The Sustainability of Swedish Agriculture in a Coevolutionary Perspective

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Abstract

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Sustainability is a social construct that must be addressed contextually both in relation to what a society views to be unsustainable, and in respect to how and why a course of non-sustainable development comes to be pursued. This thesis argues that the challenge of agricultural sustainability can be fruitfully addressed within an analytical framework that consciously and explicitly considers agricultural development as consisting of processes of coevolution involving agriculture and the ecological and socioeconomic systems. The model presented indicates that strengthening of local coevolutionary processes is a probable pre-condition for achieving sustainable agriculture.

Conditions for following a sustainable path of agricultural development in Sweden are already good and are still improving. On the national level, the costs of improvements in sustainability are decreasing, while the benefits are increasing. On the global level, the historical decline in food prices should not be expected to continue in the coming decades because of both resource limitations and environmental degradation. Ten principles and consequently ten indicators are identified that may help to promote agricultural sustainability in Sweden within the context of strengthened local interaction and interconnectedness.

When the model of coevolution and the indicators derived are applied to Swedish agricultural development during the twentieth century, the following conclusions are reached. First, a new system of traditional agriculture emerged during the nineteenth century in relation to various interactive forces within the socioeconomic system. This system was improved during the first quarter of the twentieth century and became capable of producing much more food than the old traditional system. Second, Swedish agriculture was transformed during the second and third quarters into a modern industrial system characterized by various agro-ecological problems and the uncoupling of resource flows from the surrounding ecological and socioeconomic systems. Third, agricultural sustainability during the twentieth century was generally improving and high during the first quarter, deteriorating and low during the second and third quarters, and improving and low during the fourth quarter. Fourth, the potential for substantial improvement in agricultural sustainability in Uppsala Municipality is very large.

Key words: sustainable agriculture, coevolutionary processes, principles of sustainability, Swedish agriculture, Uppsala, local interaction, agricultural development.

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To my mother, my wife, sisters, and brother, and to my son

By understanding the past and changing the present
We may make a better future

This world is not a static entity populated by thinking ants who, crawling all over its crevices, gradually discover its features without affecting them in any way. It is a dynamic and multifaced entity, which affects and reflects the activity of its explorers. It was once a world full of gods; it then became a drab material world and it will, hopefully, change further into a more peaceful world where matter and life, thought and feelings, innovation and tradition collaborate for the benefit of all.

Paul Feyerabend

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Basim Saifi
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Contents

Abbreviations

CAP	Common Agricultural Policy
EU	European Union
FAO	Food and Agricultural Organization of the United Nations
IPCC	Intergovernmental Panel on Climate Change
LRF	Swedish Farmers' Federation (Lantbrukarnas Riksförbund)
OECD	Organization for Economic Cooperation and Development
SCB	Statistics Sweden (Statistiska centralbyrån)
SEPB	Swedish Environmental Protection Board (Naturvårdsverket)
SLU	Swedish University of Agricultural Sciences
WCED	World Commission on Environment and Development
WRI	World Resources Institute

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1. Introduction

1.1. Background

Our contemporary ecological crisis calls for an increased ability to view the actual problems facing humanity in a more long-term perspective. In recent years many works concerning the connections between global sustainability and human activities have been published. For example, the United Nations World Commission on Environment and Development (WCED 1987) called for the sustainable development of the world economy in their famous Our Common Future. They urged the nations of the world to work together in following a path of development that does not jeopardize the needs of future generations. The Commission stated that "Ecology and Economy are becoming ever more interwoven - locally, regionally, nationally and globally - into a seamless net of causes and effects" (WCED 1987, p. 5). Vitousek et al. (1986) use world consumption figures to calculate humanity's appropriation of the net primary production (NPP) of the biosphere, which they estimate to have been at a rate of 40% in 1980. This is indeed a high ratio when we think of the needs of other species and the functioning of ecosystems, which provide societies with many vital services necessary for their very existence (Daily 1997). Wackennagel et al. (2002) use estimates of the human appropriation of the ecological systems for production and assimilation in term of hectares of land (footprint). They conclude that humanity's load corresponded to 70% of the regenerative capacity of the global biosphere in 1961, but grew to 120% in 1999. The message is clear: If disaster is to be avoided, we must change our behavior.

In 1992, five years after the publication of the WCED report, the Rio de Janeiro world summit on environment and development adopted the concept of sustainability, generally understood in terms of a system's ability to maintain its long-term functioning, and launched Agenda 21 as an action plan for sustainable development at local as well as global levels. The Swedish government and municipalities adopted the Agenda 21 document and produced their own programs for reducing environmental degradation and resource depletion with the aim of building a sustainable society. Sustainability in agriculture and in society as a whole are closely related. Agriculture provides not only food, satisfying perhaps the most basic human need, but also such important non-food products and services as nutrients assimilation (circulation), bio-energy, fibers, biological diversity, cultural heritage, and agro-ecological heritage. All of these have come to be increasingly emphasized in post-industrial societies (Vail et al. 1994).

An examination of the conditions necessary for an environmentally friendly type of agriculture in Sweden (Saifi and Drake 1990) has shown that the structure of agriculture along with development trends in many important areas of the socioeconomic system indicate that there is a great potential for stimulating positive change in this regard. Saifi and Drake's discussion presents a holistic view of agricultural development in relation to changes now taking place on both national and global levels. Furthermore, it advocates a pragmatic agricultural policy that balances international and regional agreements with domestic interests by redirecting such policy from price supports and highly regulated markets towards direct support and less market regulation. Although events in recent years have illustrated the importance of such synthetic studies, Saifi and Drake provided only a partial framework for showing how various issues interact with agriculture and how the potential to increase agricultural sustainability can be utilized. Nevertheless, their study stressed the importance of the future global food supply and of the particular demands placed upon Swedish agriculture, particularly in relation to its comparative disadvantage in food production.

The negative impact of environmental degradation and resource depletion upon global food production has been well documented in the above mentioned WCED report as well as in the numerous publications of international institutes and individual researchers, including the World Resources Institute (WRI), the Worldwatch Institute (WI), the Intergovernmental Panel on Climate Change (IPCC), Oldeman et al. (1991), Parry (1990), Brown et al. (1994), and Saifi (1997). Saifi in particular addresses the relationship between ongoing environmental degradation, resource depletion, and the global food situation in coming decades, revealing how climate warming, land degradation, water scarcity, water degradation, air pollution, and the depletion of biodiversity affect agricultural production capacity in many ways (Chapter 5 below). While the direct effect is to reduce production, it is possible that social choices at global, national, and local levels may not only alleviate the negative impact, but also lead to positive changes in both food supply and food demand. It follows logically from these studies that industrial countries in general, and Sweden in particular, must adopt a path of sustainable agricultural development. This would reduce the increasing utilization of global resources and also provide the knowledge needed to build sustainable agriculture systems throughout the world.

While many industrial countries share the common goal of moving towards a system of sustainable agriculture, their policy approaches vary in accordance with geographical diversity in farming, regional and local environmental and social conditions, the perception of sustainability, and economic contexts (see Naturvårdsverket 1998). No agreement has so far been reached concerning the meaning and content of sustainable agriculture. The OECD (1997) suggests thirteen agro-environmental indicator areas that member states should agree upon, namely, nutrient use, pesticide use, greenhouse gases, soil quality, water quality, water use, land conservation, biodiversity, wildlife habitats, landscape, farm management, farm financial resources, and rural socio-cultural issues. The Swedish Environmental Protection Agency (Naturvårdsverket 1997) considers urgent sustainability issues in agriculture to also include fossil fuel dependency, the accumulation of heavy metals, the dependence upon medications in animal production, and animal welfare. While it is of course important to understand what might be a very long list of problems related to agricultural sustainability, it is doubtful that using detailed indicators based on the problems mentioned above would be either sufficient or feasible for promoting sustainable agricultural development. Morse et al. (2001) in fact argue that no list of measurable indicators could by itself provide an answer as to whether or not an agricultural system is sustainable insofar as its utilization depends on value judgments.

The numerous problems concerning sustainability in agriculture are rather symptoms connected to each other in a number of ways. In addition, they manifest large variations in both spatial and temporal terms concerning sector, system, approach, framework, discipline, and theme (Riley 2001). This magnifies the difficulty of finding adequate indicators of sustainability. For example, the problems facing Swedish agricultural systems today differ from those facing agriculture in other countries, and also from the problems that faced Swedish agriculture a century ago. Moreover, it may be necessary to examine agricultural development and sustainability from an evolutionary perspective in relation to the development and history of agriculture in a particular country or region in order to understand the very meaning of sustainability. In addition, pluralism is likely a pre-condition for attaining sustainable agricultural development in a way analogous to the role played by biological diversity in the evolution of ecological systems.

1.2. Formulation of the Problem and the Aim of the Thesis

The concept of sustainability emerged in relation to public awareness of the contemporary ecological crisis, especially on the global level. The most quoted definition of sustainable development, namely, "To meet the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987), was created within the context of improving the well-being of the present generation without damaging the environment and the resource base for future generations. It is also relevant to consider sustainability in terms of managing economic activities under the conditions of protecting the natural environment and alleviating poverty (Common 1995). Since the concept of development is imprecise, necessitating contributions from disciplines other than economics, the concept of sustainable development is increasingly viewed in terms of sustainable systems, whether they be societal, ecological, or economic. An agricultural system that degrades the land or is dependant on non-renewable resources cannot be sustainable. Similarly, when human beings appropriate more energy from the biosphere than what the biosphere generates, then our economic systems are not sustainable. We may therefore view sustainable development in relation to maintaining the sustainability of human systems, including agriculture. But we must keep in mind the fact that human systems are subject to change, evolution, and collapse. Maintaining a system in the long term without the irreversible degradation of the environment and the depletion of the resource base may consequently be taken as the general meaning of sustainability.

Since the publication of the Brundtland report (WCED 1987), various ways of analyzing divergence from sustainable development have been suggested. For example, Daly and Cobb (1989) proposed an Index of Sustainable Economic Welfare (ISEW), which essentially reduces the Gross National Product (GNP) by the value of depleted resources plus the expenditures required to protect the environment from degradation and guard against societal distortion. The notion of ecological footprint measures the ecological load of a society or community in terms of land units (Rees and Wackernagel 1994; Wackernagel et al. 2002). Welfare maximization over time is the approach taken by neoclassical theory through applied welfare economics or cost-benefit analysis (Pearce and Turner 1990; Schuh and Archibald 1996). Material intensity per unit of output (Hinterberger et al. 1997) focuses on resource use, thereby addressing an important issue in sustainability. The sustainable development records approach (Bergström 1993) emphasizes three key ratio groups that describe economic production in terms of the purpose of a given operation in respect to the services obtained, the size of the operation in respect to the throughput, and the throughput in respect to the resource base. Emergy analysis (Brown and Ulgiati 1997; Björklund 2000) proposes determining how much accumulated energy, often solar energy, is used in a given product or system. Generally speaking, however, unsustainable development processes, along with the roles of product demand and the value system, have often been neglected in works addressing sustainability.

The methods mentioned above have tended to become mechanical calculations of specific aspect(s) of sustainability that emphasize measurement and comparison but pay scant attention to processes of change. While each has its own merits and should not be rejected out of hand, none of them presents scientific facts concerning sustainability that are generally valid. For instance, the ISEW provides a better indication of "welfare" than does GNP since it includes many important issues that are neglected in conventional GNP accounting, such as environmental degradation. The welfare of the Austrian people measured in ISEW per capita has stagnated since late 1970s (Stockhammer el al. 1997). Footprint analysis is also a promising accounting system for assessing sustainability since it is relatively easy both to understand and to apply by both non-specialists and the general public. It reminds me of Gandi's famous speech in which he asks how many worlds India needs in order to have the same standard of living as Britain if Britain needed to colonize the whole world to attain this standard in the first place. Emergy analysis is also a useful method for examining sustainability since it addresses the important issue of how much energy in various forms is used in particular production processes. However, all of these approaches reflect the mechanistic worldview emphasized by modern science insofar as they treat sustainability as a property that is universally valid and attainable for all nations and in all sectors of an economy.

Measuring "sustainability" through comparative analysis is important, but it is just as important to understand and influence processes of change. Moreover, sustainable development cannot be measured by means of one single indicator, but rather requires the use of a broad spectrum of indicators (Archibugi et al. 1989). In addition, the evolutionary processes typical of ecological and social systems make it impossible to design a sustainable system capable of lasting for a very long period of time. It must also be noted that scientists in general say more about where we should be in order to attain ecological sustainability than about how to get there. They concentrate on policy goals while neglecting policy instruments and processes of development. As Pretty (1995) argues, sustainability should not be seen as a static model that can be realized by particular means, but rather as an approach for learning about the ecological problems facing humanity. We need to address developmental processes as an important aspect of sustainability because the precise contents of the many dimensions of which sustainability consists differ between nations and change over time. Agricultural sustainability is not about technical fixes and expertise. On the contrary, it is a process of acquiring the ecological knowledge that needs to be applied through changes in policy, institutions, and behavior in order to attain sustainability (Pretty 1995; Röling and Jiggins 1998; Meppem and Bourke 1999).

Holling and others (Berkes and Folke 1998; Gunderson and Holling 2001) are intensively engaged in developing an integrative theory of adaptive management in human and natural systems that is based on viewing such systems as undergoing cyclical changes (growth, conservation, destruction, and reorganization) at various scales and in various temporal horizons. This theory asserts that the concept of resilience, defined as a system's ability to adapt in response to periodic stress or shocks, is crucial for sustainable development. However, it is often difficult to see such cycles in agriculture, and if we do succeed in doing so, it is difficult to translate this understanding into practical and comprehensive policy interventions. Identifying or structuring one given cycle in relation to a given variable (Carpenter et al. 2001) is not sufficient for addressing agricultural sustainability because of the existence of many variables, some of which change slowly (e.g., value systems). In addition, the idea of cycles in human systems is, at least as a general rule, not convincing.

As in any other sector, sustainability in agriculture has ecological, economic, and social dimensions that refer respectively to ecological degradation and resource depletion, sector survival, and social requirements. But these dimensions cannot be understood mechanically and must be grasped in further detail, particularly in respect to agriculture. First, agriculture affects the ecological system both positively and negatively. Not only does the idea of sustainability involve many important issues, some of them, such as food security and biodiversity, are relevant to more than one dimension. Second, the various levels of farm, local, regional, national, and global analysis cannot be linked mechanically. Third, the precise content of each dimension may change over time. For example, an increase in food security and heightened labor productivity may be desirable for a given society during certain periods of time but not in others. Fourth, the participation of many disciplines, not just economics, is needed to properly examine sustainability in respect to agricultural development.

Such complexity demands a broad perspective concerning agricultural sustainability that is capable of integrating various important issues. Norgaard's (1985; 1994) coevolutionary paradigm appears to be appropriate for this purpose since it draws upon knowledge obtained by a number of disciplines and emphasizes developmental processes, interaction involving various elements, and public involvement.

Coevolutionary theory, which views change as arising from complex interactions between subsystems, is rooted in the biological principles of mutation and selection. It maintains that the natures of subsystems, as well as the relations pertaining between them and the system as a whole, change over time as they coevolve with each other. For example, the development of traditional agriculture throughout the world did not result from the planned action(s) of an individual, group, or state during a certain period. It rather arose from many changes carried out over generations, and each such change influenced, and was influenced by, changes in the social and ecological systems. The development of industrial agriculture can also be seen as a process involving many subsystems influenced by fossil fuel usage. Similarly, the recent increase in ecological (organic) production in Swedish agriculture, which currently involves about 10% of total agricultural land, is also the result of coevolutionary processes involving consumers, citizens, farmers, policies, environmentalists, scientists, and the mass media. No single factor or group of factors can be pointed to as the sole cause of this development, which could very well be at a different level today. The future development of ecological production, in both extent and content, will also be influenced by our perception of whether or not it is sustainable as well as by our willingness to pay for it. No accurate predictions are possible in such circumstances.

Modern unsustainable industrial agricultural systems have developed over a relatively long period of time and in relation to complex processes involving interactions between food demand, policies, technology, resources, economic conditions, and value systems. The development of a system of sustainable agriculture should, therefore, be seen as a long-term goal that requires an understanding of the historical development of agriculture in general and of unsustainable agricultural systems in particular. It also requires that goals be set in terms of soft criteria that reflect, if only partially, the meaning of sustainable agriculture. Human beings inherited a world at the beginning of the twentieth century that was, in spite of the substantial damage that had been wrought by European colonization, filled with a great variety of cultures and agro-ecological systems. Agriculture over a period of 10,000 years had managed to support a world population that had doubled eight times, from some 6 million hunter-gatherers to approximately 1,500 million people. In the last one hundred years agriculture has managed to provide food for a world population that has doubled another two times, even though some 20% of us presently live in poverty and hunger. But the last one hundred years of development have incurred a great cost in terms of the environment, resources, and cultures, and they have strained the limits of what our ecology can support. Reflecting upon this history of agricultural development may provide us with important knowledge about sustainability if we interpret it adequately insofar as learning from the past is important to our future actions (Tool 1986; Boyden 1993).

The main objective of this thesis is to develop and apply a method for understanding and analyzing agricultural sustainability in Sweden upon the basis of the paradigm of coevolution. This approach is process and history oriented, being grounded in the history of agricultural development. As such, it will hopefully illustrate not only how and why today's unsustainable path of development came about, but also be useful for addressing the complex issue of what comprises a sustainable agriculture. The intent is to reflect the complexity of sustainability, describe the multiple functions of agriculture, and provide well-grounded suggestions for promoting agricultural sustainability. Although the theory underlying the coevolutionary view of ecological and social systems is not yet fully mature, it has the potential to be of great service in developing the notion of agricultural sustainability and facilitating its implementation. This thesis intends to explore this potential.

The discussion will address the following questions in an integrated and systematic way:

1) What is the coevolutionary perspective and how can we use it to "direct" agriculture towards sustainability? Building a coevolutionary model of agricultural development that illustrates the main elements and processes of short and long-term change will both clarify the meaning of sustainability as well as facilitate the development of a system of sustainable agriculture. In a complex biological and social system such as agriculture, it is first necessary to understand the historical development away from sustainability before we may then direct the system towards sustainability, not least of all because of the need for multiple policy instruments that may very well affect various parts of the agricultural system simultaneously.

2) What is sustainable agriculture and can we provide reasonable principles that could help promote the development of such a system? One obvious issue in this regard is that this relatively new concept may have different meanings for different researchers, particularly in relation to the perspective from which each one investigates it. In addition, the complexity of agriculture requires that the criteria chosen for determining agricultural sustainability be related to perceived problems and processes of changes. And if these criteria are to stimulate changes through social discourse, we need to consider their measurability at the farm and local levels as well as the extent to which the actors involved can understand them.

3) Are the conditions surrounding Swedish agriculture favorable for the implementation of comprehensive measures designed to lead to the promotion of a sustainable system of production? The agricultural system in Sweden, as well as in other industrial and post-industrial countries, is dependant on society at large. Developmental trends in societal issues related to agriculture are thus crucial in efforts to promote agricultural sustainability. Furthermore, since the Swedish farming system is characterized by internationally high production costs, then future global food production and demand are important in pursuing a sustainable path of agricultural development.

4) How can answers to the above three questions be used to understand agricultural sustainability in a region such as Uppsala as well as to facilitate

programs that promote it? It is reasonable to base our analysis on the municipal level not only because traditional agriculture coevolved with the ecological system on the local-regional level, but also because sustainability may demand greater future integration between urban and rural development. In addition, examining and measuring the sustainability of agriculture in Uppsala over time in accordance with the principles and indicators specified in 2) will hopefully contribute to understanding agricultural sustainability in other regions as well.

In order to find answers to these four questions, we must synthesize our findings from the coevolutionary perspective, identify the key issues that need to be addressed concerning sustainability, and suggest policies capable of influencing farm management and production in light of the long-term changes required for the development of a system of sustainable agriculture. Such policies may be viewed as selective pressure in order to induce the needed changes in production.

1.3. Disposition

Chapter 2 discusses the theoretical background of the thesis and briefly describes coevolutionary methodology along with ways in which it may be furthered developed in order to promote agricultural sustainability. Section 2.1 addresses the relationship between science and sustainability and argues for a pluralistic view of science that includes non-formal as well as non-atomistic and non-mechanistic knowledge. Section 2.2 examines the relationship between economics and sustainability. It argues that although the discipline of economics provides important insights relevant to sustainability, it does not adequately address agricultural sustainability. Section 2.3 outlines a methodology for investigating social and ecological systems that coevolve with each other. It interprets development in a way that contrasts with the typically modern view. Section 2.4 argues that this methodology should be developed in order that it become operational for understanding and promoting agricultural sustainability.

Chapter 3 constructs a coevolutionary model of agricultural development. This model extends the idea of coevolution involving social and ecological systems in order to describe how an agricultural system coevolves with the socioeconomic and ecological systems. Section 3.1 puts forward a coevolutionary view of the history of ecological degradation and agricultural development and outlines issues that are important for present and future development. It focuses on how coevolution involving agricultural and ecological systems was transformed to include interaction with emerging towns and cities. Section 3.2 presents a coevolutionary model that describes how processes and changes in the agricultural system arise in response to various ecological problems and to changes in the socioeconomic system. This model emphasizes the sub-systems and processes that are important for agricultural sustainability. It identifies how a weakening of local coevolutionary processes involving the agricultural, ecological, and socioeconomic systems has led agriculture on a path of development away from sustainability. Section 3.3 analyzes the meaning of sustainability along with issues particularly relevant to a sustainable system of agriculture. It also outlines basic dimensions in which the principles of sustainability reside. Section 3.4 summarizes the chapter as a whole.

Chapter 4 addresses the possibilities for a sustainable path of agricultural development in Sweden and suggests that conditions favorable for this do in fact exist. Section 4.1 examines developmental trends in important issues within Swedish agriculture and socioeconomic system and endeavors to identify areas in which policy intervention may be fruitful. It is judged that development trends within the sector, societal demands, and international conditions now encourage the adoption of agro-environmental measures in policy. Section 4.2 discusses the economic rationale for such policy. It is argued that providing financial support to agriculture for environmental improvement and taxing it for environmental degradation would favor environmentally friendly farms that operate with less "rational" methods, and that a policy of conditional support is an important instrument for promoting a path of sustainable agricultural development. Section 4.3 examines the process of greening in Swedish agricultural policy during the last quarter of the twentieth century. The main points of emphasis are on understanding how policy measures can promote environmental protection and on the need for a comprehensive policy to promote agricultural sustainability. Section 4.4 discusses the implications for agricultural sustainability.

