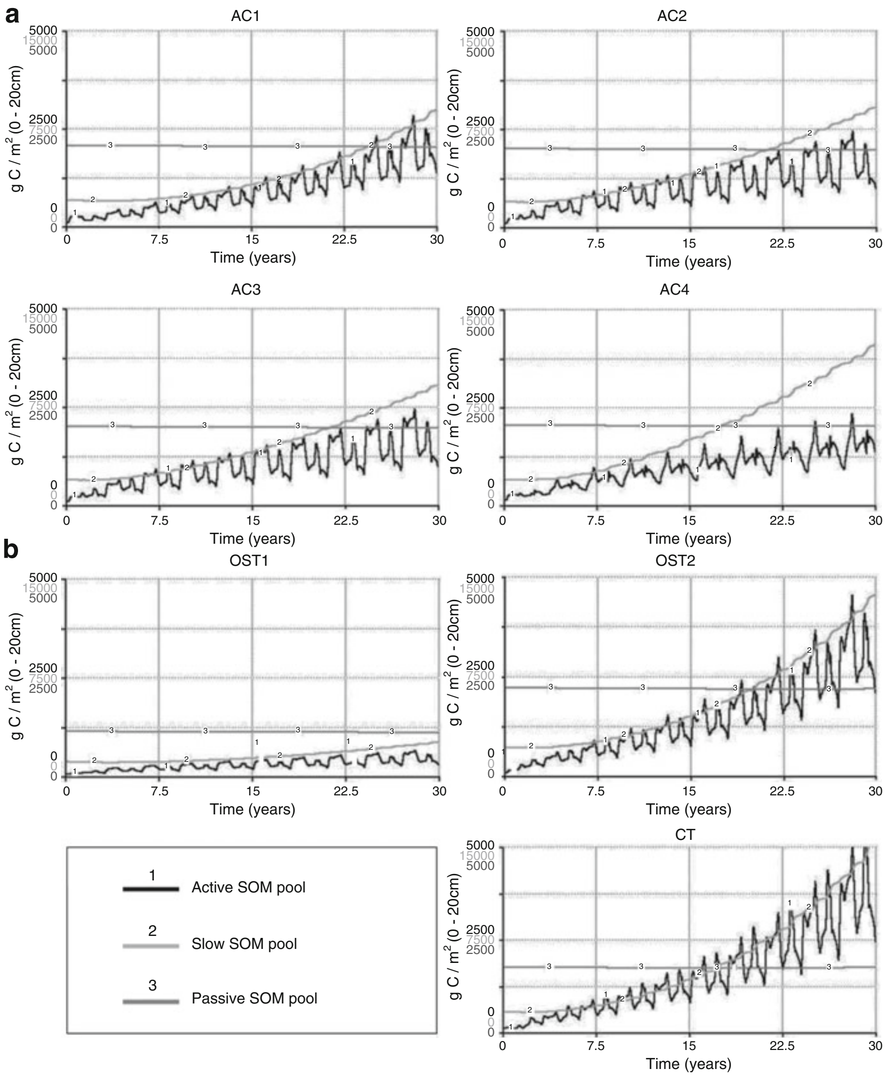

Fig. 8.2 (**a** and **b**) Build-up of soil carbon in three pools as a function of time under different management strategies. The treatments were: *AC1* = organically managed alley cropping; *AC2* = AC1 + straw mulch; *AC3* = AC1 + compost; *AC4* = AC1 + compost + straw mulch; *OST1* = organically managed + straw mulch; *OST2* = OST1 + compost; *CT* = conventional tillage and inorganic fertilizer (Figures reprinted from Jacobsen (2008), with permission from the author)

model of calcium in Fig. 1.10, because the ecosystem dynamics of strontium are similar to that of calcium (Limburg 2004). To quantify the strontium model, we measured the stable stocks in the biomass and soil compartments, and the fluxes of strontium in the leaf and litter fall, the throughfall (rainfall penetrating the forest