Chapter 5 is an application of the model developed in Chapter 3 in order to address the question of how environmental degradation and resource depletion impact global food production and demand. The analysis reveals that these ecological problems will lead to a substantial decrease in agricultural production capacity and to significant increases in food prices if no mitigating measures are taken. But if effective policy measures are enforced to resolve the problems caused by these complex interactions, then there may be a smaller increase in both food demand and food production. The present study supports strengthening efforts to find a sustainable path of agricultural development, particularly in Sweden. Section 5.1 discusses important problems related to agricultural sustainability and estimates their negative impact through a study of the literature. Section 5.2 constructs a scenario of future production and consumption in 2030 using simple reductionist trends. Section 5.3 integrates the estimated reduction in production capacity depicted in Section 5.1 with the scenario constructed in Section 5.2. Section 5.4 presents a coevolutionary critique of this type of analysis. It is argued that interaction involving the agricultural, socioeconomic, and ecological systems may result in the steady adoption of techniques, methods, and preferences that reduce ecological degradation. Section 5.5 concludes the chapter by arguing that the future uncertainty regarding global food production should motivate both industrialized and developing countries to create a new order in agricultural development that is significantly different from the present industrialization of agriculture.

Chapter 6 examines agricultural sustainability within the Swedish context, drawing on the findings and discussions of the previous chapters. It suggests various principles and indicators of sustainability that can provide support for strengthening local coevolutionary processes. These principles are not absolute criteria but rather practical characteristics of a system of sustainable agriculture based on our present knowledge. Section 6.1 suggests what sustainability means in respect to agriculture in order to provide a framework for identifying important principles and indicators. Section 6.2 further investigates the eleven interrelated dimensions of sustainable agriculture presented in Chapter 3 in relation to Swedish conditions. The aim is to identify important issues within these dimensions along with the connections between them. Section 6.3 uses this mapping of issues and connections in order to identify principles that reflect major issues in agricultural sustainability. It also seeks to provide practical, measurable indicators for indicating the deviation of a particular system from these principles. Section 6.4 summarizes and discusses the findings and suggestions that have been put forward.

Chapter 7 analyzes agricultural development in the Municipality of Uppsala during the twentieth century on the basis of the framework developed in Chapter 3 and the principles and indicators of sustainability presented in Chapter 6. The analysis indicates how a broadening of coevolutionary processes to include national and global interaction and interconnection has led to an unsustainable path of agricultural development. Section 7.1 briefly addresses the important changes that occurred prior to the twentieth century. The evidence indicates that comprehensive change during the nineteenth century placed agriculture on a new path of development. Section 7.2 outlines development during the twentieth century. It emphasizes the changes and processes that drew agriculture away from the sustainable path of development that had been typical for traditional agriculture. The four quarters of the century are specifically delimited since they each were characterized by a different path of agricultural development. Section 7.3 estimates the values of sustainability indicators for the five years that form the boundaries between quarters. These estimates indicate that agricultural development during the first quarter had a positive impact on the agricultural, socioeconomic, and ecological systems. Section 7.4 concludes with lessons that are important for a sustainable path of agricultural development. It also suggests how agricultural sustainability can be promoted in the Municipality of Uppsala.

Chapter 8, which concludes the thesis, suggests possible consequences of the study for promoting agricultural sustainability. Section 8.1 summarizes the main points and arguments of each chapter. Section 8.2 presents major conclusions relevant to promoting agricultural sustainability in Sweden. Section 8.3 outlines the policy implications of the study as well as possible future research.

1.4. Clarification of Concepts

Social concepts cannot be defined precisely and universally. Consequently, there are no universally accepted definitions of such concepts as development, globalization, progress, sustainability, freedom, and justice. The central concepts of coevolution and sustainability are, however, explained in the text along with other less essential notions. Generally speaking, I have chosen to minimize the explanation of concepts and terms since I have relied on the standard definitions. But the following brief remarks may be in order.

Method is a technique for or a way of doing something. Methodology is broader than method and refers to the way of thinking used in addressing an issue. It also relates to higher level theory about the world around us, i.e., to worldview and paradigm. I use worldview and paradigm synonymously, viewing them as belief systems about how the world is structured and functions. For example, the methodology of neoclassical economics is related to the utilitarian paradigm that rational behavior leads to the maximization of benefits and the minimization of costs. Cost-benefit analysis and cost effectiveness are only methods or techniques within neoclassical theory.

Holism is the idea that the whole is greater than the sum of its parts, and that these parts and the relationships between them change over time. It is in contrast to atomism or reductionism, and it should not be understood as bringing all related parts and issues into analysis. Technology and knowledge are interrelated concepts insofar as technology, consisting of tools or implements and methods, is an application of knowledge in order to carry out a practical task. Knowledge may be formal and informal, structured and non-structured, as well as modern and traditional. Vague knowledge or intuition may become elevated to knowledge in a more strict sense through trial and error by the use of an implement or method.

I use the concept of development to refer to irreversible change. This notion is clearly related to the forward movement of time and to a sense of history. Changes that are mechanical or related to short periods of time are thus often not considered to be development. Unlike the common notion of development as improvement and progress, especially in relation to industrialization and modernization, I use it in a neutral sense as including both improvement and deterioration. Real development and sustainable development are used to mean a long-term improvement in people's living conditions that is compatible with ecological systems.

By traditional agriculture I mean food systems characterized by the local flow of resources and consumption that evolved in interaction involving social and ecological systems. It is often, but not always, related to the period prior to industrialization. Moreover, it should not be understood in a black and white fashion since most traditional systems produced some surplus and utilized resources from other social and ecological systems. An agricultural system may remain traditional even when it partially adopts certain techniques and methods that are associated with industrialization if resource flow and food consumption remain basically local.

The concept of local is used in relation to place and community at various levels of integration, and its domain has increased in history. In early twentieth century Sweden, for example, local often referred to the village and parish levels, while today it often refers to parish, district, and municipal levels. In later chapters of the thesis I use local to refer to the municipality, including both urban and rural areas and populations. This is roughly equivalent to the Swedish kommun, which together with county constitutes the administrative division of the country. Kommun referred to parish in the early twentieth century, but since the 1960s it refers to, and is officially translated as, municipality. Major activities of a common nature, including the primary level of education and health care, waste management, as well as resource and environmental issues, are organized and managed on the municipal level in Sweden. An income tax of approximately 22% along with various charges for services, are made available to municipalities for these purposes.

2. Methodological Discussion and the Coevolutionary Paradigm

2.1. Science and Sustainability

The complex and evolutionary nature of science means that it is impossible to define it in terms of one single characteristic (Kuhn 1970; Georgescu-Roegen 1971). We cannot define science solely as an increase in knowledge, discovery, theory construction, or research, nor can we define it in isolation from other social spheres. For example, the development of writing, an absolute prerequisite for much of what we today consider to be knowledge in the strict sense, was associated with the development of agriculture and accounting (Roux 1992). In addition, not only is our history filled with many different types of learning, observation, experimentation, and construction in respect to the physical, biological, and organizational world around us, it may even be said that learning has increased our capacity for further learning. Mutation that involves higher learning capacity has been selected as fitted. Furthermore, we cannot justifiably restrict scientific knowledge to an activity typical of modern societies. For example, the WCED (1987) reported that about two-thirds of currently prescribed medicines originated from medicines originally developed in various traditional societies. In this regard it makes no sense whatsoever to maintain that scientific knowledge is necessarily connected with modern laboratory methods, or that traditional discoveries are inherently non-scientific.

The root of the word science is the Latin scientia, which is related to the act of seeing and knowing (The Concise Oxford Dictionary). The verbs to see and to know have long been used synonymously in many societies in various expressions related to the perception of certain events and problems. The Sumerian god of wisdom, Enki, who was responsible for revealing knowledge to people, was said to have great powers of hearing (Wolkstein and Kramer 1995), and the Babylonian Epic of Gilgamesh repeatedly describes the hero as “he who saw,” referring to both perception and understanding. While the Arabic and Swedish words for science, elem and vetenskap respectively, are primarily rooted in the verb to know, the Swedish word also contains the root skap, which is related to “create.” In addition, the Swedish words inse (understand) and insikt (insight) demonstrate the relationship between seeing and understanding. It could thus be said that perception, both sensual as well as mental, is the basis of knowledge and science, which in all societies also rely upon observation and experimentation. However, perception may be affected both by the intention and the experience of the observer, such as in respect to pictures and images, and also by the tools used in the observation, such as the microscope. Even in photography we may in fact focus on the image produced by the photographer rather than the reality of the object photographed.

The industrialization process of the last few centuries has consolidated a particular notion of science that relies upon an atomistic-mechanical worldview which articulates the existence of an objective external reality driven by unchanging physical laws. This worldview has led to great progress in industry and has raised living standards, but the price for doing so has been great, particularly in respect to ecological degradation. The atomistic way of knowing is to concentrate upon individual parts or elements in a value-free manner in order to understand the whole. While this may be valid for mechanical systems, it has proven itself to be invalid for biological and social systems insofar as the whole in such systems is greater than the aggregation of parts. Holling et al. (1998), for example, realize the importance of interaction between parts within a living system, and they extend this in order to argue for an adaptive management approach to sustainability and to the management of natural resources. The way of acquiring knowledge they advocate is similar to that practiced by traditional societies around the world. Indeed, human evolution in the last one hundred thousands years has been based on cultural adaptation, in respect to both technology and institutions, in which learning by doing and by trial and error brought forth suitably adapted types of knowledge.

Moreover, it can be argued that economics should also be governed by thermodynamics and by evolution in addition to Newtonian mechanics. For example, Georgescu-Roegen (1971) argues that the law of entropy in thermodynamics renders economic processes evolutionary and irreversible. Economic activities irreversibly transform low entropy energy and material into high entropy states that are inherently less useful for work. The fact that the Earth as a system is powered by the sun does not mean that the law of entropy is irrelevant to our economic activities insofar as the latter both utilize other energy sources than the direct flow from the sun, and also transform materials into less usable states.

For centuries we have been taught that scientists must be objective, i.e., they must neither influence, nor be influenced by the object studied. However, objectivity in research is difficult, if not impossible, to obtain, particularly in respect to the social sciences, insofar as interaction between the observed object and the observing subject increases as we move from hard sciences like physics to soft sciences like economics. Gunnar Myrdal’s (1978, p. 778) assertion that “Valuations are always with us” clearly demonstrates that the claim of objectivity in respect to the social sciences is illusory. On the other hand, the choice of research methods and of the object to be studied can also be affected by the researcher’s values and experience even in natural sciences like biology. Today we have a substantial number of scientific approaches to learning that explicitly acknowledge the role of values and system thinking, such as action research, adaptive management, institutional economics, the participatory approach, soft system, and coevolutionary theory. The realization that science is also learning may lead to a self-reflective model of learning that contradicts conventional objectivity (Alrøe and Kristensen 2002).

Bertrand Russel wrote in his history of philosophy that it is discouraging for respectful young students to be told that philosophy begins with Thales of Miletus, who stated that all things are made of water (cited in Checkland 1981, p. 24). Checkland goes on to state that it is unfair to view the content of ancient philosophy from a modern perspective, and he argues that Thales' myths were rational observations based on reasoned speculations. Thales' conclusions were based on the prevailing beliefs and on important, if only partial, observations concerning the world of agricultural societies. (Even today we view water as the basic necessity of life, and we taste, see, and hear the substance water, not the hydrogen and oxygen that combine to form it.) For example, Thales lived in a region that could be considered as the periphery of the Sumerian-Akkadian civilization. An important belief in Babylon at that time was that the great god Marduk created the land by placing reeds and mud upon the water, a building method that the people living in the marshes of southern Iraq have practiced for more than five thousand years (Roux 1992). Throughout our history we have sought to understand the world around us and to employ our knowledge in order to improve our living conditions through technical and organizational changes. Questions such as What are the essences of the things around us? What makes seeds grow? and How do we maintain the fertility of the land? remain important to our modern societies today.

Yet we address these questions differently. Indeed, Kuhn (1970) argues that knowledge systems must be understood in their historical contexts. And since we still have many questions with no answers, the modern worldview itself will someday become "un-modern." Throughout the history of science facts have been mixed with errors and myths (Feyerabend 1988; Kuhn 1970), and much of what we consider today to be facts, particularly in the social sciences, may well prove to be myths in the future. Like Thales many other great figures in history held views that we now see to have been incorrect in some sense. For example, Aristotle believed that a heavy body is moved by its own nature from a higher to a lower position (Kuhn 1970). Galileo introduced unfamiliar new concepts, interpretations of nature, and principles in order to support the Copernican view that the Earth moves (Feyerabend 1988). Carl von Linné classified people according to their color and asserted that different groups had different social characters, such as lazy, temperamental, and creative (Sjöberg 1997). And as recently as 1930 John Keynes viewed economic growth as the means to abolish scarcity (Common 1995).

Robert Costanza, Editor-in-Chief of Ecological Economics, wrote in the first issue (Costanza 1989) that the journal will serve the area where mainstream economics and ecology overlap. He also stated that it would encourage new ways of thinking about the inter-connection between these two systems. Shogren and Nowell (1992) discuss how ecological economists may benefit in their approach from integrating economics' emphasis on theory with ecology's emphasis on observation. In addition, Norgaard (1989) and Söderbaum (1992) argue for methodological pluralism, and emphasize that neither economics, nor ecology should be limited to one school of thought. Both economics and ecology employ a broad range of methodologies that could be applied to environmental issues. Economists generally provide three types of theories about how an economic system operates or should operate, namely, neoclassical, Marxian, and institutional. Ecologists generally propose two patterns of perceptions regarding the functioning of ecological systems, complexity as safeguard and complexity as surprise generator (Wiman 1991). The first is that nature is benign, maintaining stability and continuity through various biological and geophysical feedbacks. Gaian theory, for example, asserts that the Earth is a self-regulating and self-maintaining system that can be symbolized by the conjugal embrace (Wallace and Norton 1992). The second view is that nature involves a mix of both stabilizing and destabilizing properties that can give rise to unforeseen events in moments of instability (Wilson 1989; Holling 2001). Today's ecological crisis has also led to the emergence of human ecology as a field of study on the boundary between the social sciences and ecology (Steiner and Nauser 1993).

One of the main themes in the works of such authorities in the philosophy of science as Thomas Kuhn (1970), Paul Feyerabend (1988), and Karl Popper (1968) is that we should view science as providing knowledge to improve our understanding of the world. However, methodological pluralism is necessary for scientific progress insofar as the acquisition of knowledge cannot be limited to only one method of research. Holling et al. (1998) argue that there are other types of science in addition to atomistic-mechanical science that are needed to properly address sustainability, such as traditional knowledge and learning by doing. Pluralism should acknowledge the importance of local and traditional knowledge, respect inspiration, and reject the domination of so-called expert opinion that does not take into consideration the views of those who are directly concerned or affected (Feyerabend 1988; Norgaard 1994). Like the role of biological diversity in the evolution of ecological systems, pluralism in science is necessary for its evolution and progress. As argued by Kuhn (1970) paradigm shift is related to the emergence of major idea or finding that makes some old ideas obsolete and opens the road for new ideas to emerge.

In respect to the challenging issue of sustainability, we should view science as a body of systematic and formulated knowledge that serves to help us understand and change the course of unsustainable development. Our guide in this strive may include learning from mistakes (Popper 1965), creativity (Kuhn 1970), and free thinking from strict methodological rules (Feyerabend 1988). The acts of seeing and perceiving are essential elements of explaining and understanding. But since perception and interpretation of the same phenomena may differ according to one's worldview and experience, we should both anticipate and respect differing views concerning the meaning of sustainable development. Furthermore, insofar as scientists in various disciplines and schools of thought, along with people from different cultures and social classes, understand development differently, we should not look for a universal, or even generally agreed upon, definition of the meaning of sustainable development. Indeed, Helmfrid (1992) argues that it is difficult to agree upon the meaning of sustainable development because different worldviews have different interpretations of both of the words that comprise this concept. Moreover, such different interpretations are necessary for there to be an advance in knowledge. Kuhn (1970) makes a similar point concerning views about the nature of electricity during the first half of the eighteenth century, while Georgescu-Roegen (1971) does so concerning the need for both thermodynamics and mechanics in order to understand natural phenomena and economic systems.

Both The Limits to Growth (Meadows et al. 1972) and its rival The Resourceful Earth (Simon and Kahn 1984) draw on scientific observations. The first work examines ecological constraints and argues that societies must obey the limitations of the environment. This may be viewed as a form of environmental determinism. Natural scientists in general dominate this school of thought, arguing that since physical and biological laws cannot be avoided, we should therefore focus on reducing our impact on the environment and our resource use. The second work examines trends for the improvement of "welfare" and argues that social organization and technological development are the main factors limiting development. This may be viewed as a form of cultural determinism. Social scientists, particularly economists, have maintained for decades that the existence of different societies in similar, or even the same, ecological system(s) should lead us to focus on advances in knowledge, technology, social organization, and capital accumulation. Their view has been that development and a rising material standard of living would be able to manage constraints arising within the ecological system. On the other hand, such early economists as Malthus and Ricardo, along with contemporary economists like Boulding, Georgescu-Roegen, and Daly, emphasize the biophysical constraints on economic systems.

The cultural deterministic utilitarian approach, which is based on the view that society consists of a mechanical aggregation of individuals and organizations who seek to maximize their private gain, views development in terms of increasing consumer and producer surpluses. This is commonly reduced to total production in terms of GNP. One cannot deny the correlation between increasing GNP and many issues that are important for human welfare, such as adequate food, good health, and education. But if these issues are in fact our goals, why do we measure them indirectly? Amartya Sen (1999) instead argues that we should view development in terms of an increase in freedom from hunger, illness, ignorance, a lack of opportunity, and political oppression. Easterlin (2001) presents an interesting argument on the relation between income and happiness, claiming that happiness or satisfaction, as expressed by people in countries with different economic standards and in one and the same country during different income periods, has not increased with higher income. Viewing development as improving people's well-being would give a different perception of sustainable development than viewing development in terms of a growth in per capita GNP. In addition, reducing values and ethics to preferences has little substance in many cases, and people's ability to regulate what they have reason to value is important (Sen 1999). People may also express their values concerning the sort of systems they want through the political process, including the combination of public and private goods that they desire as well as the production methods they judge to be either acceptable or unacceptable.

There may indeed be a negative relationship between, on the one hand, per capita GNP as the aggregate of economic activities during a given period and, on the other, the ecological basis of sustainability and indicators of well-being. The Human Development Index, which is published annually by the World Development Organization, provides better and more direct indicators for measuring welfare than the indirect GNP indicator. In addition, not only do the sustainable systems of indigenous peoples have little economic value in terms of GNP, we have no objective criteria, not even through the Human Development Index, to compare their well-being with that of people in wealthy countries. People in a refugee camp may well enjoy higher standards of nutrition, health, education, as well as greater longevity than in their normal societies, but we cannot say that their well-being is thereby improved. When natural resources are depleted, energy availability limited, and changes in environmental functions irreversible, then short-term economic growth may very well be in conflict with the long-term objective of sustainability.

As Section 1.2 noted, there is now an alternative to the GNP indicator, namely, the ISEW, which accounts for defensive expenditures for both social and environmental purposes (Daly and Cobb 1989; Ayres 1998; Stockhammer et al. 1997). The GNP indicator, which is still dominant in respect to decision-making and comparison, has widely recognized shortcomings. It excludes non-market economic activities; includes government services at cost even for spending on jails, demolition, and cleaning; neglects the distribution of economic improvement; and does not take into account resource depletion and environmental degradation. A society would double its per capita GNP in 24 years with 3% annual per capita real income growth, and such an income increase would heighten its abilities to reduce environmental degradation and poverty. However, this statement has a relevant validity only if such development would compensate for losses associated with ecological degradation, and if there would be a high degree of substitution between both natural and man-made resources, such as land and implements. Well-being cannot merely be reduced to economic growth and high material standards. Well-being is a state of mind that is more related to the satisfaction of underlying needs, such as Maslow's hierarchy of needs involving physiology, safety, belonging, esteem, and aesthetics (Dodds 1997).

In contrast to GNP and to welfare maximization views, sustainability can be understood as protecting nature and ecological systems irrespective of economic consequences. What Pearce and Turner (1990) term deep ecology is representative of this perspective, which maintains that human beings have no right to alter or destroy the ecological systems of which they themselves are elements in the process of attaining higher material standards. The growing understanding of ecological systems in recent decades has brought forward an increasing concern with various environmental issues. It has also strengthened the stance of biologists and ecologists in respect to environmental determinism not only within the scientific community, but also in public debate and decision-making. However, the existing ecological systems have resulted from evolutionary processes that have been affected by various geological, climatic, and biological changes, including the emergence of human beings and the eventual development of agricultural production systems. Between the two extremes of GNP maximization and deep ecology there is thus a range of differing perceptions concerning sustainability that reflect not only differing worldviews and a number of distinct disciplines, but also differing schools of thought within each of the latter.

In respect to the conflict between social or cultural and ecological determinists certain economists have responded positively to ecologists' arguments concerning ecological constraints. For example, Georgescu-Roegen (1971) argues in The Entropy Law and the Economic Process that economic activity both induces qualitative change in terms of increasing entropy and is also affected by qualitative changes in the environment. Consequently, we must not view the economy in a merely mechanical fashion in terms of a circular flow between production and consumption. Daly (1977; 1991) acknowledges in Steady-State Economics that ecological factors place a limit on economic growth, and he argues for a type of economic thinking that views the economy as an open subsystem within a finite and non-growing ecosystem. Norgaard's (1994) Development Betrayed meets the argument of environmental determinism half-way and argues for a coevolutionary paradigm that views social and ecological systems as being in continuous interaction. The conflicts between the two perspectives, social contra ecological determinism, can be resolved by a synthesis that interprets both social and ecological systems in terms of coevolutionary processes that arise in interaction. Certain ecologists have also begun moving towards an acknowledgement of the role of the social system in maintaining and protecting the ecological system by means of adaptive changes (e.g., Boyden 1993; Holling et al. 1998).

Such discussions lead us to the growing literature on post-modernity that challenges the project of modernity. The latter arose from the European Enlightenment and the consequent domination of one particular type of science, beginning in the eighteenth century, in respect to human and societal development. We now realize that modernism has a number of significant shortcomings, particularly its neglect of the role of culture, its claim to objectivity, its destruction of cultures as well as nature, and its failure to attain the prosperity it promised to all mankind. Since post-modernity constitutes an essential philosophical background for the coevolutionary paradigm, further discussion of the topic is important, particularly in relation to the coevolutionary methodology presented in Section 2.3. I consider that the central issue in the debate between modernity and post-modernity is that we must not abandon modernity, but rather transform it so that it accepts contextuality. It would thereby include other ways of knowing and also accept the importance of cultural and ecological systems.

Modernism is based on the domination of the atomistic-mechanical way of acquiring knowledge. Modernism asserts the existence of an objective external reality driven by unchanging physical laws, and it views societies as aggregations of individuals in which every one guards his own personal interest. It maintains that we can understand and improve the whole by studying each part of a system separately, and it claims that reality should be explored through scientific research in order to increase our knowledge and promote technical development for the benefit of humanity. In short, specialized scientists working in different disciplines are to objectively identify particular facts, and people are to adopt these findings as their level of education increases. The idea of modern development thus involves a process of rational design along with a progressive movement of history in which the formal knowledge of scientists replaces the informal knowledge that has been handed down from one generation to another. Such views led not only to the belief in the superiority of modern European civilization, but also to the justification for colonizing the world, civilizing the "savages" and developing the "underdeveloped."