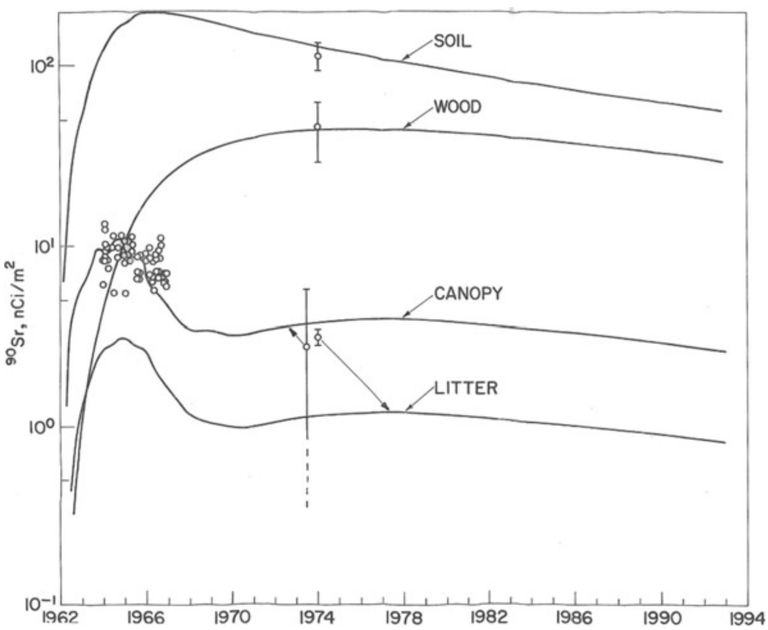

Fig. 8.3 Predicted Sr^{90} in the soil, wood, canopy, and litter of a Puerto Rican rain forest following input from atmospheric fallout. Validation samples were taken in 1962 from the canopy (individual circles), and in 1974 from the soil, wood, canopy, and litter (averages and standard deviations). Predicted values matched observed values for soil, wood, and canopy, but not for the litter

canopy) and percolation to ground water. We used a computer to solve the differential equations that predicted the activity-time curves of the radioactive analog of strontium. We simulated input as a pulse of activity equal to the amount of fallout entering the system in the early 1960s. The model then predicted the decrease in activity in the soil, wood, canopy leaves, and leaf litter on the soil surface (Fig. 8.3). Half of the activity in the whole system disappeared in 20 years (Jordan et al. 1973; Jordan and Kline 1976). Since the half life of the Sr^{90} isotope is 28.8 years, radioactive decay accounted for most of the disappearance. The nutrient cycling efficiency was 89 %, meaning that only a small proportion of the isotope left the system through percolation to ground water. The validation measurements made in 1974 (Fig. 8.3) show that predicted Sr^{90} in the canopy was too high, while in the litter it was too low, suggesting that for a second approximation, improving data on the leaf fall flux would improve predictions.

A few years after I had left the Puerto Rican project, I met the young scientist who had taken my place. He said to me "Dr. Jordan, I spent the last 2 years carefully measuring the throughfall water in the forest with five times the number of collectors that you used. And I found that your estimate was off by as much as 10 %."

I told him that time and money limited the amount of effort that could be spent on all the stocks and fluxes of the ecosystem, but I thought that trying to answer the overarching ecosystem question was more important than spending all the time and money on only one ecosystem flux that could not by itself answer any important questions.

He scowled and repeated "You were off by ten percent. That's bad science!"

I went back and did a sensitivity analysis of the model, and found that a 10 % error in the throughfall would cause only a 2-year difference in the predicted environmental half life, not enough to change any opinions about the hazards of radioactive fallout.

I often tell this story to my students to indicate how scientists trained in the reductionist approach have difficulty in understanding a systems approach to answering holistic questions about an ecosystem.

8.4 Working with Nature vs. Conquering Nature

Philosophical beliefs often guide the approach to research taken to manage ecosystems and improve sustainability. There are two conflicting philosophies: Working with Nature and Conquering Nature.

8.4.1 Working with Nature

Working with nature means understanding the processes that enable natural ecosystems to be productive and stable, and then using this understanding to guide research and management of human dominated systems. Many of these processes are based on traditional or indigenous practices, and are empirical, that is, they work but we don't know the reason why. For that reason, they have been considered mystical by mainstream science. Organic agriculture is an example of management that once was considered spiritual. When asked about the basis for their belief that compost is good for the soil, organic farmers might have answered that it is farming in nature's image, or in harmony with nature, hypotheses that can't be tested, and so are unconvincing to scientists. They are like religious beliefs. Only recently, since soil ecologists discovered the nutrient conserving functions of vast communities of micro-organisms living in soil organic matter, has there been a scientific explanation of how compost works to increase the efficiency of nutrient recycling (Box 8.9).

Box 8.9

There are anecdotal reports that diluted unpasteurized milk sprayed on a pasture stimulates growth of grass. The phenomena awaits reductionist explanation.

Studies in the Amazon rain forest have provided an example of how reductionist research eventually explained phenomena observed on an ecosystem scale, for which there was no adequate explanation other than "a natural phenomena". To explain how forests growing on nutrient poor soils of the tropics maintained high productivity despite the nutrient poor quality of the soil, Went and Stark (1968a, b) proposed a theory of "direct nutrient cycling". They suggested that nutrients in the leaf litter of these forests were transferred through mycorrhizal hyphae directly into root hairs of trees, bypassing the mineral soil where they could easily be leached. The idea was ridiculed by most soil scientists who thought that nutrients had first to be exchanged on the surface of clay minerals in the soil before they could move into roots. To test the direct cycling theory, Herrera et al. (1978), as part of the San Carlos project, inoculated leaves from rain forest trees with radioactive phosphorus, put the leaves in a Petri dish on the forest floor, and then inserted roots through a hole in the side of the dish. Six weeks later, the roots were cut, and the dishes carried to a laboratory where an autoradiograph showed the phosphorus in the leaves, in the mycorrhizae, and in the root hairs. This experiment explained how organisms living within the soil organic matter maintained the fertility of the ecosystem through direct nutrient cycling. It showed the importance of organic matter sources such as compost or leaf litter for maintaining ecosystem productivity. It is an example of the idea that working with nature can suggest ways to manage ecosystems – you can attain sustainability of your farm by conserving soil organic matter.

8.4.2 Conquering Nature

Early pioneers in the United States saw raw nature as an enemy, fierce in tooth and claw that needed to be conquered if the pioneers were to survive. Wolves, cougars, and Indians were the first that had to be exterminated. Rivers that sometimes flooded farmers fields had to be restricted and channeled. Forests had to be cleared to provide space for agriculture. The weather often was a powerful enemy, sometimes producing floods, sometimes droughts. Fields had to be terraced to slow down erosion. By the twentieth century, the war moved against insects and disease that ravaged farmers' crops. The war against the soil produced bigger plows that dug deeply, cultivators that churned the soil into a seed bed, and fertilizers that overcame the losses caused by plowing and cultivating. There were tremendous gains in agriculture, through powerful chemicals, powerful machines, and genetic engineering that produced organisms that responded to these chemicals and machines in a way that was "better" than did the organisms that were direct descendants of wild varieties.

Conquering of nature was the key to progress. If insect pests are damaging crops, spray them with insecticides till they all are dead. Not enough nutrient cycling in farmers' fields? Sell them fertilizer till they are dependent upon it. Rivers flooding farmers' fields? Build levees and channel the flow. Drought a problem? Dig a deeper well. But continuing to conquer nature is killing the goose that lays the golden eggs, that is, sacrificing long term sustainability for short term profit.

8.5 A Report to the President on Agricultural Preparedness and the Agriculture Research Enterprise

The President's Council of Advisors on Science and Technology (PCAST) is an advisory group of the Nation's leading scientists and engineers, appointed by the President to augment the science and technology advice available to him from inside the White House and from cabinet departments and other Federal agencies. In December 2012, they submitted a document entitled "REPORT TO THE PRESIDENT ON AGRICULTURAL PREPAREDNESS and THE AGRICULTURE RESEARCH ENTERPRISE" to the Executive Office of President Barack Obama.