But there have been fundamental changes since the 1960s in both society and consciousness in respect to social, cultural, economic, and technological structures that have challenged the optimism inherent in modernity (Castells 2001; Iggers 1997; Connor 1997). For example, the era of direct colonization has come to an end, and there is a growing awareness that non-Western peoples also have civilizations and histories. The conception of national consensus has increasingly given way to a diversity based upon ethnicity, gender, environment, locality, and profession that has been empowered through networking at all levels, especially in relation to the development of electronic communications. The consequent rise of information technology has strengthened the interconnectedness of societies and the awareness of the limitation of ecological systems, giving rise to global social movements concerned with such issues as human rights, environment, and fair trade. As Worster (1988) has demonstrated, the 1960s marked the beginning of a new environmental awareness that has steadily grown ever since.

This has in turn led to the emergence of postmodernism in science, which stresses the significance of culture and values, the social construction of knowledge, the role of ecological systems, and the dynamic and non-predictability of social and environmental changes. Knowledge, especially in the social sciences, has thereby become contextual. The growing conviction in respect to the significance of pluralism and contextuality clearly reflects the postmodern critique concerning the possibility of conducting absolutely objective research. Although Beck (2000) and Potter (2000) agree with much of this emphasis, they do not accept the concept of post-modernity, which I myself find difficult to define and grasp. Beck prefers the concept of "second modernity" to avoid falling into the ideology of neoliberalism, while Potter prefers the concept of "critical realism" to avoid falling into the belief that reality is a social construct.

This wide-ranging transformation of modernity into post-modernity is indeed evident in many social fields in addition to natural science, including architecture, law, literature, dance, and music (Conner 1997). In architecture such changes are visually evident insofar as culture and environment have become integrated into rational and modern architecture. Iggers (1997) explains how the discipline of history has now become a study of culture understood in terms of the conditions of daily life and experience. Thomas Kuhn's arguments (1970) concerning paradigm shifts in relation to major findings and the embedding of scientific work in prevailing culture and conditions are well in line with such criticism.

Norgaard (1994) criticizes modern beliefs with respect to how society accepts particular scientific ways of understanding and suggests a coevolutionary explanation of how social and ecological systems interact and change. He states that, “Modernism destroys cultural and biological systems because of five closely inter-linked metaphysical and epistemological premises.... they are atomism, mechanism, objectivism, universalism, and monism” (p. 62). Not only is the whole more than a simple aggregate of parts in both biological and social systems, the parts themselves are neither static, nor linked together mechanically. We now know that the basic claims of modern science concerning the supposedly static relationships between unchanging system parts, along with how improvement in a given part mechanically leads to improvement of the whole, are simply not true in many cases. This is obvious from the problems that have arisen, for instance, from nuclear power production and from the extensive use of chemical biocides. Unexpected problems arise whenever we ignore how changes to one part of a system alter other parts of the system as well relations between all the elements that comprise the system.

It is thus of fundamental importance that some researches be based on holistic and evolutionary premises that provide alternatives to the universalism, objectivism, and monism typical of modernism in order to obtain a better reflection of reality. Social and biological phenomena are not merely related to a few universal principles, but are rather contextual and involve a large number of factors. Moreover, absolute objectivity is not possible insofar as beliefs and values may transform the observer into an element of the observed problem. In addition, the premise of pluralism is more useful and democratic than the premise of monism since a complex system can only be understood through a number of different patterns of thinking. Decision making in a real democracy, which cannot be reduced to mere vote counting, requires the considerations of alternatives and the participation of non-experts.

The post-modern worldview of holism, evolution, contextualism, subjectivism, and pluralism is particularly important in respect to agriculture and agricultural sustainability. These attributes are also common to institutional economics, which Söderbaum (1993) maintains has four essential features, namely, it acknowledges that values and ideology play important roles in social research, it is interdisciplinary and holistic in character, it emphasizes history and evolution in respect to the issues it examines, and it employs a pluralistic methodology. In this regard we can say that agriculture is basically a human-biological system that evolves in relation to elements within and outside the system. Furthermore, neither the elements of an agricultural system, nor the relationships between them are static. For example, changes in weather and pest conditions have an ongoing and dynamic impact on the system as a whole and on its constitutive elements. In addition, what is determined to be the optimal level of mineral fertilizer application at the research station, using the atomistic-mechanical methodology of modern science, may very well prove to be other than optimal on the farm if important consequences of its usage have not been taken into account, or if significant issues of a qualitative nature have been overlooked. Generally speaking, objectivity in respect to agricultural research can clearly be questioned because the choice of the issue to be studied, the method used, and the boundary applied necessarily refer to value judgments, even when the experiment itself and the subsequent analysis have been conducted in a “scientific” fashion.

Three types of explanations that imply three types of solutions for today's unsustainable development can be found within the philosophy of modernity. First, poorly defined property rights lead to the application of inappropriate technologies, and thus to "non-optimal" production and consumption systems. Second, a social structure that favors the dominant (capitalist) class encourages short-term benefits. Third, individualism in modern societies has weakened the common rules and norms that shape behavior in social and economic relationships. Each one of these explanations has its merits, and we will certainly have to rely on some combination of the three as we seek to identify a path of sustainable development. However, no single approach renders the others unimportant. Moreover, not only will the combination selected necessarily be contextual, many choices must be made to modify the institutional arrangements regarding the issues in question.

In dealing with the complex issue of long-term interactions, multiple approaches serve best to reflect reality. Stated otherwise, there is no one correct method or approach to follow. Wallen (1993) examines the problem of how to choose an appropriate theory for research and concludes that, "If theories are seen as intentional and partial abstractions of reality, it is quite normal to work with more than one thinking pattern in parallel" (p. 23, author's translation). Indeed, insofar as scientific theories are generally based on partial observations related to a specific setting and time (Feyerabend 1988; Glaser and Strauss 1967; Kuhn 1970), it may be useful to be free from strict theoretical rules when our research is problem oriented. Purposeful and problem oriented research need not follow a certain theory and obey its methodological rules. Feyerabend (1988, p. 9) puts it clearly when he states that, "Science is an essentially anarchic enterprise: theoretical anarchism is more humanitarian and more likely to encourage progress than its law-and-order alternatives." A new discovery need not be based on an old discovery and procedure. Norgaard (1989) argues that a broad and less well-defined problem can only be pursued through multiple perspectives, overlapping analysis, discussion, and judgment. Partial analysis can be much more meaningful when displayed in a larger context, simply because processes of change and elements outside the reductionist model may be crucial in driving changes by deliberate actions. A larger context can provide insight concerning what issues have been overlooked and why and how a partial analysis might be changed. This is particularly important when considering positive and negative feedback, including policy as institutionalized feedback. The idea of being free from theoretical constraints does not mean that I should not use coevolutionary theory, but rather that I should use it creatively in relation to the problem under consideration, i.e., agricultural sustainability.

The discussion in this section leads to five conclusions that are relevant to the scientific background of this thesis. First, science has an evolutionary character that demands diversity and qualitative change if we wish humanity to progress. Second, modernism is destructive if it is not complemented by synthesis and studies of linkages. Cultural and ecological systems should direct modernism, and not the reverse. Third, various disciplines and worldviews perceive sustainability differently. This should both be encouraged, and also presented to groups other than scientists for discussion and debate. Pluralism should be the norm in science, particularly when examining complex social and ecological systems. Fourth, objective reality is not the norm in the social sciences, and the atomistic-mechanical worldview is not the only road to science and knowledge. Fifth, when searching for knowledge concerning sustainability, it is useful, at least upon occasion, to be free from disciplinary boundaries and methodological rules in theory building.

2.2. Economics and Sustainability

Three competing schools of economics, the neoclassical, institutional and Marxian, which emphasize the market, rules of the game and planning respectively, dominated the twentieth century, but no single one of these adequately explains the real world of economics. Elements of market institution, social/state regulation and planning can be found in most agricultural and industrial societies. For example, historical events have demonstrated that the market mechanism, whose dominance developed only after the industrial revolution of the eighteenth century (Polanyi 1957), can lead to unemployment and underproduction, cause serious fluctuations, degrade the environment, deplete natural resources, and increase economic inequality. On the other hand, the collapse of the centrally planned system of Eastern Europe shows that market mechanism should not be excluded. In both cases ideology must bend to reality.

Galbraith (1989) argues that the conflict between ideology and dynamically changing reality is the central dialectic of our time. He states that, “As capitalism is restrained by ideology from a greatly needed role for the state, so socialism, in a wonderfully symmetrical way, is kept by ideology from the useful, perhaps inevitable role of the market” (p. 9). The expansion of ecological problems to the global level, the globalization of capital, growing inequity in wealth and resource distribution, and the shrinking power of national governments to make vital economic, social and environmental decisions are some of the challenges facing economic theories that require pragmatic solutions. Fukuyama (1993) claims that the collapse of planned socialism ushered in the end of history, and that there are no longer any serious obstacles to the emergence of global capitalist system. This view can be viewed as an extreme version of modernity insofar as it affirms the progressive development of a “rational” economic system with minimal role, if any, for culture. Castells (1996-1998) argues, on the contrary, that a new world is presently taking shape due to the revolution in information technology, the economic crises of both capitalism and statism, and the flourishing of cultural social movements. These processes are generating a new social structure that is based on networking, a new economy that is based on informational technology and globalization, and a new culture that is based on virtuality.

Against this background, today’s contemporary ecological crisis can be viewed as a problem of property rights (Bromly 1997) insofar as environmental degradation and resource depletion will inevitably increase if there are no institutional arrangements that define property liabilities in addition to rights. Coase (1960) discusses how there is no difference from the point of view of economic efficiency in a situation of full information and no transaction costs whether the right to pollute is assigned to the polluter or the right to have a pollution free environment is assigned to the affected party since in either case they will negotiate an "optimal" solution concerning pollution levels and prices according to the costs and benefits entailed by the reduction of pollution. In reality no such situation exists, however, and most of the so-called external environmental problems involve many affected parties who are diversified both spatially and temporally. Indeed, Coase's other important work was on the existence of transaction costs that were often overlooked by conventional organization theory. Coase (1992, p. 717) clearly states that when transaction costs are positive, government intervention through price controls, regulations, or subsidies can lead to better results than relying on negotiations between individuals in the market. This reflects the fact that the political function is also a fundamental component of the social process in addition to the economy (Tool 1986). On the other hand, writers such as Randall (1987) and Baumol and Oates (1988) argue that if the polluter is held liable, then the imposed environmental costs would change the "optimal" production level. The principle that the polluter should pay, which is grounded on Pigou's argument that the producers should internalize external costs, is widely accepted today, but it is rarely fully implemented. Regulation is more exercised in policy intervention than by means of environmental taxes.

One of the most significant discussions of property rights originates with John Locke. Locke's notion of "natural right" stems from the idea that the one who first appropriates land through his labor comes to own it (Williams 1977). No rules and/or acceptance by others, no prior social arrangements, are required to confirm the right of ownership to property that one has been the first to seize and use. This idea of the natural right to private property has three important consequences in relation to environmental degradation and resource use. First, once someone has come to possess property, such as an area of land, he has the right to do whatever he wishes with it and to enjoy the stream of income that can be generated from it. Second, once someone begins using a common resource, such as the atmosphere, a river, a lake, or land not held as property, to dump unwanted by-products, he has the right to continue the practice. Third, if society wishes to prevent someone from exercising the above two rights, that person must be compensated for any loss of income that results.

Marx argues that the right to private property is in fact associated with class conflict, and that the institutionalization of property rights is enforced by the dominant class. He asserts that the working class will nationalize or socialize the means of production that are held as private property when they seize political power.

Kant made a distinction between two types of possession. The first is physical possession of an object, which means that I can take it with me wherever I go. The second is legal possession, which depends not on the actual physical appropriation of an object, but rather on the other's recognition of my possession on the basis of social arrangements (Williams 1977). Kant argues that property rights to an object require social recognition, which depends on the reasoning that it is good to let somebody own this or that resource. That is to say that a will or reason emerges on the basis of social institutions to sanction the right of private property in respect to what had been in a state of common group possession. This argument has four important consequences concerning environmental degradation and resource use. First, there is no natural right prior to the existence of social institutions. It is humans who create and allocate private ownership. Second, it is society who decides on the limits of property rights in terms of use, space, time, and relations to other resources. This is the case in respect to state, private, as well as common regimes. Third, reasoning is the basis for the establishment of definition of property rights. And since any given society is in a state of continuous change, what is reasonable today may well not be reasonable tomorrow. Fourth, compensation is neither required nor necessary if society changes the rules of the game, such as in respect to the reduction of pollution.

The differences between these three positions concerning property rights are obviously important in relation to the formulation and implementation of public policy regarding ecological degradation and resource use. Locke's view emphasizes compensation for enforced changes, Kant's idea supports the legal right of society to make necessary changes, while Marx' position leads to the socialization of all means of production. Kant's position clearly lends itself to a coevolutionary theory of interactive social and ecological systems in that it reflects the notion of a dynamically changing world. However, reasoning may result in a public policy that compensates private actors for regulatory measures not out of obligation, but for other socially important reasons. Reasoning can also lead to the sanctioning of societal or communal property rights, and to the regulation and management of prices and production. Reasoning, understood in a broad, contextual, and dynamic manner, should consequently be society's guide in the formulation of policies promoting sustainability that are not limited to specific measures.

Neoclassical economic theory asserts that private ownership and market economy provide optimal solutions for resource allocation and environmental degradation. And if market failure does occur, such as in the case of pollution, then government intervention can correct the failure through such policy measures as taxes. Today, however, most economies employ a combination of market mechanisms, regulation, and planning, and each of these approaches can play an important role in dealing with the challenging issue of sustainability. For example, most industrialized countries use agricultural policies, food price supports, and a long list of regulations that affect production methods even though the state of agricultural production, especially regarding farms numbers, would allow for a nearly optimal market model. On the other hand, the long-term scarcity of natural resources is not adequately expressed in prices. Although resources such as oil, lead, and zinc have a reserve/yearly consumption ratio of less than one hundred years, there are as yet no indications of price increases. In addition, ecological systems have no market prices.

Indeed, mainstream economics is facing increased pressure to better reflect reality, particularly in respect to the environment. Many authors have in fact criticized the mainstream economic perspective for excess abstraction, a departure from reality, and the neglect of important ecological and social issues (Georgescu-Roegen 1971; Galbraith 1972; Myrdal 1978; Boulding 1981; Tool 1986; Clark and Juma 1987; Sagoff 1988; Archibugi and Nijkamp 1989; Daly and Cobb 1989; Dietz et al. 1992; Norgaard 1994; Common 1995; Ayres 1998; Sen 1999). For example, Galbraith (1972) argues that the central assumptions in neoclassical economics, namely, the consumer is sovereign, the individual has ultimate power, and corporations maximize profit but do not influence the market and consumers, are simply incompatible with reality. Myrdal (1978) points out that institutional economists criticize neoclassical models for their departure from reality. He states that "when institutional economists are critical of the closed models of their conventional colleagues, this does not, of course, imply that we are hostile to models and theories. But we want the models and theories - conceived by us as logically integrated systems of questions directed to the empirical reality around us - to be more adequate to this reality" (p. 776). Concerns about agriculture and the environment have many dimensions. There are many issues that need serious consideration in addition to questions concerning the supply and demand of agricultural commodities, such as food quality, environmental damage, and resource depletion. Accepting the argument that many changes have non-monetary social impacts and deplete natural resources also underlines the need for a more realistic perspective in economics research, particularly in relation to the environment and to future development.

Sagoff (1988) argues that environmental policy should be based on ethical, aesthetic, cultural and historical considerations. It must then involve political debate, not merely economic analysis. Indeed, if we focus on economic analysis, we may in fact enforce its importance. Daly and Cobb (1989) propose an alternative view of economics that will serve the needs of the real world, particularly in relation to ecological limitations. They emphasize that market analysis must be conducted with the aim of both short and long-term service to the community. Tool (1986) rejects the positive-normative dichotomy and asserts that since the purpose of an economic enquiry is to contribute to problem solving, the mode of such enquiry must be value-laden. When we are faced with actual social and environmental problems, the necessary changes in modes of economic activity (institutional restraints and arrangements) must come through democratic processes and planning in which values and ideology are explicit among the involved researchers. Söderbaum (1999) argues in much the same way that the role of values and ideology must be made explicit in ecological economics since the latter resides on a value commitment to contribute to a sustainable type of development.

Georgescu-Roegen (1971), Boulding (1981) and Clark and Juma (1987) address the limitations of neoclassical economics in respect to long-term analysis, arguing for an evolutionary approach to understanding long-term changes that views the economy as an open subsystem of the ecological system. Boulding (1981) explains how energy, raw materials, and know-how are the real production factors, while capital and labor are only distribution factors. Norgaard (1985 and 1994) argues that a coevolutionary worldview, which views a system as evolving in response to two or more interacting species or subsystems, is more appropriate for understanding and generating insights concerning complex issues of development and environmental degradation than the atomistic-mechanical worldview of neoclassical economics. The limitations of the neoclassical model in dealing with long-term problems stem from the fact that ecosystems and energy problems are not adequately included, and that such vital parameters as technology and preferences are not stable in the real world. Daly (1992) and Dietz and van der Straaten (1992) emphasize the concept of carrying capacity. They maintain that the physical properties of the ecological system should be the basis for environmental policies. Ayres (1998) demonstrates that the technological development and economic growth in the Western world during the 1970s and the 1980s neither benefited the majority, nor compensated for the associated resource depletion, environmental degradation, and deteriorated social contract. He argues for an end to the growth paradigm.

Neoclassical cost-benefit analysis (CBA) also has serious limitations in respect to a consideration of sustainability. The need to manage environmental degradation and the depletion of natural resources is a common issue in both economics and sustainability studies. CBA maintains that environmental improvements are to be carried out as long as the associated marginal social benefit exceeds the marginal producer costs of doing so. Marginal social costs, which are the valuation of damages in monetary terms, rise as environmental degradation increases. Marginal producer costs, which are an aggregate of the costs for reducing environmental degradation incurred by all producers in a region/country, rise as the level of improvement increase. There is thus an "optimal" level of pollution in respect to prices/costs for a specific problem, in a specific society, at a specific time. Environmental costs can be included in the costs incurred by producers by means of taxes or other policy instruments so that they produce in accordance with their marginal production and environmental costs. Taxes thus provide an incentive to producers to reduce environmental degradation.

Addressing sustainability on the basis of the CBA model faces the following theoretical and practical problems:

1. The concept of sustainability is complex and involves numerous issues, many of which cannot be described in terms of externality or market failure. For example, the depletion of natural resources is supposed to be managed by market mechanisms as resources become scarce. There is presently no shortage of fossil fuels or phosphates that is expressed in rising prices, but we already know that there will be within this century and the next respectively if present trends in usage continue. In addition, the use of these and other natural resources cause environmental damage that is more easily seen as the degradation of the capacity for assimilation than as resource scarcity. Concerns about the depletion of biodiversity, the spread of toxic materials, the degradation of ecosystems, and improper animal treatment on aesthetic, economic, health, or moral grounds are

also complex issues that cannot be adequately addressed by CBA. If all sustainability issues were viewed within the context of resource scarcity, then sustainability would be related to preserving resources that are directly connected with economic activities, including land, energy, and minerals, as well as those that are indirectly connected through societal concerns, such as biodiversity depletion, ecological degradation, chemical spread, and unacceptable production methods. But these complexities call for a broader approach than what can be offered by CBA. Indeed, problems concerning resources and the environment have an interwoven character consisting of depletion, degradation, impact on health, and moral commitments.

2. The issue of substitution concerning natural and man-made resources, different natural resources, and different sources of a given natural resource is important in an examination of sustainability. The assumption that there is a high degree of substitution between resources may lead us to conclude that the basic characteristic of a sustainable system of production and consumption is that total capital should not decrease. Costanza and Daly (1990) argue, on the contrary, that the role of human made capital is basically complementary to natural resources, while many writers tend to accept the view we should emphasize the long-term protection of environmental capital (see Section 3.3). Substitution among natural resources can also be limited in many cases. Nitrogen cannot replace phosphorous, and machinery and other capital investments cannot replace land. In addition, replacing one source of a given natural resource with another source faces various problems related to decreasing quality and increasing inputs. And while technological development may increase the potential for substitutions, this is not without long-term limitations. The law of diminishing returns also limits resource substitution since it implies that more inputs, especially energy, are required per unit of output. This makes energy availability a crucial aspect of many substitution issues. Since our production systems are largely dependant on non-renewable resources, especially energy, we are thus bound to accept the limitations upon resource substitution and emphasize the protection of natural resources and the environment.

3. In order to resolve issues associated with sustainability, we must address many complex environmental and resource problems that have long-term effects. Not only does this involve a great deal of uncertainty, we have not yet agreed upon methods for converting future effects into present values. Land degradation, for example, reduces productivity as well as carbon deposits and biodiversity, all of which have long-term effects. Even with a discount rate as low as 3%, an environmental cost of one thousand crowns merely one century from now would have a present value of about only fifty crowns. This heavily downgrades the interests of future generations and calls into question the services that may be available from ecosystems (Norgaard and Howarth 1992). Certain damage may also be irreversible, such as biodiversity depletion, as well as unpredictable, such as climate warming. Complexity and uncertainty may, therefore, strongly justify taking precautions and guarding against the possibility of large future costs (Perrings 1991; Wiman 1991).

4. There is the problem of tradeoff between sustainability and increased production since each can provide benefits in welfare at the expense of the other. Maximizing welfare in terms of consumer and producer surpluses can be achieved by increasing production and consumption at steady or falling prices, but this can very well result in increased environmental degradation and resource depletion. Any additional production of a commodity has some ecological impact, even if only a small amount of resources are used. And although increasing production raises GNP, increasing environmental degradation decreases welfare. This contradiction can be anticipated when both food production and food demand continue to increase. But if a country has a stable or falling food demand and a protected market, such as is the case in Sweden and in the EU, then this contradiction can be reconciled. This contradiction is now generally evident in the developing countries whether or not their agricultural systems are protected since they face the dilemma of a growing food demand and environmental and resource degradation.