The Executive Summary begins as follows:

The United States is the undisputed world leader in agricultural production today, but as we look out across the twenty-first century, agriculture faces a series of challenges:

- *Managing new pests, pathogens, and invasive plants.*
- *Increasing the efficiency of water use.*
- *Reducing the environmental footprint of agriculture.*
- *Growing food in a changing climate.*
- *Managing the production of bioenergy.*
- *Producing safe and nutritious food.*
- *Assisting with global food security and maintaining abundant yields.*

(President's council 2012)

8.5.1 Managing New Pests, Pathogens, and Invasive Plants

PCAST begins with several examples of pests and pathogens that threaten sustaining high yields. One is the problem of wheat stem rust, a fungal disease (*Puccinia graminins* f.sp. *tritici*) that can reduce normal wheat yields by 70 %. Another is citrus greening disease, caused by a bacterium (*Candidatus liberibacter* spp.) and spread by an insect that was detected in Florida for the first time in 2005 and now threatens the state's citrus industry. The PCAST recommendation – "Using a range of discoveries in basic molecular biology and genetics, new approaches must be developed to deal with the problem of resistance to treatments of both plant and animal diseases. In addition, new treatment strategies must consider the impact of medicines or chemical treatments on the nutrition and health of the consumers and of the environment. A diversity of safe and effective (chemical) treatments for a wide suite of pests and pathogens must be developed to ensure that agricultural practitioners have an arsenal of defenses in reserve to protect their crops."

These are short-term "band-aid" solutions. They treat the symptoms, not the cause. Once disease organisms and pest insects evolve resistance to the chemical defenses, new ones must be developed. It is a never-ending arms race. Sustainable solutions based on understanding of ecosystems are nowhere mentioned, solutions such as crop rotations, crop diversity, control of insect pests by beneficial insects, allelopathic weed control, and other management strategies that fall under the category of Integrated Pest Management.

8.5.2 Increasing the Efficiency of Water Use

PCAST identifies the problem as follows: "Today, agriculture accounts for 80 percent of the Nation's overall consumptive water use, and in many Western States, it accounts for over 90 percent. In the Great Plains, recent droughts have substantially depleted the Ogalala aquifer, which runs from South Dakota to Texas, and have created the dual problems of high soil salinity and water shortages, thus making the water unavailable or unusable for farmers." The suggested research agenda – better design of irrigation systems, and development of new crop varieties that are more drought tolerant. The idea that agriculture is not suited for arid lands is not mentioned, perhaps because it would mean that agriculture should be phased out in such regions, a suggestion that would threaten short term economic interests, but would provide economic and energetic savings in the long term.

8.5.3 Reducing the Environmental Footprint of Agriculture

PCAST's third major challenge for agriculture is to increase production of food, fiber, and fuel while simultaneously decreasing the environmental footprint with respect to fertilizers, pesticides, soil erosion and depletion, pollution associated with livestock production, and agriculture's contribution to greenhouse gas emissions. Their only solution is "to develop new management practices that reduce the different environmental impacts attributable to agriculture and to improve and restore the natural resource base such as soil and water, while maintaining a high level of productivity. Some trade-offs will be inevitable, but new technologies can be used to reduce the environmental impacts of fertilizers, livestock waste, and other inputs by enhancing efficiency and management." It is hard to evaluate this suggestion, since no specific new management practices and new technologies were mentioned. The only techniques presented are the ones that we already know, – precision agriculture (the highly targeted use of fertilizer), animal dietary manipulation, improved plant and animal productivity, and manure management.

8.5.4 Growing Food in a Changing Climate

PCAST urges the United States to "develop greater resilience to a changing climate through a broad research program aimed at new agricultural strategies to adapt to shifts in weather and climate." No specifics here either, but there is the admission that "climate change, driven primarily by the addition of greenhouse gases to the atmosphere is changing the nature of the challenge that farmers now face." They could at least have mentioned that a major contributor to climate change is the carbon emitted by industrial agriculture, and that reducing these emissions (through the use of the services of nature) would help slow down climate change.

8.5.5 Managing the Production of Bioenergy

There has been a substantial public investment in biofuels research both by the US Dept. of Agriculture and by the Department of Energy in the production of biofuels from cellulosic feedstocks such as corn stalks, components of municipal waste, forest residues, and high biomass crops grown specifically for energy production (in other words, energy crops). The main concern of PCAST regarding bioenergy is that the use of arable land for biofuels production competes with food production on arable lands. Their recommendation is to begin research on biofuel production from marginal lands that are not suitable for crop production. In contrast to the large acreage food crops such as corn, most prospective energy crops for marginal lands would be perennials such as trees that require low inputs. The only vulnerabilities that they mention are associated with droughts or other extreme weather events. No consideration was given to the energetic costs of converting woody biomass into ethanol or other materials that can be used in combustion engines. These costs are much higher than for corn, because wood contains compounds such as lignin and tannin that evolved to resist decomposition of the wood into forms that are readily oxidized such as fructose. Corn, in contrast, breaks down easily into simple carbohydrates and sugars. But even for corn, the energy output per unit energy input to produce it is marginally better than one.

8.5.6 Producing Safe and Nutritious Food

PCAST recommends "a continued public investment in food safety that requires integrating the newest scientific and technological discoveries from the health sciences, developing new detection technologies, and a deep understanding of the entire process of food production, from the environmental conditions on the farm or ranch, through any possible exposure opportunity in food processing and distribution. Research opportunities also include continued investment in the regulatory science that supports the regulatory framework applied by the Food Safety and Inspection Service." In other words, more technology and more regulation. But they don't ask why there is a food safety problem in the first place.

Outbreaks of food sickness caused by Salmonella, Listeria, and Escherichia coli on a nation-wide scale result from the monolithic food production, food processing food distribution industry, where contamination in a single field or slaughter house can affect people throughout the nation and abroad. The problems caused by monopolies in the food production and distribution system are not mentioned.

8.5.7 Feeding the World

The assessment of PCAST is "The United States has a strategic and security interest in maintaining a strong global food market and avoiding food shortages, especially in regions that are already politically or socially unstable". This seems to imply that the U.S. needs to figure out how to feed the world. Their recommendation is that the U.S. should "invest in innovation that will increase the efficiency (*efficiency not defined*) and intensity of food production in the developed world with respect to average yields per land area". However, they have "significant scientific concerns about how far crop yields and livestock and livestock-derived productivity (milk, eggs) can be pushed by biological improvements from marker-assisted breeding or technological improvements from precision agriculture in the face of inherent physiological barriers and environmental limitations." Perhaps they should think about crops that don't require huge energy inputs such as traditional crops that already have insect resistance built in, and that don't require heavy amounts of fertilizer because of adaptations evolved in the wild that enable them to scavenge nutrients unavailable to varieties bred for the "Green Revolution".

8.5.8 The Overarching Challenge

One "overarching challenge" according to PCAST, "is the need for better information technology capabilities. Modern technology allows for the collection and use of many different types of agricultural data, from soil moisture and chemistry, meteorology and market conditions, crop and market conditions, consumer nutrition and preference, to gene sequences and ecological variables. Data sets in many of these fields are massive, which presents challenges for accessibility, interoperability, and persistence. As research efforts proceed, there will be a need for better data management strategies addressing such issues as data storage, search algorithms, analytical methods, data sharing, and data visualization". It is not clear, however, how more data is going to eliminate obstacles to sustainable agriculture, obstacles from misdirected government policies to over-reliance on energy subsidies.

8.5.9 What Was Left Out

Nowhere in the document is there a suggestion that *people* should be incorporated into the research agenda. The assumption is that researchers are the only ones with the insight and ability to solve agricultural problems. It is a "top down" approach. All good ideas originate with research scientists. They then pass their findings to extension agents, who in turn tell the farmers what is best for them to do.

The new Long Term Agricultural Research (LTAR) program in the U.S. (Walbridge 2012) calls for a "Transformative Changes To Agriculture" an holistic path of research that includes humans in the equation. Recognizing that humans are an integral part of food producing systems would shift the discussion of innovations and technology from only those "hard systems" that focus entirely on increasing yield, and towards social aspects of "cultural knowledge, human experiences and potentials for technological development," so called "soft systems" (Dalgaard et al. 2003; Ellis 2013). There is yet no widely accepted name for such a vision. "Agroecology" is used by some researchers. Initially the term agroecology was viewed as a plot or field scale discipline involving the application of ecological principles to farming practices, but now the term is often used to incorporate the economic and social aspects as well as the production side of sustainable food systems. (Altieri 1989, 1995; Francis et al. 2003; Wezel et al. 2009). It recognizes that research scientists are not the only source of improvements in agriculture, but that farmers in the field are often the ones who come up with innovations to improve the sustainability of agriculture, frequently with techniques that depend on the services of nature that lessen agriculture's reliance on fossil fuel energy. It is sometimes called the "bottom up" approach (Box 8.10). It recognizes that while academic researchers uncover the underlying mechanisms of services of nature, it is the farmers that often discover them in the first place.