5. The social benefits that are incurred when various environmental problems are treated in an integrated fashion are of a different order that when each problem is treated separately since policies may either conflict with or reinforce each other in respect to different environmental issues (Drake 1994). Because of the difficulties associated with estimating the social costs of environmental degradation, it is more credible to provide an estimated cost range. However, the more problems we integrate, the less accurate our results will be in terms of estimates since the range of social benefits and costs become wider. When the notions of weak and strong sustainability are introduced, this range increases even further. In addition, because of the problems associated with estimating social costs in monetary terms by means of the contingent valuation method in respect to individual willingness to pay for reducing a problem, it is more reasonable to investigate preferences on collective issue in terms of the common budget. There are distinctive differences between, on the one hand, the willingness to collectively allocate resources for a social objective and, on the other, the willingness to pay privately, measured by the contingent valuation method, in order to meet the resource allocation for non-market goods. The former approach treats community members as citizens acting collectively in order to deal with common issues. It views society as a biological system in which the whole is greater than the sum of parts. The latter approach treats the members of the community as consumers acting individually in hypothetical markets and aggregates their willingness to pay for reducing environmental degradation to estimate social costs. Sagoff (1988) and Sen (1995) argue that environmental policies need to be addressed in respect to citizens' concerns and through political debate.

6. Certain problems concerning sustainability are global by nature, such as the mining of resources and climate warming, while others have a local or regional character that may acquire global significance because of scale, such as land degradation and water depletion. In both groups, however, there is a problem of scale that requires collective action (Daly 1989). Different regions may therefore face both similar as well as different problems concerning sustainability, which may or may not be perceived as problems by a given society or local community.

For example, increased food demand in developing countries tends to focus attention on the need to increase production rather than on environmental degradation. Even a problem like erosion, which affects agricultural production capacity, has been ignored in many areas around the world. Such is the case in industrialized countries, where economic pressure has forced farmers to overlook environmental degradation in spite of stable or even declining food demand. The driving force for sustainable development has to come from society at large. In this regard Opschoor and van der Straaten (1993) argue that labor, capital, and the state must work together to prevent damage to the environment.

Sustainability is a broadly defined concept that deals with interaction and complex processes. Such properties can be neither perceived, nor addressed solely by means of static cost-benefit analysis. The dynamic effect of environmental degradation stems from the fact that there is significant negative as well as positive feedback. The added fact that humanity is able to both counteract and reduce environmental degradation by means of numerous possible measures renders the cost-benefit model of little value if it is not located within a larger context that reveals processes and interactions as well.

But the principles of diminishing return along with supply and demand do accord with the evolutionary approach (Boulding 1981), such as when more effort is required to hunt a prey when its numbers are reduced. The cost-benefit logic can also be derived from the ecological-evolutionary model, particularly in respect to the various types of behavior in primate species that involve knowledge and learning. This becomes more evident if we replace the term cost-benefit with a synonymous term like effort-gain. It is common among hunter-gatherers to consider effort and gain when choosing the prey or plant they will use for food. Indeed, the evolution of human societies and the development of agriculture and industrialization were to a large extent driven by judgments concerning efforts and gains in respect to alternatives at individual and group levels. This still plays an important role in decision-making at individual, firm, societal, and global levels when taken together with collective rules, moral commitment, and psychological influences. Cost-benefit analysis thus has validity when understood in a broad sense in respect to decision-making and choice on the part of both individuals and groups.

Insofar as the neoclassical economic model emphasizes self-interest in decision-making, it transfers CBA to a high level of abstraction in a search for optimal positions and welfare maximization in terms of consumer and producer surpluses. The market model may be able to identify an optimal allocation of resources under ideal conditions, but it cannot identify optimal scale and income distribution (Daly 1992). Such a supposedly optimal position can in fact change overnight if another researcher performs a better analysis, or if the conditions taken as given in the analysis are changed. Ayres and Kneese (1989) argue that even if such an optimum does exist, current price structures do not reflect it, lead to an excessive use of natural resources, and reduce environmental services.

Carrying out environmental improvements to the level where marginal benefits are equal to marginal costs does not mean that we have established a sustainable system, but it may indicate feasible short-term levels of improvement. This equation of marginal benefits and costs may also be used to formulate policies that produce incentives for further long-term improvement. However, we face serious problems with finding this feasible level of improvement for each environmental problem. Not only is our ability to understand the complex effect of each such problem limited, much of the impact cannot be adequately measured in monetary terms. Furthermore, there are numerous interconnected problems. And even if we did manage to obtain accurate information on the social costs of every environmental and resource problem, and then succeeded in integrating that data into production costs, we would only be able to improve the situation in certain respects, not achieve sustainability. The most important factors and processes are those that move the level of "equilibrium" towards greater environmental conservation, such as a suitable value system, increased knowledge, better education, and increased income, which raises the social costs of environmental degradation. In addition, technological developments spurred on by regulation, public research, better information, and economic incentives may decrease the producer costs of environmental improvement. Since environmental degradation and resource depletion are related to the production and consumption of products and services, and since a given product or service is often related to a specific sector, it would also be important to address sustainability by focusing on the processes at work in the sectors that produce the products in question. This example certainly applies to agricultural production.

Five conclusions relevant to agricultural sustainability may be drawn from this discussion. First, economic theories are social constructs that cannot be universally verified. The market mechanism, economic incentives, institutional arrangements, regulation, planning, and control can all contribute to promoting sustainability. Second, the definition and framing of property rights and liabilities are essential institutional arrangements that must be based on reasoning. This makes them experimental and subject to change. Third, estimating costs and benefits is important for promoting sustainability, but it is far from sufficient. At least as important are those processes and factors that change both costs and benefits. Fourth, environmental and resource problems must be addressed by examining the processes of development in the sectors and industries that cause them. Fifth, agricultural sustainability must be addressed within the context of public concern, collective action, resource allocation, and political debate, not merely in respect to economic utility analysis.

2.3. Coevolutionary Paradigm

System thinking can address a system in either an atomistic-mechanical fashion, which takes parts and the relations between parts as constant and/or predictable over time, or in a holistic-evolutionary fashion, which views both parts and the relations between them as changing and non-predictable. The former is common in operations research and systems engineering, where the elements and the relations between them are expressed in mathematical terms. It views changes in the system and in the parts as reversible, predictable, and quantitative. The latter is common when investigating complex biological and social systems, where elements and the relations between them cannot be expressed in mathematical terms. It views changes in the system and in the parts as irreversible, non-predictable, and qualitative. Checkland (1981) develops the concept of "soft system thinking" to tackle "real-world" managerial problems in human activity systems. He states that a poorly structured and poorly defined problem cannot be expressed by mathematical relations, particularly in respect to complex interactions and conscious actions. The complexity of sustainability, which involves social and ecological systems at a number of different levels, requires that a holistic-evolutionary methodology be used in order to examine it.

The word coevolution in respect to ecology was coined by Ehrlich and Raven in 1964 in their work concerning the evolutionary influences that plants and the insects that feed on them have had on each other (Futuyma and Slatkin 1983). A restrictive meaning of the word, namely, pair-wise coevolution, implies that a trait of one species evolves, via mutation and selection, in relation to a trait in other species, which itself has evolved in response to the trait in the first. But many plants have evolved chemical defences against a range of insects, and many insects have acquired the ability to withstand toxicity from a wide range of plant chemicals. This is called diffuse coevolution. Coevolutionary reciprocal changes can be based on different relationships, such as competition, parasitic-host, mimic, symposium, and prey-predator.

The idea of coevolution was also familiar to Charles Darwin, who wrote that, "Thus I can understand how a flower and a bee might slowly become, either simultaneously or one after the other, modified and adapted in the most perfect manner to each other" (quoted in Futuyma and Slatkin 1983 p. 3). Evidence gathered from various studies of coevolutionary relations between species demonstrate that diffuse coevolution is much more important in nature than pair-wise mutual adaptation. Because such reciprocal changes involve many traits, many species, and a changing environment, the predictive power in coevolutionary theory is limited, being confined to certain features in pair-wise coevolution.

The concept of coevolution in respect to economics and the other social sciences was first used, to my knowledge, by Richard Norgaard in his theory that societies coevolve with ecological systems. The coevolutionary paradigm, which explains the development of a society in terms of coevolutionary processes that involve ecological systems, presents economic development as an adaptive response to environmental change while itself being a source of environmental change. This type of development allows for changes that are characterized by long-term suitability, and which have helped agricultural societies to survive for thousands of years. The industrialization of societies, which is based on the domination of the atomistic-mechanical view, weakened the coevolutionary processes that involve the surrounding ecological system. Nature came to be viewed as the provider of unlimited resources and the assimilator of an unlimited quantity of waste. Ecological limitations gradually shifted towards the global level, and societies become more complex and more dependent on other societies through the mechanism of exchange for resources and outputs. Most societies today consist of a number of sectors that provide various goods and services, such as agriculture, education, manufacturing, health, communications, transport, forestry, energy production, and waste management. Some of these sectors, such as agriculture and forestry, are in direct interaction with the surrounding ecological systems.

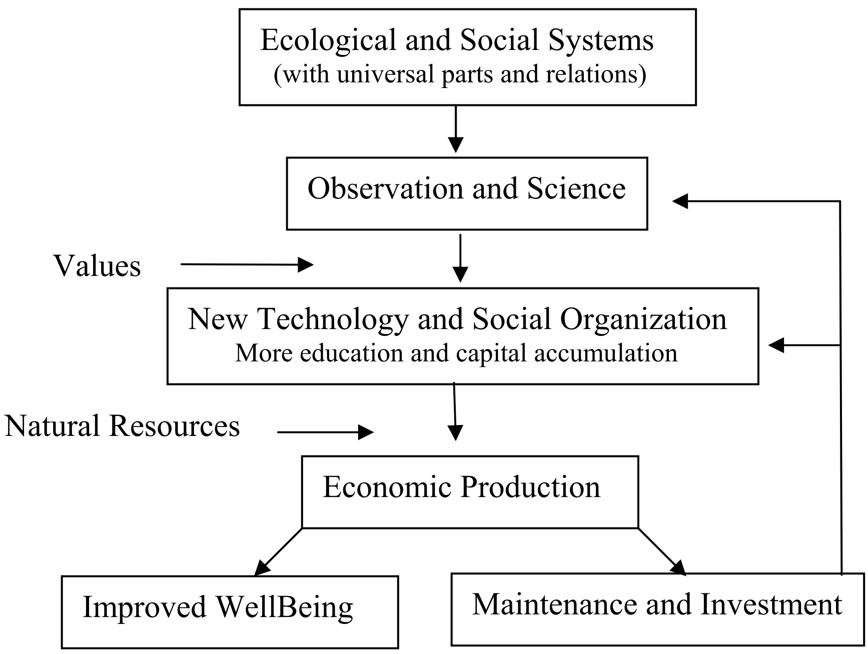
Norgaard's (1985; 1994) discussion is based on observations of how indigenous peoples developed their own technological and social systems. For example, people in the Amazon region developed a production system in coevolution with the ecological system that was based on multi-crop, slash-and-burn agriculture that was supplemented by fishing, gathering, and hunting. This system proved itself to be suitably adapted and sustainable. This idea that people develop their economic and social systems as adaptations to the surrounding ecological system is now widely recognized (Boyden 1993; Steiner and Nauser 1993; Hjort af Ornäs 1996; Holling et al. 1998). The variation among Polynesian island societies is associated with differences in economic structure, material products, social organization, and political organization. It is related to the way in which the natural environment provides the opportunity for subsistence production as well as intensified food production (Diamond 1998). Traditional subsistence societies, whether hunter-gatherers or agriculturalists, in general followed a path of development that was adapted to the natural environment.

Similarities between coevolution in the ecological and social systems are extensively discussed by Norgaard (1994). Species coevolving together in an ecological system affect and shape each other, and are affected by changes in physical factors, such as climate, through a number of traits that are controlled by the genetic code of DNA molecules. Traits mutate through imperfect DNA duplication and defects in certain individuals, some of which may help a species either to function better in its current niche, or expand it. A successful mutation changes the selective pressures on associated species and may lead to successful mutations in them as well, which in turn change the selective pressures on the first species. The numerous characteristics that we can find in any social system can be placed in four general interactive subsystems, namely, values, knowledge, organization, and technology. Each of these subsystems consists of numerous characteristics (traits), and it both affects and is affected by other subsystems, all of which interact with the ecological systems (Figure 2.2).

Changes in most of the characteristics of the social system in relation to the ecological system can be interpreted in much the same way as changes in traits between coevolving species. For example, if a new technology, such as a new crop or horse/fossil fuel-driven machine, is transferred into a traditional agricultural society, it may be rejected by the value system on various grounds, such as taste, taboo, and norms. Alternatively, it may be accepted by the value system but rejected by the ecological system if it is not suitable in respect to the soil structure, climate, or biotic relations. Its acceptance would bring new selective pressures to bear on other crops, the social organization, and the knowledge system, which may change in a way that increases the relative dominance of the crop and thus enforce further changes in the value system. Subsystems in the social system thus reflect each other as do subsystems in the ecological system. Myrdal (1999) discusses the possibility that a new technique may be rejected because it is unsuitable in respect to the prevailing technological complex. In our model of coevolution the adoption of a new technique is also determined by the ecological, organizational, knowledge, and value systems.

In modernism, development is a process of rational design in which modern atomistic-mechanical knowledge is employed to improve living standards with little consideration of any possible ecological and social damage. The modern understanding of the relationships between development and the ecological and social systems has focused on the role of science and technology in discovering and organizing the use of resources for improved and expanded production. It views the ecological system as a provider of natural resources rather than as a complex system that is transformed by development. Similarly, the social system is viewed as a provider of labor and capital rather than a complex system that is transformed by development not only in respect to the production system, but also in respect to culture and values.

Figure 2.1 A modern view of the process of development



Source: Based on Norgaard (1994)

Figure 2.1 illustrates this view of development, in which advances in science, education, investment of surplus, scientifically-based technology, and social organization complement each other and give rise to a higher standard of living. The ecological and social systems are outside, and unaffected by, the development process, although they provide the data needed for scientific advances and the resources needed for economic production. This view allows for no consideration of the ecological system as comprising complex physical and biological systems that, to a large extent, cannot be expanded and predicted (Futuyma and Slatkin 1983; Wiman 1991; Daly 1992). It also places culture and values in the background and outside the development process, unlike the case in post-modernity.

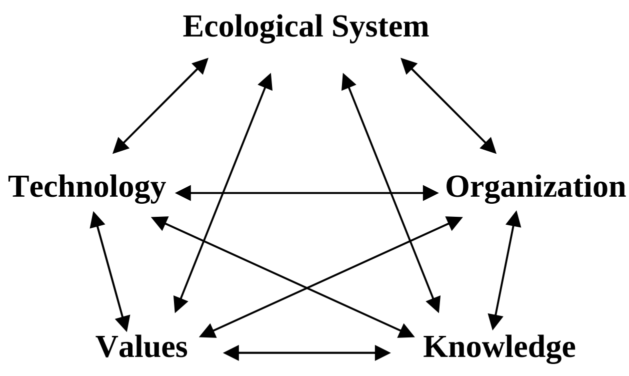
The model in Figure 2.1 is consistent with both the neoclassical and Marxian views of development since both consider development as rational design based on an understanding natural and societal "laws." Neither neoclassical, nor Marxian economic theories take nature as the starting point since both emphasize labor and capital in production processes (Dietz and van der Straaten 1992). During the twentieth century dogmatic neoclassical theorists asserted that social organization and economic production should be organized around private property rights and the market, while dogmatic Marxians assert that they should be organized around social property rights and a planned economy.

This model is primarily associated with the era of industrialization and the dominance of modernism. The view it represents was responsible for tremendous economic achievements during the twentieth century, but at significant ecological and social costs because it excluded the environment and culture from the development process. For example, food production doubled twice, accompanied by serious ecological degradation and resource depletion, but there are still food deficits in many countries and a decline in cultural and biological diversity. In addition, the model is of limited usefulness in explaining the development of traditional agriculture throughout the world, along with its success in supporting an eight-fold doubling of world population prior to the twentieth century.

The paradigm of coevolution presents development as consisting of interactive changes involving social and ecological systems. In this respect, our history can be interpreted as comprising continuous change in the traits of social and ecological systems (Figure 2.2). The former consists of the value, knowledge, organizational, technological sub-systems. A character or trait in any of these systems and sub-systems develops in relation to traits in other systems and sub-systems. An example worth noting is the development of diverse irrigation systems in relation to the ecological system and to the knowledge, value, and organizational systems of a given society. In the coevolutionary view of development, all of these systems are interactive elements of the development process.

A more specific case that can be adequately explained by coevolutionary theory is the story of pesticides development as interaction between pests, pesticides, and policy. Norgaard's (1994) discussion of pesticide use in the United States as consisting of coevolutionary processes can be applied to most industrialized countries and even to some developing countries as well. He begins by observing that prior to World War II inorganic compounds such as arsenic, lead, and sulfur were used to control insects and other pests. However, organic pesticides like DDT and PCB took over the market after the War because of their greater effectiveness. But pests gradually developed resistance to these organic chemicals, which resulted in the need to apply greater quantities. The few insects that survived the application of DDT, for example, were the individuals who were the most resistant to this agent, and when these individuals reproduced, which could be several times yearly, a high proportion of their offspring carried the genetic trait for resistance. This led to increasing biocide use and thus the cost of pest control. Organic pesticides also caused other problems, associated in particular with their toxicity to humans, their general effects on insects and birds, and their accumulation in food and feed. During the 1960s a new environmental consciousness emerged that eventually led to increased regulation and legislative control concerning chemicals. The subsequent ban on DDT and PCB during the 1970s opened the door to stricter regulation of new biocides and of biocide use in general. Although industry responded to these events by producing new chemical agents, not only did new problems continuously emerge, development costs also steadily increased due to the stricter regulations. Biocide resistance problems thus brought both direct and indirect pressure to bear on researchers, who were forced to address the issue in terms broader than the mere effect of a biocide on its target. Two new lines of research in the knowledge system eventually emerged in relation to pest resistance and changes in value system, namely, biological control and integrated pest management. In general, the future development of biocides cannot be predicted.

Figure 2.2 The coevolutionary process



Sources: Based on Norgaard (1994)

Coevolutionary processes are evident in the agricultural systems of both developing and industrialized countries through the adoption of suitable technological and institutional changes. Changes took place during the pre-industrial period within a more closed socio-ecological system. This led to the survival of changes that were adapted to the particular conditions and to the knowledge accumulated over generations that was based on long-term interactions involving the environment and the resource base. Techniques, methods, and crop varieties that were characterized by long-term suitability were thus adopted. In contrast, modern agriculture emerged in relation to the domination of atomistic-mechanical science, rapid population growth, globalization, and comercialization. This gave rise to a more open socio-ecological system that involves a great many accumulated changes that have been adopted over a relatively short period of time with scant consideration of their long-term impact on the environment, the resource base, and society. Nevertheless, the influence of historical development and physical environment can still be seen in modern agricultural systems in spite of industrialization and market expansion (Grigg 1974). We now know that modern industrial agriculture raises many problems in respect to sustainability, some of which have already begun to have a negative impact on the present generation.

A reference to Norgaard (1994, p. 36) summarizes the above points:

"The modern explanation of history links development to control over nature and to environmental interventions which necessarily reduce the 'naturalness' of the environment. The coevolutionary explanation recognizes that many aspects of environmental systems are the result of human intervention over millennia. It emphasizes how nature is social by incorporating how people have put selective pressure on the biosphere. Similarly, it emphasizes how societies are natural."

In recent decades certain biologists and ecologists have begun to emphasize the interaction that involves human and natural systems. Up to the 1970s it was widely believed that the fact of the coexistence of a large number of species meant that they are locked together into a robust ecosystem, nature benign, on the basis of their food web and life cycles (Wilson 1989; Wiman 1991). This diversity-stability theory has gradually given way to a stability-diversity theory that asserts that a fragile structure of species is built up when the environment remains stable for long period. Holling et al. (2001) argue that such ecological complexity gradually emerges through continuous adaptive cycles which occur on various hierarchical and temporal scales, and that this is valid even for systems at the boundary of human-nature interaction. Boyden (1993), Steiner (1993), and Meppem and Bourke (1999) also argue that biological and cultural processes reciprocally impact each other. The coevolutionary paradigm maintains that ecological systems determine the suitability of societies' values, ways of knowing, types of technologies, and organizational forms. At the same time, however, our conscious and unconscious choices of values, knowledge, technologies, and social organizations determine the suitability of the characteristics of evolving ecological systems. For both systems, mutations and alternative characteristics are essential to coevolutionary processes and sustainable development.

Six lessons can be drawn from the paradigm of coevolution.

1. History provides important knowledge concerning sustainability in general and sustainable agriculture in particular. The sustainable system of traditional agriculture provides important lessons for future development. The story of pesticide use teaches us important lessons for the as yet unwritten history of genetically modified crops.
2. It is not possible to predict what future social and ecological systems will be, and we should drop the idea of social and ecological engineering. This, of course, does not mean that we should not discuss the future and influence its development.
3. Experimentation and the careful study of possible consequences must guide our choice of action concerning larger scale implementations. Large-scale experiments that lead to long-term commitments and consequences, such as nuclear power, and to possible large-scale irreversible damage, such as genetically engineered crops, should be avoided.
4. If we cannot predict the future, then pluralism and diversity in thinking, organizing and producing are essential.
5. Keeping the local/regional constraints that arise within ecological systems visible and real is a likely pre-condition for achieving real development, particularly in respect to sustainable agriculture.
6. Modern values, knowledge, organization, and technologies have emerged in coevolution with fossil fuel usage rather than with ecological systems.

2.4. Addressing Agricultural Sustainability through Coevolutionary Theory

Sustainability is essentially a global issue that emerged from concerns about the problems now facing humanity as a result of increased ecological degradation caused by the accumulated effects of increased economic activities in the absence of any significant physical constraints. Such problems can only be alleviated in direct relation to the economic units that generate them, whether it be the individual farmer who clears forest or consumes non-renewable resources, or the multinational corporations that transfer production, pollution, and resource depletion throughout the world in search of higher returns. Consumers who seek an ever-higher material standard are also active partners in the destruction of the environment that threatens both present and future generations. While certain improvements are now being made on local and national levels by concerned citizens acting through the political process, these are limited in their effectiveness not only by various economic factors and structures, but also by their reductionist nature that arises from the domination of the modern model of development. A significant problem is that there are no adequate institutional arrangements to protect the global common space, even though there is open access to it. Certain institutions do presently exist, such as the United Nations Environmental Program and a number of non-governmental organizations, but their mandates are very weak. In addition, they engage in little interaction with people, policies, values, and consumption, and they are unable to effectively enforce constraints on economic activities.

Our world consists of many different nations, each with its own diverse economic sectors. Each sector may include many coevolving economic units that develop both in relation to other sectors in a given society, and in relation to similar units and sectors in other societies. The paradigm of coevolution discussed in Section 2.3 hopefully provided an adequate explanation of the development of local agricultural communities in relation to ecological systems, and of aspects of modern industrial society, including biocide usage and coevolution involving fossil fuels. However, coevolutionary theory and methodology has yet to address the large gap that exists between, on the one hand, the small community that coevolves with the immediate ecological system and, on the other, modern states with their diverse and complex social and economic organizations. For example, increased agricultural surpluses rendered agricultural development more complex, and growing specialization made labor available for other sectors. The development of the growing non-agricultural sectors, along with the integration of agriculture into a larger socioeconomic system, was further intensified during the period of industrialization. It is thus reasonable to view society as consisting of coevolving sectors, among which agriculture is the most important in respect to the long-term survival of the society in question.

Cities and towns, some of which have existed for thousands of years, coevolved with agriculture. The Sumerian-Acadian city states provide excellent examples of how cities can survive for millennia if they succeed in keeping their agricultural systems suitably adapted to the surrounding ecological systems, which are largely shaped by interaction involving agriculture and the urban centers. For example, the city not only provided the specialists needed for producing various agricultural inputs and processing agricultural products, but also shaped a social system shared by both city and agriculture that consisted of the sub-systems of values, knowledge, technology, and organizations. Moreover, the driving forces of agricultural development eventually became urban-based in many areas. Agricultural sustainability can thus be addressed within a framework of coevolutionary processes that include the agricultural, the socioeconomic, and the ecological systems (see Chapter 3).

The coevolutionary revisioning of societies as discursive communities is indeed a vision that cannot be designed and implemented under the current conditions of highly specialized communities that are dependant on each other as well as on national and global economies. Simply waiting for this vision to emerge after today's dominant social organizations collapse is probably not a wise option. Viewing agricultural development as coevolution may be the key for the emergence of such a vision since food and locality have historically been interconnected. In addition, the weakening of such connectedness in respect to agriculture can likely be reversed even in post-industrial societies much more easily than in any other sector.

Sustainability as a societal affair

Ecological and social problems associated with sustainability exist at many different levels, from the economic unit to the level of global interaction, and they vary in relation to the level in question. For example, what is perceived as sustainable at a given level may be quite different at a higher one. In addition, people in different societies face different challenges and have different aspirations, and such diversity cannot be compressed into a single objective. Environmental degradation is also problematic in respect to sustainability since we will never be able to fully understand its impact. In addition, a given community may perhaps not consider a particular issue to be an environmental problem since it has been transported to another system, or perhaps because it will clearly emerge only in relation to another issue and over time. And the question of the sustainable use of resources is likely more problematic and complex than environmental degradation. Such complexities led Common (1995) to state that there is no blueprint for sustainable systems that is waiting to be discovered, while Norgaard (1994) dismissed the possibility of defining sustainability in operational terms. This does not mean that we should abandon the concept of sustainability, but it does mean that we should abandon the notion of ascribing to it a detailed universal operational definition.

Section 2.2 discussed how the logic of cost and benefit, or effort and gain, is an important component in the coevolutionary processes involving the ecological and social systems. However, if we wish to estimate the value of the costs and benefits associated with reducing a particular environmental problem, then our estimates have to be related to a particular society at a certain time. For example, the costs and benefits of reducing nitrogen leaching cannot be the same in both Sweden and Tanzania, or in Sweden today compared with the situation some decades ago. We should not expect that people struggling to overcome undernourishment will focus their attention on climate warming and biodiversity as they decide to produce more food. Indeed, Common (1995) demonstrates that the alleviation of poverty is a basic component of sustainability. Moreover, insofar as sustainability has ecological, social, and economic dimensions, it is inevitably contextual while the essential issues change over time and differ widely between nations and communities.

The diversity of societal and ecological systems indicates that sustainability can only be broadly defined, although it should include as much substance as possible. It must be noted that even problems that exist on the global level, such as climate warming and fossil fuels depletion, can only be effectively addressed today on the national level through processes that involve policies, producers, values, knowledge, consumers, and citizens, which remain the mechanisms driving development. It is thus useful to address sustainability at the national level while incorporating issues from the global level.

Focusing on the sector level

Instead of emphasizing human welfare in terms of gross national income, it is more appropriate to focus on what people have reason to appreciate, such as health, education, social security, environmental conditions, and material standards (Sen 1999). Similarly, instead of addressing sustainability through cost-benefit analyses concerning environmental and resource problems, it may be more useful to study sustainability directly and to focus on related issues, including those affecting the costs and benefits of changes and improvement. Georgescu-Roegen's paradigm of economics (1971), which is based on the law of increasing entropy and not mechanics, on which standard economics is based, invites us to focus on the biophysical properties of resources instead of their mere economic value. For example, Section 2.2 observed that there is a multitude of sustainability problems that need to be addressed in relation both to the economic units that produce them and to the processes that might be able to alleviate them. An economic unit often operates in interaction with similar units, which taken together are organized as a sector. Each society consists of a number of such sectors that coevolve with each other, and each sector produces a set of environmental and resource problems that can be addressed in relation to the processes of development at work in the sector. Examining environmental degradation and resource depletion in relation to the industries and sectors involved in these problems can thus be just as useful as studying each problem separately insofar as this would focus on how it is produced, the demand for associated products, and the process of change in the sector in question.

A model of long-term evolution in economics may follow the general principles of biological and cultural evolution, viewing knowledge, energy, and natural resources as the most significant production factors (Boulding 1981). If we take into consideration environmental degradation as an output in any sector, along with the value system as the basis for both sustainability and non-sustainability, five issues emerge that must be addressed in respect to sustainability. First, any given sector coevolves with the socioeconomic and ecological systems and responds both directly and indirectly to the various selective pressures that arise within these systems. Second, a sector can be viewed as a species interacting with the larger socioeconomic and ecological systems in light of the increasing power of central governments and growth the various sectors themselves. Third, each sector consists of units that both compete and cooperate with units within a given society and with other units in other societies. Fourth, the "mutation" and "selection" of technology and institutions become the basis for sector development when changes in sectors, including the agricultural system, are viewed in terms of coevolution,. Fifth, since there are neither operational, nor universal definitions of sustainability in respect to any given sector, we must ask why we perceive a sector to be unsustainable. We can then attempt to reduce non-sustainability by influencing the processes of development within the sector.

The role of developmental processes

The development of any sector is associated with various interactions involving the larger socioeconomic system as well as various elements within and outside the system, and the level of complexity makes it clear that we can make no precise predictions. In addition, we can only influence sector development without knowing the exact consequences. More importantly, we must understand how non-sustainability has arisen in a given sector, which is always associated with historical development, before we can act to reduce it. For example, understanding that the emergence of resistant bacteria is associated with coevolutionary processes involving medicine, policy, bacteria, science, and the value system can help us to realize the importance of reducing medical treatment instead of resorting to more sophisticated and expensive medicines.

The value system, institutional arrangements, and technological development are central issues in sector development and sustainability. They in fact can show the way to reduced load and stress on the environment, whether through lower consumption, alternative commodities and services, or lower energy and material use per unit of output. Historically these systems have been major factors in human expansion and consumption, and it is doubtful that we will be able to resolve our contemporary ecological crisis without their assistance. For example, the value system, which includes preferences, norms, attitudes, and ethics, is an important element of the socioeconomic system that is capable of influencing the development of both production and consumption. This occurs especially through product preferences, attitudes towards the environment, technological development, moral commitments to other species, other groups, and future generations, and even the choice of a way of knowing. What and how much to consume is an issue of values, not merely of prices.

The coevolutionary interpretation of development in social-ecological systems reveals that we influence the present system to adopt a new path of change in order to reduce what we perceive to be unsustainable. Sustainable development is a process of change that is based on the suitability of each specific change in respect to the long-term survival of the system. Process implies the operation of various forces in an interconnected and causal manner. Today this involves the globalization of commodity and input markets, which creates various linkages between the local, national, and global levels of production. Environmental degradation has become part of the global agenda, either because it is specifically global in character, such as climate warming and ozone depletion, or because it has become globalized by virtue of scale and public concerns, such as land degradation and the depletion of biodiversity. Even so, improvement must come about from national or societal processes influencing both production and consumption.

Principles and indicators of sustainability

It is generally accepted that indicators and targets should be closely related. If we cannot define our overall target with precision, and if we wish to address problems of non-sustainability in relation to the sectors that produce them, then our indicators must be connected in a meaningful way with the processes of change in the sector and with various factors or subsystems that affect sector development. Sustainability indicators are important for facilitating communication among various actors in order to implement changes that promote sustainability. The model of coevolution presented here is useful for identifying principles on the basis of the interconnected elements and subsystems which contribute in an important way to the process of change that are capable of reducing what we perceive to be unsustainable in a given system. They can also serve as long-term objectives in light of our present knowledge. Progress towards these objectives may require changes in many related systems, including demand, technology, and policy, as well as the integration of short-term analyses concerning the impact of relevant policies. How people and their political representatives perceive sustainability is an important issue, especially for short-term changes. Connecting the principles of long-term agricultural sustainability to the short-term interests of citizens and farmers requires indicators that are easy to measure and understand by both the involved actors and the general public. People often do not respond well to findings and facts that are abstract and cannot be easily understood and measured.

Studying the development of a sector can illuminate complexity, feedback effects, major elements (subsystems), and patterns of change. For example, the elements of the ecological system that are important for agriculture are those that affect present and future changes in agricultural production capacity, such as soil and climate conditions. The correspondingly important elements of the socioeconomic system are demand, prices, and regulations. Within the agricultural system itself we can identify a clear pattern of change in respect to production capacity that is related to the technologies employed and to resources. The paradigm of coevolution makes possible an interpretation of agricultural development that emphasizes the processes of change on the local level as they reflect interaction with a specific ecological system. It has limited power to predict changes since the latter can be understood only after the fact insofar as they result from interactions. Nevertheless, this paradigm does make it possible to discuss future development as dependent on choices supported by analyses of non-sustainability and of the conditions of sustainability insofar as a sector is governed by the larger socioeconomic system. Deriving principles and indicators of sustainability in respect to a given sector by understanding its historical development will contribute to its future coevolution insofar as they provide important information that facilitate discourse concerning how its level of sustainability can be improved.

The vision of coevolution

During the twentieth century socioeconomic systems in industrialized countries coevolved around modern technologies powered by fossil fuels. Signals and constraints involving the social and ecological systems have been steadily weakened. The fact that fossil fuels are non-renewable resources, that their use increases pollution, especially climate warming, and that there is yet no alternative adequate source of energy should lead to rethink the project of modernity, our technologies, and today's dominant social organization. From a coevolutionary perspective the most important option for dealing with our contemporary ecological and social crises is to reverse the historical weakening of coevolutionary interaction involving social and ecological systems at the local level. The vision is to build societies that coevolve with the surrounding ecological systems through discursive communities and to reduce distance connectedness by selecting appropriate technologies and social organizations. Today's growing awareness of the environmental consequences of modernity and the reawakening of cultural differences support this vision.

Local communities must accept greater responsibility and reduce economic and organizational linkages to distant organizations and ecological systems. Modernity has led to environmental and cultural destruction, and yet the vast majority of the world's population are still waiting for the prosperity that was promised. The model of modernity is based on the view that society is a sum of individuals who behave rationally according to their economic interests, and that science indicates which technologies are the best and which social organization is optimal. The coevolutionary understanding of history aims to provide a new vision that fully comprehends the significance of cultural differences and leads to a better awareness of the interactions between people and their environment.

Norgaard (1994, p. 174) writes that, "Coevolution is a process. Yet our understanding of process is intimately linked to our understanding of the possible. Thus one contribution of a coevolutionary explanation of development is that it facilitates a new image of how the future could unfold, opening our understanding to new and possible desirable future."

We thus have two images of the future. The first is a world of one single culture consisting of the best consumer products, individual "rational" behavior, and a global market economy that uses the "best" technologies and shifts mass production from one nation to another according to the logic of maximum profit. This is a world in which a few highly paid managers, opportunistic capitalists, politicians, and bureaucrats make the best decisions on behalf of the rest of the world's population. This is also a world of increasing insecurity and continuing ecological degradation, with ever fewer ecological systems and declining biological diversity. The second is a world of many cultures coevolving with their ecological systems and with each other not on the basis of competition, but on the basis of cooperation. This is a world in which people participate in building their societies in coevolution with the ecological systems. They attain real development for the benefit of the society as a whole, not merely for the benefit of strong nations and global corporations who exploit both peoples and ecological systems.

How the future will unfold depends on choices made by the present generation throughout the world. Ever more people are becoming aware of today's ecological and social crises, and many of them have begun acting, through networking, to create a new social structure and a new world order that is not based on dominance, unfair competition, and homogenization. Humanity's ecological and social problems are global, but solutions must come from local communities, households, and economic units around the world. This is evident from much work that has been done in the last decade that supports the role of local knowledge, values, and social institutions in successful environmental and development policies (Hjort af Ornäs 1996), that calls for local action to reduce environmental stress (Agenda 21), and that argues for locally-based development in which humans are more than just consumers and production factors and nature is more than natural resources (Berry 2001). The vision of local interaction and interconnectedness is thus not unrealistic. As Aristotle wrote, "Not even god can change history, but the future is ours to make" (quoted in Sen 1995).

A model of agriculture coevolving with socioeconomic and ecological systems

The coevolutionary model of development discussed above provides a broad framework for understanding sustainable society and sustainable sectors with a society. Although it provides an important perception of sustainability, it is not sufficient by itself to promote sustainability in a given sector since each sector has its own specific elements or traits concerning the ecological, technological, organizational, knowledge, and value systems. Understanding and promoting sustainability thus requires that we construct a model based on Figure 2.2 that is specific to each sector in question. Such a model must also provide knowledge concerning the type of sustainability principles one should seek and how to include the various relevant factors. Both short and long-term processes affecting technological development, values, energy, and resource utilization must be addressed.

Analogous to the evolution of one species by means of mutation and selection in response to another species that itself evolved in response to the first, agricultural development can be understood in relation to interactions involving the surrounding ecological system. And as a given species may coevolve with more than one other species at the same time in a more complex relation, agricultural development can also be understood in relation to interactions that involve the socioeconomic system as well. Few mutations are useful to the survival of a species, while the rest disappear through natural selection. This is also the case in respect to the historical development of agriculture, in which most of the experiments carried out by agriculturalists, both intentional and accidental, have proven to be unsuitable in respect to the ecological and socioeconomic systems. This coevolution is based on cultural adaptation in terms of trial and error, in which efforts and gains are observed in both the short and long-term, in order to meet increased food demand. At times this development not only increased food production, but also expanded the ecological system and increased its complexity by producing more biomass energy through knowledge application. At others, particularly in forest-dominated areas, the ecological system was reduced although food production was increased. At all times, however, methods were selected as suitable in respect to the integration, albeit partial, of the ecological system (see Chapter 3 below).

Viewing agricultural development as an adaptive response to ecological and societal change, while itself being a source of ecological and societal changes, implies that in addressing agricultural sustainability we need to understand these coevolutionary processes. Constructing a model of agricultural sustainability will not only assist us in understanding the issue, but may also provide guidelines that will serve to promote sustainable development.

3. The Coevolution of Agricultural, Ecological and Socioeconomic Systems

Unlike the conventional atomistic-mechanical approach that explains development by emphasizing the role of "modern" science and "rational" decision-making and behavior, the coevolutionary approach views agricultural development as resulting from interacting processes that involve the agricultural, social, and ecological systems as well (Norgaard 1994; Chapter 2 above). The nature of the subsystems, the systems themselves, and the relations between them all change over time as they coevolve with each other. This type of thinking, which has its roots in the biological principles of mutation and selection, can be applied to agricultural societies and agro-ecological systems throughout the world.

Chapter 2 discussed four issues of importance for promoting sustainability. These are: 1) A society or community's perception of what sustainability means and of the processes that may be used to improve the situation are what is important, not supposedly universal properties of sustainability. 2) In order to address what is unsustainable in a given society, it is necessary to examine the issue in respect to the various sectors that form that society along with the important linkages between them. 3) It is essential to understand the processes of development in the various sectors of society so that they can be used to promote sustainable development. 4) The principles and indicators of sustainability in each sector must reflect the complexity of the situation in question as well as the processes at work. They must also be easy to understand and to use by both the main actors and the general public.

Section 3.1 presents a coevolutionary view of the history of agricultural development and of environmental degradation. An explanation is put forward for how coevolution involving agricultural communities and the local ecological systems has been largely transformed into coevolution involving the agricultural, socioeconomic, and ecological systems. Issues that are important in respect to present and future development are emphasized. Section 3.2 constructs a coevolutionary model describing how processes and changes within the agricultural system comprise responses to various ecological problems and changes within the socioeconomic system. This will be of assistance not only in identifying principles of agricultural sustainability, but also in understanding major elements and processes in respect to short and long-term changes. Section 3.3 analyzes issues of relevance to a system of sustainable agriculture and outlines the dimensions in which the principles of such system can be located. Section 3.4 summarizes and concludes the chapter.

3.1. Agricultural Development and Environmental History

Life on Earth has been evolving for some 4 billion years. Climatic, biotopic, and geological changes, including volcanoes and meteorite impacts, have shaped ecological systems throughout the history of the Earth. Some of the changes they brought about altered the course of evolution and opened the road for the eventual emergence of Homo Sapiens. Our evolutionary divergence from chimpanzees took place in relation to the appearance of hominids about five million years ago, Homo Erectus about two million years ago, and finally Homo Sapiens about two hundred thousand years ago (Sjöberg 1997). Our dominate traits of upright posture and increased brain size slowly emerged during this long period of time, in which we successfully competed against our near relatives and also changed and were changed by ecological systems. As our hunting and gathering techniques became more sophisticated through the use of cultural instruments, including both technical implements as well as such institutions as language, group protection, and knowledge, our species spread throughout the world and was able to survive in ecological systems that differed substantially from those in which we initially evolved.

As hunter-gatherers, our numbers were under the constraints imposed by the ecological system, as was the case with all other animals. As we gradually became able to eat a wider range of fruits, seeds, and animals, knowledge about food became an important conscious element in our survival. Tools and organizational development made hunting and gathering more effective and increased the quantity of food available to us, some of which occurred at the expense of other species. Nevertheless, our food intake remained limited by what the environment could provide on a steady basis and by the perception of whether we were degrading that environment. The eventual development of agriculture expanded the limits of ecological systems because of the deliberate changes it introduced into them. For example, by protecting certain plants and animals and encouraging them to grow at the expense of others, we not only increased the quantity of food that could be taken from the environment, but also placed it at our disposal in a more regular fashion. Such activities encouraged further learning about how to increase production, and they both permitted as well as demanded settlement. This in turn made it possible both to accumulate more knowledge, and to increase production further by means of grain cultivation and feed management. Emanuelsson (1997) has estimated that a square kilometer of land in Sweden may have supported one hunter-gatherer and twenty primitive farmers, but two hundred persons using the advanced traditional agriculture of the late nineteenth century.

Humans ceased to be wandering hunter-gatherers in various parts of the Near East around 7,000 BC, becoming farmers attached to small plots of land who also domesticated sheep and cattle. This provided them with a regular supply of food (Reilly 1980; Roux 1992; Diamond 1998). The subsequent need to care for and protect both land and animals led to the building of houses, the development of implements for carrying out the new tasks that had to be performed, and increased social cooperation. Excavations in Shanidar cave in Iraqi Kurdistan reveal that it was inhabited by Neanderthal hunter-gatherers (60,000-35,000 BC), Homo Sapiens hunter-gatherers with a broader diet as well as improved and diversified stone implements (35,000-25,000 BC), and by people in transition to agriculture who had domesticated animals and improved stone tools for killing and cutting animals and for storing and grinding wild grains (around 9,000 BC) (Roux 1992). Women probably triggered the agricultural revolution when they realized that wild grain would produce a better return if it was cultivated rather than merely gathered (Reilly 1980). This discovery was built upon centuries of experimentation involving different areas, methods, and times of the year, but the results eventually became obvious: more food was made available to people through manipulating the ecological system. Wheat, barley, peas, sheep, and goats were the first plants and animals to be domesticated. Farming then spread from the Fertile Crescent to the Balkans, the Indus valley, and Egypt around 6,000 BC, and to Northern Europe around 4,000 BC (Diamond 1997). Sjöberg (1997) argues that agriculture spread into Europe during this period primarily through the movements of peoples, not through the transfer of ideas. However, farming arose throughout the world both independently, such as in China, where rice and pigs were domesticated, and in the Andes of South America, where potatoes and llama were domesticated, and through the transfer of ideas, such as in the Sahel region of Africa, where sorghum and guinea fowl were domesticated (Diamond 1998).

The rise of farming in the Fertile Crescent, as well as in other areas around the world, was associated with the presence of wild plants and animals that were suitable for domestication. Stated otherwise, the type of farming adopted has to be suited to the ecological system. The idea that agricultural communities shape ecological systems, and that the latter shape the people in the communities involved, is now widely accepted (Norgaard 1994; Diamond 1998; Fernandez-Armesto 2001). For example, Fernandez-Armesto (2001) argues that civilization is the relationship that people establish with their ecological systems. He states that "to understand man properly, you have to see him in the context of the rest of nature. We cannot get out of the ecosystem which we are linked to, the 'chain of being', which binds us to all the other biota" (p. 7). Subsistence agricultural communities follow a path of development that is adapted to the surrounding ecological systems. Their values, knowledge, organizations, institutions, and technologies are shaped by the ecological systems, which are in turn shaped by these communities.

The development of early villages and towns was connected with the use of specialized implements and institutional arrangements that supported agricultural production and development. Larger and more technically advanced irrigation-based agricultural settlements flourished for relatively long periods of time in Mesopotamia south of the Zagros foot hills, where early-rain based agricultural villages existed. These include the Sammarra period (6,000-5,000 BC) and the Ubaid period (5,000-3,750 BC) (Roux 1992). The Ubaid culture, which was characterized by an improved ability to control water for irrigation, greater sophistication in such agricultural implements as sickles and in pottery, and the establishment of a social organization around temples and religious beliefs, dominated southern Mesopotamia. The region also began to experience a drier climate during this period. Draining marshes and building irrigation canals opened the way for large-scale agriculture and for the emergence of the Sumerian civilization around such city states as Erido, Ur, and Uruk. Writing, too, developed towards the end of the 4th millennium (Roux 1992).

An important feature of this slow development is the change from coevolution involving simple farming and the immediate ecological system to a more complex evolution of agriculture in association with the larger ecological system and a growing socioeconomic system. Growing farm surpluses made agriculture development more complex, and while there were consequently more people not involved in food production, they nevertheless influenced food production in various ways. This latter development, which was radically enhanced during the industrial revolution, is common in agricultural societies.

In order to deal with limited precipitation, periods of unfavorable flooding, and variations in the Tigris and Euphrates rivers, complex irrigation systems were built and maintained. The scope of this task required assembling large labor forces from the countryside and the city. This interdependence was heightened by the eventual production of items that required raw materials supplied by agriculture, such as textiles and leather goods. Many city states ceased to exist when the nearby land became unsuitable for continued cultivation because of salinization or changing river course. During the third millennium BC agriculture thus became increasingly dependent on the associated city state, which in turn promoted various adaptations to ecological systems as well as changes in these systems themselves. For example, date palm cultivation spread extensively because of favorable conditions. A rotation system involving fallow and crops was adopted to maintain soil fertility and reduce salt concentrations, and it also supported grazing. Barley was also increasingly used because of its tolerant to salt concentrations. Such adaptations lasted for more than 4,000 years, and they not only provided societies with stable supplies of staple foods, but also supplied the raw material needed for building and for the production of sweets, beer, clothing, and furniture. Around 1,700 BC, however, the Babylonian state lost large areas of agricultural land to rebellion and to rival cities. In order to restore needed levels of grain production, landowners apparently abandoned the practice of rotating crops and fallow. This reduced soil fertility, accelerating salinization, and brought about ecological disaster, which was followed by economic and political collapse (Roux 1992).