The bottom up approach to agricultural problems moves knowledge generation from research institutions as the principal supplier of new innovations to an interaction between multiple actors and multiple sources of knowledge within a specific context, as in the Participatory Action Research case described above. It needs to include all stakeholders involved in restructuring local and national food systems, from those who produce and market food to the activists who lobby for reform of Farm Bills. One organization with such a view is The Center for Rural Affairs (http://www.cfra.org/) whose mission is: "Establish strong rural communities, social and economic justice, environmental stewardship, and genuine opportunity for all while engaging people in decisions that affect the quality of their lives and the future of their communities."

Box 8.10

SARE (Sustainable Agriculture Research and Education) is organization that subscribes to the bottom up philosophy. It gives grants to working farmers for developing innovative practices in sustainable agriculture, then posts results on the SARE website (www.sare.org).

8.6 Why Is It so Difficult to Embrace Holistic Thinking?

Holistic solutions often are economically and politically unpalatable. In the short term, they will have negative economic impacts on the farmer, unfavorable ratings on the politicians, and inconvenient implications for the bureaucrats. Reasons for rejection of holistic approaches to agricultural problems are:

- There is a huge investment in the status quo.
  - Farmers have invested in machinery specially designed for monocultures that extend over thousands of acres, and in pesticide delivery systems to blanket those monocultures.
  - Chemical companies own huge phosphorus and potassium mines, and factories to produce nitrogen fertilizer.
  - There are hundreds of miles of chicken houses (if laid end to end) owned by farmers who supply poultry to processing plants.
  - The infra-structure that supports concentrated animal feeding operations stretches from farmers who supply grain to the millions of confined animals to companies delivering equipment for animal waste disposal.
  - Companies that specialize in genetic engineering of farm crops employ thousands of scientists.
  - Companies that manufacture agricultural equipment constitute a significant part of the American economy.
- There seems to be no good solution to the problem of farmers trying to grow annual crops in regions that experience frequent drought. More efficient irrigation systems will only prolong for a few years the inevitable drying up of their reservoirs. Having the government buy up such farmlands and turn them back into short-grass prairies smacks of authoritarianism, an anathema to most farmers and the politicians that represent them. But government loans, subsidies, and crop insurance that allow the farmers to continue their folly is socialism at its worst. It not only harms the environment, it costs the American taxpayers.
- Energy intensive agriculture has done an outstanding job in feeding not only North America, but many other parts of the world. Why stop, if you have a good thing? Yes, they admit, there seems to be a need for funds to deal with "externalities" like dead zones in the Gulf of Mexico, but such costs are minor compared to the costs of trying to change the face of agriculture.
- Scientists, for the most part, don't know how to do holistic research. They are trained and rewarded for doing reductionistic science. Reductionistic studies do not help solve sustainability problems because such studies are too narrowly focused. Humans are not part of the picture.
- Holistic research, such as Participatory Action Research is considered by reductionistic scientists as "soft science", "pseudo science" and "not real science" because it gives answers that may be locally true, but are not universally true.
- The continual increase in regulations concerning food production, harvesting, preserving, and marketing, and the increase in bureaucrats to enforce the

ever-expanding network of rules stifles any effort to change the system. The first priority of bureaucrats is to make sure that fiats from Washington are obeyed, no matter if they harm or help the problem. Using common sense to help a farmer solve a problem is not a legal defense if common sense is contrary to the rules.

8.7 The Dilemma of Sustainability

The dilemma of sustainability is the conflict between economic expansion that demands maximum power output, and ecology that demands maximum energy use efficiency (Odum and Pinkerton 1955). It means changing goals from maximizing *gross* output to maximizing *net* output. It means changing thinking from short term to long term. It means changing from the reductionist approach which has been successful in the past to an holistic approach necessary for charting the future.