Agriculture developed in Sweden in relation to local ecological conditions and, eventually, to the emergence of towns and cities and the rise of state power (Larsson et al. 1997). Regional variations in climate, topography, and soil quality have influenced the extent and type of cultivation in the various regions of the country since the introduction of slash and burn agriculture and animal husbandry some 5,000 years ago. The rise of a strong state and an effective central administration under the reign of Gustav Vasa in the sixteenth century promoted the rapid expansion and technical development of agriculture, which in turn increased the power of the state insofar as it led to growth in both the population and the tax base. A number of documents illustrate how Gustav Vasa was directly involved in promoting an increase in agricultural production by advocating the cultivation of new lands, the clearing of meadows and forests, and the ditching of agricultural land (Myrdal 2000, p. 217). As has been the case in most agricultural regions of the world, including ancient Mesopotamia, the connection between land cultivation and animal husbandry on the basis of nutrients and feed was realized early in the history of Swedish agriculture, and it was effectively used not only to increase and improve food production, but also to maintain soil productivity. This connection was strengthened by a thousand years of technical improvements that proceeded with varying degrees of scale, pace, and continuity. Although modern industrial agriculture has weakened this relation by importing nutrients for plant cultivation and feed for animal production from other regions, Swedish agriculture still combines crop and animal production to some extent.

The impact of agriculture on the ecological system has been most substantial, upon occasion even being destructive. Negative effects were reduced through short and long-term trial and error, but when the environment was indeed destroyed, people simply left the affected area. Nature then took over once again and usually repaired the damage over a certain period of time. Important elements in the method of trial and error that has driven agricultural development include effects on the resource base and the ecological system, efforts undertaken at the levels of farm and society, improvements in the quantity and quality of food, along with constraints and incentives arising from the systems of values, knowledge, and organization. For example, a new method, technique, or crop can only be adopted if it is suitable both in respect to society's values, institutions, and knowledge, and the surrounding ecological system. Moreover, its initial adoption puts into motion a series of changes within these interrelated subsystems that determine the degree to which it continues to be used in the long run. This type of development may be viewed in terms of suitable mutations that respond not only to farmers' short-term interests, but also to the ecological and social systems. The fact that agriculture has survived in most regions of the world for thousands of years implies that people learned agricultural practices that led to long-term increases in production as they protected the resource base and adapted to the conditions imposed by the ecological system. It also implies that the ways in which nature was modified into agro-ecological systems were appropriate to systems of production and culture.

The scale of human impact on ecological systems has increased dramatically in recent centuries. For example, Worster (1988) views two events in the history of human exploration, Columbus' discovery of the "New World" and the development of space travel in the 1960s, as in fact marking a distinct phase in environmental history. During this period two major forces underlay environmental change, namely, the explosive growth in European population followed by waves of emigration, and the rise of the modern capitalist economy, including its evolution into industrialism and its spread to the rest of the world. The demographic expansion of European colonization was indeed related to the take over of the environment by human beings and by animals closely associated with human beings, weeds, and micro-organisms that cause diseases in humans and animals (Crosby 1988). But in addition to various social, economic and ecological destructions, the processes of colonization and globalization have also created opportunities for the rapid spread of technology and for joint action to solve global problems. And although population growth and industrialization continue to degrade the environment, new forces have emerged since the 1960s that work to counteract their effects, such as environmental concerns, a clearer awareness that we all live together in one world, and an interest in global solidarity and justice. The growing interest in sustainable development may also be associated with such forces.

With the rise of industrialization and the domination of the atomistic-mechanical way of knowing, modern states have increasingly focused on development in order to raise the material standard of living. Such development has generally been discussed in the literature in terms of economic development, which is often linked to per capita income. The modern model of development illustrated in Figure 2.1 represents this type of view. Meier (1970), who provides a comprehensive selection of materials and commentary concerning a host of related issues, views development as “the attainment of a number of ideals of modernization, such as a rise in productivity, social and economic equalization, modern knowledge, improved institutions and attitudes, and a rationally coordinated system of policy measures ” (p. 6). We now know that this model has many empirical, cultural, and ecological shortcomings (Section 2.2).

A substantial percentage of development studies endeavor to identify the factors and forces that trigger development in various regions and periods. For example, Boserup (1981) emphasizes population growth and urbanization as driving forces behind development and technological change, pointing to the importance in this respect of shortages in such natural resources as land and wood. Utterström (1988) explores the role of climate fluctuations in population and economic development, arguing that they could very well have been of decisive importance not only in Scandinavia, but also in Central and Western Europe. Population pressure can also be viewed as an important factor in agricultural development, driving the growth of production and leading to increased environmental degradation. At the same time, however, limiting production may hinder population growth and/or encourage emigration. In addition, the role of technology and education in development is widely recognized (Meier 1970).

Studies of agricultural development often take a broad perspective insofar as our history, unlike that of other species, may be viewed as evolution in cultural, technological, and institutional terms. It is important to note that there are very few genetic differences between human groups while there is a large range of cultural diversity. Agricultural development has historically enlarged the food production base and given rise to many important technological innovations and institutional arrangements. However, as societies have attempted to increase their production base in the process of cultural evolution, methods have upon occasion been adopted that undermine it. In order to avoid this problem and achieve stability, various cultural changes must then take place, including population control and limiting the consumption of resources. Wilkinson (1973) argues that development is primarily the result of attempts to increase output from the environment. He states that, “Stability is achieved when the culture is adequately adapted to a particular ecological niche; further development only takes place in response to some alteration in the adaptive-problem situation. The most likely causes of such an alteration are population change and the unintended consequences of man's action on the environment" (p. 17). The development of agricultural systems can thus be viewed, on the one hand, as a process of adaptation to the increasing demand for food and, on the other, damage to the ecosystem, including degraded production capacity. Myrdal (1997) interprets the historical development of Swedish agriculture in terms of periodic waves of technological and institutional development in response to crises experienced within the sector and in society.

Crosson (1986) uses a broad formulation of the hypothesis concerning induced innovations in order to explain future changes in agricultural technology and institutions in reference to awareness of environmental degradation and resource scarcity, and concerns about equality. He views agricultural systems as consisting of four interacting components, namely, resources, technologies, institutions, and environments, that are shaped and constrained by a number of external factors, including energy, other resources, population growth, income growth, and climatic change. The existence of diverse agricultural systems can be explained in relation to differences between ecological systems and differing social adaptations. Moreover, one of the main driving forces behind the coevolutionary development of agriculture is comprised of an awareness of problems and interactions involving the various changing components of the system, particularly in light of the fact that the factors mentioned above are to a great extent not external to the system. Grigg (1974) explains the characteristics and distribution of agricultural systems throughout the world in terms of their evolution. He argues that although a very large degree of accumulative change is associated with industrialization and market expansion, the influence of historical development and physical environment on agricultural systems continues to be substantial. In addition, many landscapes that have been created by agriculture are increasingly valued as historical heritages.

Section 2.3 discussed how the suitability of technological change is determined by the ecological system and by other social systems, particularly values, knowledge, and organization. While agricultural development may be viewed as an improvement in people's living standards insofar as it increases in the availability of food, such improvement occurs in interaction with the social and ecological systems and for the benefit of the system as a whole. One of the characteristics of a stable social system, which has coevolved with an agro-ecological system, is that it tends to provide an adequate food supply to its population. Agricultural development in fact must take place when population growth and changing ecological and social conditions lower the standard of living, which has often been the case historically. However, relatively rapid population growth, ecological change unfavorable to food production, organizational change, or the emergence of values that give rise to a deterioration in food distribution may very well work to destabilize the system by reducing the availability and quality of food. This sets in motion a new series of coevolutionary interactions involving social sub-systems and the ecological system. One of the primary historical driving forces behind agricultural development, understood as adaptive practices in order to increase food availability and quality, has thus been a deterioration in conditions.

The evolution of life on Earth into diverse ecological systems and a complex biosphere has been powered by solar energy that has been captured in the form of biomass by means of photosynthesis. The net primary production of biomass energy by plants is the basis for the maintenance, growth, and reproduction of all species that feed on plants both directly and indirectly. Interaction between plant and animal species, whether by design or at random, is the basis for the evolutionary processes that have led to today's complex ecological systems, which are characterized by a high primary production of biomass energy. There are reasons to believe that we contributed positively to ecological systems as hunters-gatherers, although we may have driven some species to extinction and our numbers remained limited. We managed as agriculturalists to provide food to more than a billion people and create many diverse and sophisticate cultures without causing substantial ecological damage, and without using technologies associated with industrialization. If we come to succeed in increasing the primary production of biomass energy by reducing the physical constraints brought to bear upon it and /or increasing energy flow in the web food chain by increasing the complexity of the system, then we will have made a positive contribution to the ecological system.

The history of agricultural development indicates three types of changes in relation to ecological systems. First, certain changes increased food production but also damaged the ecological system, destroyed the resource base, and led to the collapse of both production and society. Stated otherwise, production increased in the short-term, but was not sustainable. Such changes, regardless of scale, must have taught people how to protect and enhance the resource base. Second, other changes increased the production of food and of total primary biomass energy by reducing the physical constraints on the ecological system. For example, water harvesting, irrigation, and improvements in soil structure and chemistry have generally resulted in the creation of new ecological systems that not only have provided more food, but also increased the supply of biomass energy to the ecological system as a whole. Third, still other changes increased food production but affected ecological systems both negatively and positively, such as by producing less biomass energy than the natural ecological system even though they created a stable agro-ecological system with increased biological diversity. This can be the case when a highly productive ecological system in terms of biomass, such as a forest, is transformed into cultivated land.

The coevolutionary view of agricultural development coincides with the idea of a self-organizing system and adaptive resource management for which Holling et al. (1998) argues. It can also be compared with the idea of self-organizing ecological systems, based on maximizing energy flow (Odum 1988), or with that of a self-organizing social system, based on the minimization of entropy and dissipation (Adams 1988). A coevolutionary, self-organizing agricultural system is based both on the conscious experimentation of farmers for the purpose of increasing and/or diversifying food production, and on the selection of practices that are suitable in relation to the socioeconomic and ecological systems. It may also be viewed as an intervention in the ecological system that improves its ability to utilize available solar energy. Traditional agriculture generally fits this latter description better than modern industrial agriculture, particularly in respect to nutrient management and energy flow.

It can be argued that agricultural development before industrialization in many instances enlarged the ecosystem insofar as new habitats were created for many species and the long-term production capacity in terms of biomass was increased. Even in forested areas, exploiting part of an ecological system for agriculture, coupled with learning by doing over generations, produced similar results. This was the case, for example, with many indigenous peoples and in certain regions in Sweden. The agro-ecological systems created in this way were sustainable since they survived for generations, regardless of whether or not they produced less primary energy than the original ecological system. Although it is true that we will never fully understand all the short and long-term changes in the natural environment that have resulted from agriculture, we can nevertheless say with a significant degree of certainty that traditional agriculture was ecologically sustainable.

In the era of traditional agriculture the expansion of the human species was characterized by a growing efficiency in its interactions with the ecological system. This made it possible for the social system to undergo long-term development through changes in knowledge, social organization, and the environment that were suitable in relation to the ecological system. It was the suitability of a technique, method, or organization for long-term survival, without environmental degradation and resource depletion, that made agricultural development real and sustainable and laid the foundation for towns and cities to emerge by virtue of farm surpluses. For example, the dominant strategy of risk aversion and multiple productions among many African farmers (Brossler 1991) may be viewed as development in relation to drought and other factors that cause crop failure. A system that combines crop and animal production, which integrates waste from consumption, may be viewed as development in relation to soil productivity that returns a portion of the nutrients that had been utilized in cultivation. Indeed, many agricultural practices around the world were developed in relation to the need to maintain and improve the fertility of the land and increase the production of biomass as well. (It should be noted that the use of muscle-powered machines is dependant on the biomass energy provided by the agro-ecological systems.) The suitability of a given method, technique, value, or organization was thus determined by ecological constraints, and it was this factor that determined whether or not it was sustainable. However, traditional agriculture was unable to adapt to rapid population growth and to the effects of industrialization.

The industrialization of agriculture has led to a reduced agro-ecological systems in terms of diversity and complexity, and it also rendered food production increasingly dependent on non-renewable resources not supplied by the agro-ecological system, particularly mineral phosphate and fossil fuels. However, it did substantially increase land productivity in terms of yields, thereby satisfying the sharp increase in food requirements associated with rapid population growth and increased per capita cereal consumption. Industrial agriculture also succeeded in reducing constraints arising from within the ecological system by drawing on the physical and intellectual resources provided by other systems, but it did so without sufficient experimentation and with no consideration of its social and ecological impact. Insofar as the "suitability" of modern agriculture is thus greatly dependent on non-renewable resources and leads to a deterioration of the ecological system, it can hardly be considered as sustainable in the long term.

Six central issues stand out in this brief discussion of agro-environmental history that are relevant both to the notion of coevolution and to sustainable agriculture. First, although human beings initially evolved through genetic mutation and selection, the changes we have undergone in the last 100,000 years have been almost entirely cultural. Consciousness and learning have become the main forces in our ongoing development. Second, agricultural development is a coevolutionary process that initially involved the agricultural and ecological systems. It came to involve the socioeconomic system as well after the emergence of cities and towns. Third, this coevolutionary development has been enhanced by conscious actions that resulted in increased long-term food production. These actions were based on a complex system of inter-generational learning and knowledge that has generally relied on the trial and error method. Fourth, increasing food demand continues to be the most important force that introduces instability into the system and drive agricultural development. A slow growth in the demand for food enabled traditional agriculture to increase production while protecting the resource base. Fifth, the interactive forces that influence agricultural development have gradually come to include the regional, national, and global levels of the ecological and socioeconomic systems. Sixth, under certain conditions agriculture is able to both improve the availability of food and enlarge the ecological system.

3.2. A Conceptual Model of Coevolution

If an evolutionary model of economics is constructed upon the general principles of biological and cultural evolution, then knowledge, energy, and natural resources emerge as the most important factors in long-term production (Boulding 1981). While the coevolutionary perspective developed by Norgaard (1994) reflects interaction between people and ecological systems, we may view the agricultural system as coevolving with both the ecological and socioeconomic systems and responding to various selective pressures arising within the latter, particularly in light of the increasing power of central governments and the growth in other sectors of society. When changes in an agricultural system are explained in terms of coevolution, then the "mutation" and "selection" of technologies and institutions can be viewed as the basis for agricultural development. We thus need to focus on the processes whereby an agricultural system adapts to changes within the two larger systems. Furthermore, since consciousness and perception now play central roles in human development, the creation, exacerbation, and alleviation of ecological degradation are largely matters of choice given today's rapid growth in knowledge. The time lag between creating, recognizing and solving a problem and uncertainties regarding the causes, magnitude and consequences of that problem are rather important.

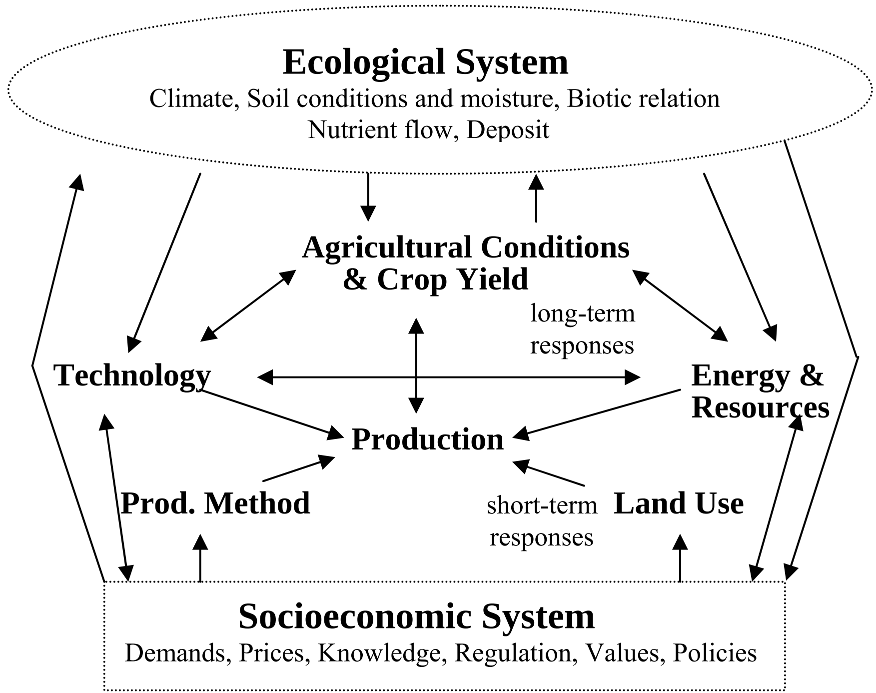
Coevolutionary processes are evident within the agricultural systems of both developing and industrialized countries through the manner in which suitable technological and institutional changes become adopted. The suitability of a given change emerges not merely in respect to the costs and benefits incurred to farmers, but rather in respect to the reactions of various related systems, including the environment, values, knowledge, and organizations. The development of agriculture into a modern industrial system, which is characterized by the use of fossil-fuel powered machines and by the use of chemicals to protect crops and provide nutrients, has been driven primarily by various selective pressures exerted by technological change, growing food requirements, falling relative prices for external inputs, and the desire for an adequate standard of living on the part of farmers. Because of increasing contacts between people living in different areas, technological and institutional changes have become less reliant on innovation than on the transmission and modification of existing ideas and practices. Since such changes may have both positive and negative long-term effects when introduced on the basis of trial and error, a thorough consideration of their possible consequences is necessary in order to minimize their negative impact.

Agricultural development may be viewed as continuous cultural adaptation, involving both technology and institutions, in order to increase production from the ecological system in response to population growth and to increased demand for food, which in turn interact with these cultural adaptations. The development of traditional agriculture consisted of an inter-generational accumulation of knowledge based on long-term interactions with the environment and the resource base so that suitable techniques, methods, and crop varieties could be adopted. As Goma et al. (2001) and Holling et al. (1998) observe, this involves knowledge that is important in respect to agricultural sustainability. But traditional farmers often cannot provide the types of reasons demanded by scientists for particular practices since many of the latter embody inherited knowledge. A more explicit type of knowledge is needed to deal with the nutrient and pest management problems that are associated with increasing production and farm surpluses.

Modern industrial agriculture emerged and expanded in relation to the domination of modern science, rapid population growth, colonization, globalization, and the commercialization of food production. It incorporates a great many accumulative changes that have been adopted in a relatively short period of time with little consideration of their long-term effects on the environment, the resource base, and society. We now have a much better understanding, for example, of the problems caused by pesticide usage, the finite nature of natural resources, the role of the ecological system, and the complexity of agricultural systems. These are issues that cannot be adequately addressed solely by reductionistic science. Modern industrial agriculture can thus be described as comprising short-term responses to economic, societal, and ecological conditions, although certain of these responses cannot be sustained in the long run because of ecological limitations, resource depletion, and ecological degradation. Future agriculture, unlike the modern agriculture of the twentieth century, must take such factors into consideration.

Peoples' awareness of the problems associated with modern agriculture has increased in recent decades. This means that we should expect a new path of agricultural development to open up as the socioeconomic system responds to include the ecological factor in agricultural production. Figure 3.1 describes the relations that pertain between the agricultural subsystem and the ecological and socioeconomic systems as agriculture evolves in response to various ecological factors and to the requirements of the socioeconomic system. The agricultural subsystem is represented by long-term agricultural conditions and crop yields, or by production capacity, and by relatively short-term changes in production. It is influenced directly by environmental problems and indirectly by means of the socioeconomic system. Production capacity is determined by long-term changes in technology and in resource and energy consumption. By bringing more land and water under cultivation, increasing the use of off-farm resources, and employing technological innovations, agriculture was able to meet the food requirements of the increasing population, who in turn were affected by the improved availability of food. However, the scale of this process negatively affected many ecosystems. The weight of the reciprocal influences in the interactions between subsystems may differ widely from case to case since one system may be more dependent in such relations than another.

Figure 1 The coevolution of the agricultural subsystem with the socioeconomic and ecological systems



This model also simplifies reality in order to facilitate understanding. The emphasis is on complex processes, feedback effects, conscious influences, and issues of importance for sustainable agricultural development.

Production methods represent the techniques and knowledge available to agriculture at a given point in time. The production method chosen and the level of inputs are determined by the farmer in response to output and input prices, knowledge, and regulations. Values and habits may also influence the farmer. In addition, the complex and multidimensional objectives of farmers do not eliminate the role of farm economy in ecological degradation. For example, many Swedish farmers have been concerned for decades about the negative effects of modern production methods on the environment and animal welfare (Nitsch 1982), but economic conditions have more or less forced them to follow a path of resource and environmental degradation. A large survey in 8 EU countries showed that farmers' positive attitude towards the environment is one important factor behind individual decision to participate in EU agro-environmental schemas (Drake et al. 1999). Costs and benefits have always played an important role in decision making on the farm. Indeed, Bergkvist and Fredriksson (1998) have demonstrated in their study of farmers' motivations for converting to organic milk production that ideology and economics are the main factors in their decisions. Economic feasibility, which is often influenced by macroeconomic factors, is thus crucial in efforts to improve the environment and follow a path of sustainable development. However, economic feasibility is contextual and must be related to societal norms and to an appreciation of the range of agriculture's contribution to society

Ecological degradation and resource depletion are caused by production and consumption within the socioeconomic system, which consists of citizens who work in various sectors, gather in various organizations, and have both common and conflicting interests and values. Some of these problems have a negative effect on agricultural production capacity, while others affect the health and well-being of present and future generations. The core issue here is that public knowledge and concern could make the socioeconomic system respond consciously to actual and perceived problems that are likely to emerge in the future. For example, the increasing resistance of many pests to various pesticides, which may well pose a growing threat to agriculture, can give rise to a serious search for alternative pest control strategies, such as the use of cultivars with genetic resistance, biological pest control, and integrated pest management. Other examples include the retirement of highly eroded land from cultivation and the redevelopment of multiple cropping and agro-forestry to deal with nutrient and erosion problems (Dover and Talbot 1987). Such responses take place primarily on the societal level, and the resulting changes emerge through local interaction, regulation, and national stimulus processes.