The agricultural establishment is reluctant to embrace new paradigms because it leads to medicine that is difficult to swallow. Change is difficult and inconvenient for many in the business of agriculture, who have much invested in the status quo. But if we are concerned about agricultural sustainability and the future of agriculture in the U.S. as well as the rest of the world, we need to confront solutions that are costly in the short term, but that provide sustainability in the long term. Long term thinking requires insight and wisdom that comes about only after gaining an understanding of the whole problem, not just of fragments. It comes about as a result of observing ecosystems that have been managed sustainably, as well as unsustainably. It comes about through hands-on experience in the field. It leads to the realization that sustainability is expensive for us but is important for our children's future.

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Appendices

Principles of Sustainability

1. **To develop a sustainable agroecosystem, we must analyze the system in which we are embedded.**
   Fossil fuel energy is the driving force in today's agriculture. To increase the sustainability of agricultural systems, we must analyze how energy flows through the agricultural ecosystem, and consider alternative sources for the energy needed in agriculture.
2. **Energy flow through ecosystems is not random but is controlled and self-regulated by feedback interactions between humans, organisms and environment.**
   Example: The feedback loops within the community of soil micro-organisms are controlled by the larger-scale farm feedback loop: cattle produce manure; manure feeds soil organisms; soil organisms recycle nutrients to crop; crop supplies farmer with income; farmer uses income to feed cattle.
3. **The stability and sustainability of energy flow in a managed system can be increased by replacing external energy subsidies with Services of Nature.**
   Natural ecosystems are sustainable because they use the free services of nature. When services of nature are incorporated into agricultural ecosystems, these systems become less reliant on external energy subsidies, and therefore more sustainable.
4. **The stability and sustainability of ecological systems can be increased by maintaining species and landscape diversity.**
   Stability is achieved through redundancy. The more pathways there are for energy to flow through an ecosystem, the more sustainable that ecosystem will be. The more species there are in a field, the more pathways that exist.

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5. **In farming systems, the services of nature that lend stability and sustainability have often been destroyed.**
   The need to survive, the need to make a quick profit, and the need to grow fast to beat out competitors are reasons that individuals, corporations, and nations have not been good stewards of the land. The history of agriculture is a history of how individuals, companies, and nations have destroyed the very services that make ecosystems sustainable.
6. **Yield is not a measure of sustainability.**
   Yield is gross production, not net production. It tells us nothing about the costs to produce the yield. It should not be used to gauge the performance of Green Revolutions.
7. **The transition from non-sustainable to sustainable systems requires time and has a cost.**
   It is difficult for farmers to begin or change to sustainable farming, because the lag time between initiation and profitability is too long. Sustainable agriculture needs a subsidy to get it jump-started. But the subsidy must have a time limit. Otherwise it will become a burden on the economy just as subsidies for commodities have outlived their necessity and given resources to those who no longer need them.
8. **Despite the cost, there is an urgent need to make the transition.**
   The short-term cost of transitioning to sustainable agriculture is small compared to the long-term cost that will incur if the transition is not made.

Books About Agricultural Sustainability

In my library I have more than 50 books that deal with sustainable agriculture. The oldest one is “Plowman’s Folly” by E.H. Faulkner (1947). “ Silent Spring” (1962) by Rachel Carson is widely credited of launching the attack on what is now considered unsustainable agriculture. “Alternative Agriculture” (National Research Council 1989) published by the National Academy Press looks at environmental problems created by what is now called “Industrial Agriculture”. I have a number of books with “Agroecology” and “Agroforestry” in the title, such as “Agroecology: Ecological Processes in Sustainable Agriculture” (Gliessman 1998) and “Toward Agroforestry Design” (Jose and Gordon 2008). There are a number of books with “Organic Agriculture” in the title, such as Organic Farming (Lampkin 1990). Some volumes address the problem from an Ethical viewpoint, for example that of Chiras (1992) who wrote “Lessons from Nature: Learning to Live Sustainably on the Earth”, and that of Orr’s (1994), “Earth in Mind”. Others look at agriculture from a landscape perspective (Bird et. al. 1995, “Planting the Future: Developing and Agriculture that Sustains Land and Community”). Soule and Piper (1992) in “Farming in Nature’s Image” develop the point that natural Ecosystems are models for sustainable agriculture. Jackson and Jackson (2002) talk about ecosystem restoration as a key to sustainability.

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