Figure 3.1 illustrates how an agricultural system continuously changes because of changes in the many influences brought to bear upon it from both within and outside the system. Agricultural sustainability must therefore be viewed dynamically and in relation to the major forces and elements that influence its development. When we say that agricultural sustainability has ecological, societal, and economic dimensions, we refer to those aspects of the coevolutionary processes involving agriculture and the larger socioeconomic and ecological systems that are of primary importance. These dimensions serve to illuminate the nature of agricultural sustainability, and the linkages between them provide an understanding of the development processes that either move towards or divert from sustainability. For example, food security is a vital aspect of a sustainable society, but it can be understood only in relation to agricultural production capacity, food demand, food structure, and the processes that influence theses factors. The main elements and processes depicted in Figure 3.1 can thus be viewed as issues that are important for agricultural sustainability. If we leave aside ecological problems, we could say that the agricultural system has coevolved in response to increasing food demands, and still does so in developing countries, through an increased use of resources and the adoption of new technology. But when the issue of ecology is introduced into this picture of agricultural development, a new path of development is shown to be necessary in three respects. The first consists of the direct environmental impact upon agricultural production capacity, such as land degradation and climate warming. The second consists of indirect socioeconomic effects by means of public concerns and governmental public policies, such as the reduction of nutrient leaching and the preservation of the landscape. The third consists of the increasing opportunity costs of resources, such as land for forestry, recreation, and conservation. This type of development can influence short-term production methods and land use as well as long-term technological innovation and resource use.

The socioeconomic system is the engine that produces change within agriculture because of the dominating influence it exercises by means of demand, prices, knowledge, values, policies, technological development and resource allocations. In this respect, agricultural policy can be viewed as an institutional arrangement for carrying out societal objectives. Although certain groups in society may influence certain policies more than others, and certain policies may become obsolete or prove unfit, actors and ideologies clearly have a role to play in shaping and implementing environmental policy (Söderbaum 1992). We could thus say that agricultural and environmental policies may be viewed largely as reflections of social will, even though certain forces may work for policy changes that favor environmental improvement while other forces may resist such changes. The main obstacles to collective action in order to alleviate environmental degradation include increasing production costs, the lack of concrete evidence, the lack of appropriate cost estimates for damage, and self-interested private actors who operate through market mechanisms. Policy change in the socioeconomic system thereby arises from complex processes that reflect material interests, knowledge, moral convictions, and macroeconomic efficiency (Vail et al. 1994).

Policies affect agriculture through short and long-term responses. Short-term responses stem from product and input prices, regulations, and policies that affect production methods and land use for various crops. For example, an environmental tax on a given input may lead to a decline in demand and encourage the use of alternative inputs. Regulations may change both land use and production methods within the range of presently available technology. In addition, product prices and price support policies may encourage that certain land be used for different products or in different ways, such as for organic production, legume crops, energy production, or permanent pasture.

Among the long-term responses, technology and resources can have a substantial impact on the agricultural system. For example, technological change and innovation may both continue to increase agricultural potential, but also make new products profitable and resolve at least certain ecological problems. It is obvious that there are certain contradictions between, on the one hand, increased production per unit of land and, on the other, ethics and ecological problems. Nevertheless, it is possible to reduce such contradictions if an important aim in implementing technological innovations is to ameliorate perceived ecological problems. An important aspect of this process is to drive technological development towards both resolving and avoiding ecological problems. For example, instead of searching for a variety that provides higher yields but requires more protection and nutrient nursing, we can search for a variety that gives a reasonable yield but has good genetic properties in respect to the environment. Research institutes in many industrialized countries are now working on the development of so-called ecological (low input, organic, biological, traditional) agriculture. However, different paths of technological development may emerge even within a given country or region. If investments and technological developments are directed towards an increase in production, then the production base may strongly expand; if they are directed towards the alleviation of ecological problems, then the production base may expand only moderately.

What determines the emergence and adoption of a new technology? In modernity type of development (Figure 2.1) it is determined by need and economic factors. Yet, many technologies implemented during industrialization did not emerge from needs, but rather created needs (Fernandez-Armesto 2001). Early tractors and cars were not more economically efficient than horse power. Furthermore in developing and adopting various technologies no consideration is made to their social and ecological impacts. In locally-based coevolutionary development the suitability of technology is determined by interaction involving values, knowledge, organizational systems, and ecological systems (Section 2.3).

Agricultural systems have, in general, been in steady development, although the pace has varied. They will never become static or completed because the conditions that constitute agriculture are continuously changing and, moreover, we will never be able to predict fully all the consequences of any given change. The changes that arise from the short and long-term responses and processes described above take place in three interconnected ways. The first is through local interaction involving farmers and citizens, production and consumption, and the resource base and the agro-ecological system. This is the basis of the self-organization that shaped the development of traditional agriculture through suitable adaptive changes. Traditional farming practices evolved through generations of informal experimentation that integrated the ecological system

(Norgaard 1994; Hjort af Ornäs 1996; Gibbon et al. 1995). Villages and towns developed largely in relation to the ability of the agricultural system to provide food and other goods, which in turn developed in relation to various influences brought to bear from within the ecological, socioeconomic, and ecological systems. As the territory of a given socioeconomic system expanded, these local coevolutionary processes began to incorporate non-local responses, leading to a wider range of interaction with larger socioeconomic and ecological systems.

The second involves stimulus on the national level by means of induced technological development, large project investments, agricultural policies, and changing value systems. The processes of industrialization and internationalization increased the importance of national level interactions at the expense of local level interactions. In most industrialized countries today agriculture has generally become independent of the local community as the direct flow of food, material, and information has been weakened. It has also become less dependent on the local ecological system insofar as a large percentage of inputs are imported and as pollution is exported to other systems. Perhaps the most important negative impact of this particular development is the sharp reduction in feedback from agro-ecological constraints. It was this feedback mechanism that rendered traditional agriculture suitable in relation to the ecological system and thus able to survive for millennia.

The third involves the regulation of inputs and production methods, such as animal husbandry and the use of hazardous chemicals. This path of change is closely inter-connected with the other two, but it requires special attention because there is presently no efficient link for providing important information to consumers and citizens. It also represents qualitative social demands that cannot be adequately and effectively addressed by incentive-based policy intervention. If these last two paths of change are used to support the strengthening of local interaction, there can be a useful advance in the promotion of agricultural sustainability.

Technological development and the utilization of natural resources comprise the basis of agriculture. Technology as the accumulation of techniques and methods that have been developed in response to various changes and adaptations has been the major cause underlying the long-term increase in production per unit of labor and land. It has also enhanced the ability to increase as well as decrease the employment of natural resources. Many writers today emphasize the role of technology in agricultural sustainability (e.g., Aldy et al. 1998). For example, many new technological developments, particularly biotechnology and genetic engineering, can be directed to the replacement of chemical and mechanical inputs by biological inputs, even though ethical concerns and uncertainty regarding the possible negative effects of biotechnology may restrict its implementation. Perennial crops for erosive land, integrated cropping, salt-tolerant cultivars, efficient irrigation systems, pest resistant cultivars, integrated pest management, agro-forestry, and integrated crop and animal production are other examples of technologies that can increase production while reducing ecological degradation. It may be argued that this type of development requires that an emphasis on system thinking and social requirements replace the focus on marginality and private profit (Norgaard 1994; and Rörling 1996).

The coevolutionary aspects of technological development in support of sustainability can be illustrated by an example borrowed from Norgaard (1994), mentioned in Section 2.3 above, to the effect that pests, pesticides, value, and policy coevolve, particularly in relation to pest resistance and pesticide hazards. The results of this coevolution may be either the use of more expensive chemicals in pest management, or a movement towards integrated pest management in which knowledge concerning the pest population is coupled with biological control in order to reduce chemical applications. The success of this movement largely depends on choices that must be made at local, national, and international levels involving research institutes, economic interest groups, political institutions, and the concerned public. Another pertinent example concerns the expansion of ecological milk production, which could very well dominate the Swedish milk market within a decade or so insofar as it involves few additional costs but is of great benefit to the environment (Lundström 1997). The expansion of organic farming in general will also be influenced in the near future by our perception of its sustainability. Like the role of diversity in the survival of a biological system, such dual-purpose development of technology and production may prove to be vital in respect to sustainability.

Concerning natural resources, agriculture in general now depends both on on-farm resources, which are more or less related to the ecological system immediately involving the farm, such as land and water, as well as off-farm resources, which are brought to farmers from other areas by the market or the government, such as mineral fertilizers and fossil fuels. Traditional agriculture developed in relation to on-farm and local resources except for some large-scale collectively organized irrigation. The basic problems that arise in respect to natural resources are depletion and degradation. Resources increase production when moved into agriculture, but this may only be a short-term improvement, such as when the cultivation of marginal land eventually renders it unproductive. Land and water are the main resources that limit the expansion of agriculture. However, technological development and the increased use of other resources, such as energy, may increase the production from a given quantity of land and water. It is important to note that fossil fuels, mineral nitrogen, and mineral phosphorus, vital inputs in modern agriculture, are nonrenewable resources, although phosphates and fossil fuels may continue to be produced at relatively low cost for decades. Mineral nitrogen fertilizers are also heavily dependent on fossil fuels.

The use of such off-farm resources as fossil fuels, mineral fertilizers, and synthetic pesticides in modern agriculture has strongly contributed to the creation of environmental problems affecting air, water, soil, the biotic system, and human health. In addition, the prices of natural resources are influenced by competing uses and by the perception of scarcity and environmental degradation. Protecting on-farm resources from degradation and depletion, securing the long-term availability of off-farm resources, and limiting the negative impact of off-farm resources are basic issues concerning sustainability.

The issue of energy will demand particular attention in future agricultural development since energy flow constitutes a fundamental link between agricultural activities and the ecological and socioeconomic systems. Agriculture is basically a transformation of solar energy into food energy for human beings. This is at the expense of certain species in the original ecosystem, but since it is also of benefit to others, both new and old, agriculture creates new ecological systems, or agro-ecological systems. As Section 3.1 argued, agriculture enlarges the ecological system when it increases available energy in terms of biomass and creates new systems that provide habitat for a broader range of biodiversity. However, it also degrades the ecological system when it appropriates a large percentage of the natural environment and produces less biomass. The connection between sustainability and the energy flow that powers the ecological and socioeconomic systems is revealed by the work of many writers (e.g., Georgescu-Roegen 1971; Odum 1983; Daly 1991). Except in cases of irreversible damage, we can restore environmental degradation to some degree and re-circulate much of the material, that would otherwise have been lost, if we have enough low entropy concentrated energy.

Energy concerns agricultural production in a number of aspects. For example, the primary product of land is bio-energy, whether in the form of cereals, sugar cane, or forests. Fossil fuels supply the power that drives many activities in agricultural production today as well as the production of important off-farm inputs. However, agriculture can produce bio-energy crops that can replace fossil fuel energy. But this is also true for forests, which often capture more solar energy than agriculture.

Food demand is another important factor in agricultural sustainability. There are fundamental differences between the ways in which ecological degradation and resource depletion impact agriculture in industrialized and developing countries. Land degradation, for example, has different short and long-term implications. In an industrialized country, with low or negative population growth, relatively stable or decreasing demand for food, and a small percentage of disposable income spent on food, the short-term effects could involve taking land out of production or using less intensive production methods. The long-term responses could involve the adoption of environmentally friendly practices and moving resources, particularly land and labor, into new types of production, such as biomass energy, or into other sectors. In a developing country, on the other hand, with high population growth, an expanding demand for food, and a large percentage of disposable income spent on food, the short-term responses may aggravate degradation insofar as more land and more intensive methods may be required to meet the need for more food. It can be expected that more land and capital will be moved into the sector in the long run, but the rate at which this will occur will very much depend on the rate of change in the demand for agricultural products, technological development, capital availability, and food preferences.

The ratio between crop or animal products in the typical diet will also have a significant effect on the agricultural capacity required for food production. Should agriculture internalize the social cost of environmental problems, animal products would bear a much larger percentage of any resulting increase in price than vegetables and grains. Moreover, the environmental costs increase when diet is based on animal products and animal production is based on feed grain. Durning and Brough (1992) argue that the livestock economy must be reformed in order to include its full ecological cost, which they expect would double or triple the price of meat. The matter of health also provides a case for reducing the quantity of meat and animal fat in diets in that both national and international recommendations emphasize the need for a balanced diet that consists primarily of plant sources. Another important factor in the development of preferences for crop products is the growing public sensitivity concerning animal treatment. Data from the WRI (1996) show that while the share of grain fed to livestock is increasing in most developing countries, it is now decreasing in many industrialized counties. A balanced diet would thus help to develop a system of sustainable agriculture since it would reduce food demand in terms of cereal and energy inputs in animal production.

The value system, which includes preferences, norms, attitudes, and ethics, is an important part of the socioeconomic system that influences the evolution of agriculture. This is particularly the case in respect to food preferences, the attitude towards the natural environment, animal welfare, and even the choice of technological development. Changes in the value system have been one of the primary social means utilized for adapting to unfavorable situations in the absence of adequate techniques when there is a perception of significant long-term benefits associated with doing so, particularly in relation to the agro-ecological system. Vegetarianism, animal worship, and birth control are examples of values that benefit both social and ecological systems.

An increase in income is not the only factor that influences our preferences. Education and values can have great influence on the way we address ecological issues and on our food habits. For example, an important issue concerning agricultural development is how society perceives agriculture. Agriculture gives rise to increased ecological degradation and a reduction in social services when society emphasizes food production at competitive prices and ignores other important social functions of the sector. This leads to decreasing agricultural sustainability.

The knowledge system is another important element of the socioeconomic system that coevolves with values, technologies, food demand, resource use, and the ecological system. What to know as well as how to know clearly influence, and are influenced by, these systems. As part of the larger socioeconomic system, agriculture contains a body of formal and as well as informal knowledge that shapes it. The formal knowledge emerged with the advance of the atomistic-mechanical mode of inquiry during the nineteenth and twentieth centuries. It increasingly replaced much of the informal knowledge that was embedded in traditional agriculture, which was acquired through learning by doing and was transferred from generation to generation. It is significant that these two types of knowledge can complement each other, particularly as the shortcomings of reductionistic knowledge have become evident and the demand for more systemic research is growing. Most of the knowledge available today concerning the connections between production, consumption, ecological degradation, and resource depletion has been produced by modern science, but with the assistance of new technologies that were previously unavailable and with new types of emphasis that were previously overlooked.

Food security is an important issue in the coevolution of agriculture, and it in fact has been the primary driving force in the historical development of the system. Food security is now defined as access by all people at all times to the food required for an active and healthy life (Ellis 1992), which implies that food availability is one essential element in food security. The other essential element, which has been increasingly emphasized in the recent literature, concerns the ability of all people to acquire food. For example, Amartya Sen's (1981) discussion of entitlement failure changes the focus in respect to poverty and famine from food production to the ability of individuals and households to acquire control over food, whether it be through production, wages, trade, or transfer. Sen emphasizes how a strengthening of entitlements through social security programs can work to eliminate both poverty and starvation. However, the ability to produce one's own food is deeply rooted in most societies. Although international trade in various commodities has reached a high degree of liberalization, agricultural production is still highly protected nationally and regionally in spite of the clear economic disadvantage of doing so in countries with high production costs. The drive for food security underlies this complex motivation to protect, at least partly, domestic food production.

Other issues of importance in the evolution of agriculture are related to production methods for both crops and animals and to various types of environmental degradation that affect the ecological system as a whole and, consequently, the welfare of society. Some of these problems are primarily based on moral grounds, such as animal welfare and the protection of biodiversity, while others reside on both economic and moral grounds, such as eutrophication and land degradation. The protection of biodiversity, which is also important for technological development through its provision of genetic material, requires the conservation of many ecological systems over large areas (Myers 1989).

Health concerns increasingly influence consumer preferences as well as policies regulating food production methods. People today are concerned not only with pesticide residues in food and the effects of biocides on farmers and workers, but also with many problems associated with animal medication, hormone usage, food processing, food preservation procedures, including the use of radiation, biological toxicity, and diseases that affect the animals we eat. Many measures have been taken to reduce the effects of pesticides on workers and food, including the banning of certain chemicals. Problems such as salmonella, feed contamination, and the spread of BSE (mad cow disease) have generated concern at both national and international levels (FAO 1998). Evidence obtained through a large number of studies has demonstrated that many widely-used biocides suppress immune reactions in fish, birds, and mammals, including humans (Repetto and Baliga 1996).

The coevolutionary processes at work in agricultural development can be perceived at local, regional, national, and global levels. However, the higher the level of focus, the more abstract the model in Figure 3.1 becomes because of increasing variations in numerous issues, including policies, prices, and ecological systems. Agricultural development began with coevolutionary processes at the local level that gradually widened to include higher-level influences. This change became greatly intensified during the industrialization of agriculture, leading to a weakening of interaction involving the local community, agriculture production, and the ecological system. Insofar as this comprises the source of most of the ecological problems associated with industrial agriculture, strengthening coevolutionary processes on the local level should be our long-term focus in respect to sustainability.

The development of a system of sustainable agriculture is not possible without the creation of a socio-environmental system in which policies, knowledge, values, and people are able to interact effectively in order to establish and realize goals (Masters et al. 1998). This implies that we must reconsider important strategic issues, such as the administration of agriculture, food processing, food distribution, resource use, resource circulation, and both individual and institutional food consumption. Furthermore, these issues cannot be adequately addressed if there is no local authority that represents local citizens in the political process, acts in accordance with suitable national directives, and follows the guidance of principles and indicators of what is understood to be sustainability. In addition, these principle and indicators need to be measurable and understandable by actors involved on the local level.

Agro-ecological problems have grown to be issues of global concern today. Problems such as land degradation, the clearing of forests, the depletion of biodiversity, surface and ground water pollution, and climate warming no longer affect us on merely local and national levels (Saifi 1997). Indeed, many environmental problems can be exported to other countries and to the atmosphere and oceans we all share. Consequently, they can only be adequately resolved by a substantial transfer of resources and technology for the specific purpose of halting environmental degradation. Indeed, the amelioration of global environmental problems is the responsibility of industrialized countries and the international community, and it requires global regulation and governance (Harris 1992). Agriculturally-related environmental issues are also interrelated not only with each other, but also with the structure of international trade and investments and with population growth. The strengthening of local coevolutionary processes thus cannot successful attain its goals without an integrated strategy that also addresses important sustainability issues at higher levels as well, such as climate warming.

Climate change due to the increasing concentration of atmospheric greenhouse gases has a particularly dynamic effect on the agricultural system (IPCC 1995). For example, increased atmospheric carbon dioxide levels could enhance crop yields, while temperature increases, which are also related to changes in precipitation, have both negative and positive effects depending on the geographical area in question. Rising sea levels resulting from global warming would also negatively affect agriculture in many coastal areas. Farmers can respond to such changes and adapt their management practices to offset the negative effects and/or take advantage of the locally favorable developments in climate (Parry 1990). Governments can respond in order to reduce the rate of warming by reducing emissions and increasing land usage for energy production, carbon deposits, and forest. Such responses would have a substantial impact on agriculture since it is a major source of such atmospheric pollutants as methane, carbon dioxide, and nitrous oxide, but it can also produce bio-energy that can partially replace fossil fuel energy sources (Saifi 1997). The availability of financial resources and supportive institutions is an important factor determining whether or not farmers make adjustments in their methods and practices that could serve to alleviate such problems. Unfortunately, the situation in this respect is not favorable in developing countries, which are expected to suffer the most from climate warming.

Policy intervention and action plans are needed in order to drive the process of reducing the impact of environmental problems, whether by eliminating their cause, or reducing their negative effects. Even in cases when the sector or even the individual farm is damaged by certain practices, government intervention will be needed to create incentives and regulations for dealing with such problems because of their long-term effects, the lack of knowledge among producers, mutual influences among farmers, and the lack of appropriate market mechanisms. For example, two major factors involved in the ecological degradation caused by agriculture today are population growth and the international economic structure (Redclift 1987), both of which can be directly influenced by policy intervention. Drake (1994) analyzes various environmental problems in agriculture in terms of market imperfections due to non-exclusiveness and non-rivalry. He concludes that there are significant conflicts between market economy and efforts to protect the environment, and that the specific characteristics of a particular environmental problem are crucial in the choice of an efficient policy instrument for resolving it. The Agenda 21 document is a clear demonstration of the need for policy action and planned investment in order to protect the environment. In addition, many scientists are now coming forward with policy recommendations in order to protect ecological systems and invest in natural capital (Jansson et al. 1994).

There is no universal type of government intervention that functions best in respect to all environmental issues. However, Kant's insight that property rights are shaped by the social system and by reasoning (Section 2.2) is important in launching policy interventions. For example, the enforcement of property rights may be a good approach when the problem in question has been caused by common access. On the other hand, placing limits on property rights may be necessary in respect to such issues as the scarcity of underground water or the use of land in sensitive areas. Taxing emissions, inputs, or even certain products may be a better approach to problems that require research, economic incentives, and investment in order to be resolved. And there is no effective alternative to regulation in other types of cases, including the use of dangerous chemicals and other undesirable practices in production. Regulation is also clearly important when it is a question of ethical issues concerning production. Planning and investment are required to support research, the pursuit of long-term objectives, the dissemination of technology, and land use in sensitive areas. In addition, it may be necessary to combine taxes with regulations, planning, and investment in order to deal with the complex problems of climate warming and the recycling of organic waste. It may also be necessary to make changes in our value system concerning consumption in general in light of ecological constraints.

The coevolutionary interpretation of agricultural development as a product of local interactions involving the socioeconomic and ecological systems implies that proposed changes in the various elements comprising an agricultural system must be carefully studied in terms of their suitability. Stated otherwise, it is necessary to adopt only those changes that show the promise of being suitable in respect to the ecological and socioeconomic systems. The way in which society responds to ecological problems and to the question of agricultural sustainability influences the coevolution involving knowledge, policy, and value systems that may lead to measures that reverse environmental degradation. Although the growth in knowledge plays an essential role in reducing environmental problems, public policy support for this purpose is also needed (Ehrlich et al. 1999). As Hollander (1986) observes, it is necessary to specifically support research concerning sustainability because decision making in respect to agricultural research involves values that favor the status quo. Furthermore, the strength of efforts to redress environmental problems is a matter of choice that is influenced by various issues related to food demand, vested interests, knowledge, economics, moral convictions, and long-term survival. The path of future development will thus depend on the various selective pressures arising on the local, national, and global levels that are brought to bear on agriculture and on the associated systems of knowledge, values, and policy. For example, a slow increase in food demand provides the opportunity for a higher degree of technological improvements to be employed in efforts to reduce environmental degradation. With a stable demand for food and a willingness to safeguard agriculture, searching for such technologies would be an important strategy. The selective pressure on agriculture in industrialized countries may be viewed as having changed during the course of the twentieth century from increasing production, to increasing labor productivity, to increasing ecological considerations.

Many ecological and resource problems have obvious economic consequences for agriculture since they influence production negatively and are also negatively regarded by society. However, increased production and investment costs will be incurred as such problems are addressed. If such costs are integrated into production, a substantial rise in prices would result if the same quantity of output is to be produced at a given technological level. Furthermore, such price rises, which can be seen as representing the differences between marginal social costs and marginal private costs, will only increase with time. Not only are social costs influenced by knowledge, education, and income, their marginal increment at higher production levels is often greater than the marginal increment in private costs. The accumulated effects of environmental degradation would thus incur even greater social costs. A similar logic can be applied to natural resources, especially non-renewable resources. There will thus be growing incentives in terms of rising social costs to direct agricultural development towards environmental improvement and sustainability. We may also expect increasing pressure to allocate resources to rectify the damage that has been done to the ecological system in light of the growth of the environmental movement. This may particularly be the case because of the rise of the network society and of global access to information, with the consequent shift in focus from local problems to a perspective that integrates all of mankind and nature (Castells 1997).

The impact of alleviating ecological degradation on the development of agricultural systems is complex, and it may very well affect food demand and supply. Agriculture in the future can be considered to be a function of various complex and interacting factors. Some of them, such as land and climate, are on-farm resources that are directly affected by environmental degradation. A second group, including technological development and ecological degradation, are socioeconomic factors that are affected mainly by choices and policies on the national and global levels. A third group, such as fertilizers and fossil fuel energy, are off-farm inputs. While their prices are more or less globally determined, the quantities used are locally determined in relation to production methods and socioeconomic considerations. While it is very difficult to provide a detailed account of how these factors will be affected, we can conclude that there will be three major effects concerning food supply affecting technological development, the use of off-farm inputs, and energy production, and two major effects concerning food demand affecting population growth and diets. These are discussed in Chapter 5 below.

The value of an environmental service increases as income rises (Randall 1987; Crosson 1990). Indeed, it is in the most recent stage of industrialization that public concern about the environment and the meaning of agriculture has become distinctively important (Vail et al. 1994). In addition, food demand increases more in a low-income economy when income rises than in an industrialized one, particularly in connection with the growing portion of animal products in the diet. This means that there should be growing demands for both food and environmental improvement on the global level in the coming decades as population, economic standards, and environmental concern increase. It should be noted in this regard that the cost structure of food in most industrialized countries does not encourage an increase in exports to the international market. Consequently, the demand for an improvement in environmental quality is growing in industrialized countries at a rate faster than the demand for such basic goods as food, while the demand for food is growing in the developing countries at a rate faster than the demand for an improvement in environmental quality. The OECD (1995) recommends that member countries follow policies that improve the sustainability of agriculture, and EU regulation 2078/92 provides rules for payments that encourage farmers to use environmentally sound production methods. Member states contribute directly to the implementation of this policy both by providing financial support, and by the formulation of the national program that the regulation in question calls for. But pressure to improve the environmental performance of agriculture is increasing even in the developing countries because of its negative effects on agricultural production capacity.

The impact of environmental problems on global food supply and demand may affect agriculture in both developing and industrialized countries in three main respects, namely, world food and input markets, global cooperation in ameliorating environmental degradation, and agricultural development. Less population growth, preferences for less animal products in typical diets, and an increased conversion efficiency of cereals in animal production would decrease the pressure to increase cereal production, thereby allowing more resources to be directed towards sustainable agriculture. However, a competitive global market conflicts with various legitimate local and national interests, particularly those related to food safety, moral convictions concerning production methods, and environmental degradation. In addition, free trade in agricultural commodities without integrating the costs of environmental degradation would intensify the destruction of many ecological systems. Briefly stated, market forces lower production costs but increase ecological and social costs.

The main dilemma facing developing countries is the negative impact of continuing environmental degradation on agricultural production capacity accompanied by a growing demand for food. Most of the increase in population and food demand during the coming decades will occur in developing countries. And although agricultural production in many of the countries in question may enjoy a comparative market advantage in the coming decades, and in spite of a substantial potential to increase agricultural production, developing countries are expected to import large quantities of cereals (Saifi 1997). Moreover, the effects of global environmental degradation, especially land degradation and climate warming, will be most sharply felt in developing countries. It is important to emphasize the need for increasing resource allocation for real development at all levels and for research so that balanced technologies, in respect to production levels and decreased environmental damage, become available to all countries. National and international policies toward agricultural research and development are crucial to the rate of growth of agricultural output (Ruttan 1991; Schuh and Norton 1991). Even traditional sustainable agriculture requires development in order to cope with changing conditions, including increased farm surpluses, nutrient deficits, and pest management.

The model of coevolution presented here illustrates that agricultural sustainability must be understood in relation to the systems that shape agriculture, namely, the socioeconomic and ecological systems, the subsystems that form an agricultural system, and the processes of change in agricultural development. It is not possible to transform today's modern agriculture into a sustainable system in the near future due to various economic and social factors that hinder the resolution of the many complex issues involved. Furthermore, a sustainable system of agriculture is interconnected with sustainable society, and not many societies are yet prepared to bear the associated demands and costs. But while we now cannot construct an agricultural system that is sustainable in all respects, it is possible to enhance the sustainability of agriculture by strengthening local coevolutionary processes and reducing what we perceive to be unsustainable elements and practices with a given agricultural system. Agricultural sustainability is contextual. Not only is it defined in relation to a particular community or society at a certain point in time, we need to learn from the past what made traditional agriculture ecologically sustainable if we are to strengthen local coevolutionary processes in the future. As Steiner (1993) argues, we need to draw lessons from the past and to reacquire something we have lost in our relation with nature.

3.3. The Meaning and Dimensions of Sustainable Agriculture

The above analytical framework consciously aims to reflect the nature of agricultural development as comprised of coevolutionary processes involving the agricultural sector, the socioeconomic system, and the ecological system. It clearly illustrates that any operational definition of a sustainable agricultural system has to be related to place and time, thus being subject to change. In addition, promoting the establishment of such a system demands that we strengthen coevolutionary processes on the local level so that ecological constraints and social requirements interact directly with the farming system in the area. However, we must be able to define the meaning as well as principles appropriate for this type of development. Since such principles are meant to support local coevolutionary processes, they may be located in the various subsystems and issues that have been discussed above in respect to the model that has been proposed. This section will provide an initial meaning of sustainable agriculture in general and discuss the various dimensions of such a system with reference to Figure 3.1.

The most popular definition of sustainable development, namely, to satisfy the needs of the present generation without compromising the ability of future generations to satisfy their own (WCED 1987), was put forward for the purpose of protecting the environment and the resource base. While this may support an understanding that economic activity should be managed under the conditions of protecting the natural environment and alleviating poverty, cost/benefit analysis is seriously inadequate or insufficient for addressing environmental degradation and resource depletion, especially regarding resource substitutions (Section 2.2 above; Stockholm Studies in Natural Resource Management 1988). Within the framework of neoclassical economics, one might view sustainability in terms of consuming less than the net income generated by a society, taking into account the depreciation of man-made capital, the depreciation of natural resources, and damage to the environment. The preservation and accumulation of such man-made capital as machinery, buildings, and know-how supposedly should thus compensate for any reduction in natural capital, which consists of such environmental and natural services as clean air, forest, and land.

If we assume that there is a high degree of substitution between resources, particularly between natural and human-made capital, we may arrive at the position that it is the total capital that should not decrease in sustainable development. This idea may be termed weak sustainability. Pearce and Atkinson

(1993) use this notion to measure the sustainability of selected national economies in terms of national savings, seeking to determine whether the latter is greater than the combined depreciation of man-made and natural capital. The curious conclusion of their exercise is that the economies of the industrialized countries are on a sustainable path of development, while the economies of developing countries are on an unsustainable path of development. This view is in obvious contradiction with the fact that the richest 20% of the world's population consumes 80% of the world's natural resources, and that industrialized countries are the main contributors to global degradation. Many other writers emphasize that it is the environmental and natural resource capital, or simply natural capital, that must be protected in the long run because of the inherently low degree of potential substitution between natural and man-made capital (Costanza and Daly 1990; Dietz et al. 1992; Jansson et al. 1994; Common 1995). This is the idea of strong sustainability.

The role of such man-made capital as machinery is essentially to complement that of such natural resources as land. Even Pearce et al. (1990) tend to accept the position that it is ecological capital that should be protected: "There are strong reasons to think of sustainable development as involving further constraint, namely that the stock of environmental assets as a whole should not decrease" (p. 48). Ekins et al. (2003) propose that we must protect critical natural capital in order to approach sustainability. However, there are also substitution problems involving both various natural resources due to the ways they complement each other in food production, such as is the case with nitrogen and phosphorous, and the various sources of a given resource in light of differing production costs, including the corresponding energy requirements. The argument that we must protect natural capital and the life-supporting ecosystems is inevitably strengthened if we acknowledge that economic systems are part of the larger and finite ecosystem, and that we now have access to only a limited quantity of "safe" energy. Indeed, investing in resource circulation, which can be viewed as a form of resource substitution, reduces the deterioration of two of the major functions of the ecological system, namely, the provision of resources and assimilation.

Schuh and Archibald (1996) view sustainable agriculture in terms of maintaining maximum welfare from resources, which is the conventional economic approach of reducing environmental degradation to a level that complies with cost-benefit analysis. Tisdell (1997) argues that agricultural sustainability is multidimensional, and that we cannot adequately address it mechanically in terms of specific characteristics, such as sustained income, welfare maximization, or decreasing intensity. Defining agricultural sustainability in terms of economic viability or in terms of ecological integrity is also inappropriate. While the former is socially related and can be changed through policy, the latter is impossible insofar as all agricultural systems are intruders in ecological systems (Lehman et al. 1993). Common (1995) states that there can be no blueprint for sustainable systems because the economy-environmental linkages are both complex and change over time. Norgaard (1994) and Section 3.2 above reject the idea that we can operationally define sustainable agriculture. Indeed, it is difficult to determine whether the agricultural system in a particular region is sustainable in light of various difficulties associated with the level of analysis, food demand, material and energy balances, the extent of long-term environmental degradation, and climate change. For example, a system of agriculture that appears to be sustainable in terms of on-farm resources, economics, and the ecological system may in fact prove to be unsustainable in terms of off-farm global resources such as phosphates and fossil fuels, and also in terms of a climate regime that undergoes long-term change. Future development can also transform what is presently judged to be a system of sustainable agriculture into one that is unsustainable, and conversely. In addition, an energy crisis, climate warming, technological development, and value system changes can dramatically alter the conditions for agriculture in a given region. Furthermore, achieving food security and preventing hunger are important social dimensions of sustainability that may justify a short-term reduction in ecological sustainability.

Our model of coevolution taken together with the above discussion indicates that there can be no detailed description or operational definition of a system of sustainable agriculture that is generally valid for most regions and for most periods of time. We must instead approach the question of agricultural sustainability by means of a broad definition, but with specific principles and indicators that pertain to a particular country or region at a particular period in time. These principles and indicators are not to be taken as absolute measures of sustainability, but are instead as tools that can help either to promote agricultural sustainability, or reduce agricultural non-sustainability. Broadly defining sustainable agriculture as "a system that can satisfy the food requirements of the present generation without compromising the ability of future generations to satisfy their own" can provide a framework that is useful for examining and evaluating currently existing agricultural systems in respect to sustainability. This definition, which is clearly analogous to the WCED's definition of sustainable development, is neither operational, nor by itself sufficient for directing agricultural development towards sustainability. It rather must be further elaborated, particularly in regard to the function of agriculture, the level of analysis, the meaning of food requirements, and the number of future generations. Clarifying these issues is important for portraying the principles of agricultural sustainability in a given region.

First, the function of agriculture has historically been to provide food for farmers and other people in society. It has also produced other important goods, such as fibers and leather. The process of industrialization led to the realization that agriculture has other functions as well, such as providing export earnings, capital surpluses, and labor for industry. Agriculture has an even more complex role in post-industrial societies (Vail et al. 1994), including waste circulation, the preservation of cultural heritage, the maintenance of biological diversity, and the conservation of a living countryside and open landscape. In many developing countries the primary emphasis continues to be on increased food production in order to meet the food requirements associated with a growing population and a rising standard of living. The actual and perceived services other than basic food production that are provided by agriculture clearly vary significantly between societies and between different periods of development with one and the same society. Since agriculture is thus part of the socioeconomic system, the meaning of agricultural sustainability must consequently be defined in relation to services determined by the society in question.

Second, sustainability is essentially a global issue that has arisen from concerns about problems that face humanity as a whole, especially environmental problems (WCED 1987). Nevertheless, solutions and improvements must be carried out primarily on local and national levels. In addition, the model of coevolutionary development that we have proposed can be applied to analyses pertaining to global, continental, national, regional, local, and farm levels, each of which has its own specific issues of importance. In order to deal with the difficulties this presents to analysis, it seems reasonable to base our investigation on the local-regional level while integrating important issues from other levels. The idea that agriculture is a system that coevolves with the socioeconomic and ecological systems gives rise to the image that the agricultural system coevolves with a particular community and a particular ecological system with a clear flow of materials and influences. The integration of issues from higher levels, especially the global level, also has a moral dimension that is related to the fair distribution of natural resources in both spatial and temporal terms.

Third, the question of what to sustain and for how long is basic to discussions concerning sustainability (Costanza and Patten 1995). We thus need to address the question of how long we wish to sustain an agricultural system. For example, when we mention future generations, do we mean two or a hundred generations? When we speak of an appropriate time span, are we referring to one hundred years or ten thousand years? The former would hardly cover the life times of most children who will be born to people alive today, while the latter is roughly as long as the entire known history of agriculture. Judging agricultural sustainability in terms of a time span of one thousand years is perhaps reasonable in light of development in most regions of the world, the current known deposits and rates of consumption of vital non-renewable resources, and natural climatic and geographic changes. This judgment helps to clarify important features of a system of sustainable agriculture, particularly the levels of phosphate consumption, land degradation, energy production, and energy consumption. For example, if the known land deposits of phosphate are to last for one thousand years, then its current rate of consumption must be reduced by a factor of ten.

Fourth, the nature of food requirements demands further clarification and must be related to the quantity and quality of food sufficient for a healthy and active life. Although most cultures view food as something more than the energy intake needed for survival, it is not appropriate in a discussion of long-term sustainability to include demand for luxury products or introduce the distortions caused by poverty and excessive wealth. Thus it may not be appropriate to consider neither food need nor food demand in the meaning of food requirement for sustainability. More precisely, we could follow the recommendations of such authorities as the World Health Organization (WHO) concerning a healthy diet, which consists of a pyramid structure with cereals and other staple crops at the base, vegetable and fruits in the middle, and meat and animal fat at the top. In this respect, food consumption in most industrialized countries significantly exceeds food requirements, and changing consumptions patterns to reflect the guidelines presented by health authorities will reduce resource use and increase agricultural sustainability. Goodland (1997) argues that diet pattern is indeed important for agricultural sustainability. He proposes a food conversion efficiency tax on the least efficient converters of cereal energy (such as pork and beef production) in order to reduce food waste and improve both health and food availability.

Various principles and indicators can now be derived from the model of coevolution and from the above clarifications that may provide guidelines for the development of a system of sustainable agriculture in a particular region and period of time. In order to do so, we will have to make certain assumptions based on our present knowledge and focus on what are now perceived to be the most important problems. In addition, these principles are subject to discussion and judgment and must take social requirements into account. As Hammond et al. (1995) observe, sustainability indicators are not ends in themselves, but rather tools that can provide support for needed changes, facilitate communication among stakeholders, and guide the actions of decision makers. In identifying certain principles and indicators that could be useful for strengthening coevolutionary processes on the local level, we need to consider the relations pertaining between various sustainability issues and also take into account social requirements and social perceptions. While the realization of such principles may not be feasible in the short-term for a variety of reasons, it is possible to direct agriculture towards the moving target of sustainability by using appropriate policy instruments and following a path of development that strengthens local interactions. This approach is similar to some extent to the goal-oriented strategy proposed by Wirén-Lehr (2001) for closing the gap between theoretical sustainability and agricultural practices. The approach for which we argue has the overall goal of strengthening local coevolutionary processes in respect to principles and indicators that are socially determined.

Although no predictions concerning future development are possible, it is important to understand past development as well as the major problems facing systems that exist today rather than concentrate on how policy measures affect short-term production. For example, Boyden (1993) argues that it is necessary to adopt a conceptual approach to human ecology as bio-history, and that a knowledge of patterns and processes at work in the interplay involving culture and nature within human history is important for understanding the past and planning for the future. Moreover, we must attempt to understand the processes in which principles of sustainability have been realized, as well as those in which they have been violated.

The coevolutionary model presented in Section 3.2 indicates that there are many important subsystems, or elements, in agricultural development that interact both with each other, and with the larger agricultural, societal and ecological systems. Insofar as these subsystems constitute the characteristics of a given agricultural system, when taken together they indicate the level of sustainability of that system and should thereby be considered as dimensions or aspects of sustainability. Not all the dimensions illustrated below are explicitly indicated in Figure 3.1 insofar as the importance of traditional agriculture, historical development away from sustainability, and food security are discussed in Section 3.2. Although the following eleven dimensions are relevant to sustainability in respect to most agricultural systems, they vary in content between societies, between periods of development within a given society, and between communities in relation to nutrients circulation and local ecological systems. Each society, and ultimately each community, may arrive at its own internally and externally consistent principles and definition of sustainable agriculture.

1. Value system and ethics

The value system within a socioeconomic system is probably the main source for dynamic changes as well as short and long-term responses concerning agricultural sustainability. Important issues directly related to the value system include technological development, production methods, diet patterns, food demand, ecological degradation, resource depletion, and the appreciation of the services provided by agriculture. The value system itself undergoes continuous change, as do all social and ecological systems. Under the present conditions of the rapid dissemination of information and knowledge, some elements of the value system, such as preferences and attitudes, are now changing much more quickly than they even have before. For example, public awareness of the negative environmental impact of a certain practice increases concern at various levels of society. Indeed, the failure of self-interested private actors to respond in an appropriate fashion to environmental degradation may lead to the implementation of policies that either tax or compensate farmers in order to induce technological changes and/or change the value system. Positive and negative feedback from various systems and actors either strengthen or weaken such measures.

As part of the value system, ethics expresses the commitment of a society to protect and foster its well-being. Section 2.2 argues that issues related to values and ethics should not be merely reduced to individual preferences, as if they were mere consumer issues. For example, people can express through the political processes the values they uphold concerning the type of agriculture they want and the production methods they judge to be acceptable in their society. Resulting regulations may very well increase on-farm production costs, thereby giving rise to conflicts concerning sustainability on economic grounds if farmers are left without compensation and imports increase. But although the value system is related to all other dimensions of agricultural sustainability, it cannot be directly and explicitly outlined as a principle of sustainability. Its inter-relations with technological development, food demand, and farm economy demand special attention since these three issues may play particularly important roles in the development of agricultural sustainability. Without pluralism in technological advancement, balanced and reasonable food demand, and a willingness to accept additional costs, it will be difficult to substantially improve agricultural sustainability.

2. Traditional agriculture

Traditional agriculture, which coevolved with the ecological system at the local-regional level, was clearly sustainable for long periods of time under certain social and physical conditions. The latter have obviously changed during the processes of industrialization and modernization. Rapid population growth and industrialization powered by fossil fuels have exerted great pressure on agriculture to rapidly increase food production and productivity through the transformation of traditional production methods into industrial methods. Such methods are not ecologically sustainable insofar as linkages between people, food production, and the ecological system on the local level, in which the sustainability of traditional agriculture was rooted, have been broken.

On the basis of empirical studies in various countries, Goma et al. (2001) demonstrate how traditional knowledge can contribute to the formation of better and more practical indicators of sustainability. Regardless of the great range of diversity in traditional agriculture, such features as crop rotation, crop diversification, and the combination of animal and crop production continue to be common in most regions of the world. The knowledge embodied in traditional agriculture can be of great importance in efforts to develop modern industrial farming towards sustainability.

3. Food demand

Food demand and production were largely connected at the local level in traditional agriculture, which generally faced relatively low and stable food demand. Particular societies developed, through trial and error, specific forms of production that could be sustained in the long run insofar as they were suitable in respect to the ecological system. Few countries can meet their increased food demands today by means of sustainable traditional agriculture. Indeed, the most important factor in orienting agriculture towards sustainability is to have relatively low and stable, or even falling, food demand. This makes it possible to change the selective pressure on agriculture from the need to increase production to an emphasis on improvements in the system related to its long-term survival. Although a traditional agricultural system can modestly increase production and still maintain sustainability, non-sustainability can increase in a modern system even with decreasing food demand, particularly if competition between producers is based on the survival of the cheapest. But food demand in itself cannot indicate agricultural sustainability. It is rather that food demand and diet patterns taken together indicate whether there is an opportunity to develop a system of sustainable agriculture. The main components of food demand are population size and per capita consumption. Both can be influenced by deliberate action that leads to institutional change through developing part of the value system to adapt to sustainability, such as reducing the birth rate and adopting vegetarian pattern of food consumption. Many societies have historically made such adjustments in their value systems in order to meet challenges of scale and distribution.

4. Technological development

The history of agriculture can be viewed in terms of various adapted techniques and production methods. Throughout history certain techniques have been abandoned while others were developed further, not least of all as farming spread across countries, continents, and ecological systems. Most countries now have research centers with the aim of replacing traditional trial and error methods with modern means of technological improvement. However, today's institutional arrangement of agricultural schools, universities, and research centers has been developed primarily to expand production and increase factor productivity with little attention given to the issue of long-term feedback from the ecological system. It may be argued that a sustainable path of agricultural development requires a new way of thinking that emphasizes systems thinking and social requirements instead of focusing on factor optimization, marginality, and private profits (Norgaard 1994; Röling 1996). Just as biodiversity is important for agricultural sustainability, particularly concerning crop and animal varieties and their undomesticated relatives (Tisdell 1999), diversity in technological development is likely a pre-condition of sustainable agriculture. When one form fails to adapt to external changes, others may survive. In examining whether or not a new technology is sustainable, we need to bring its relations with other dimensions, such as values and ecological systems, into the discussion.

5. Energy and biomass

The primary production of energy by plants through photosynthesis is the basis for the maintenance, growth, and reproduction of all species on Earth. Ecological systems on Earth are completely dependent on the energy flow from the sun, and all of their components, including agriculture and other economic sectors, are connected by flows of energy (Odum 1983). While the first law of thermodynamics states that matter and energy can be neither created nor destroyed, the law of entropy implies that changes in both natural and economic activities are evolutionary and irreversible (Georgescu-Roegen 1971). Any closed biological or economic system inevitably degrades energy and material resources into a more disordered and less usable form and will eventually die out. Since fossil fuel energy is limited and nuclear energy still faces many unresolved problems, our economies should be based on renewable energy provided directly and indirectly by radiation from the sun. In mining fossil fuel we may never reach the point of exhaustion because of the increasing energy input per unit of output due to decreasing marginal return. Restoring degradation and resource circulation are important elements in this process. Consequently, emphasizing the balance between energy input and output is much more relevant than simply focusing on resource exhaustion.

The direct relevance of entropy to agricultural sustainability resides in the need to develop a system that increases available low entropy energy in terms of biomass. On the basis of irrigation, agriculture may not only increase the quantity of food energy available for human consumption in arid and semi-arid regions, but also the total energy captured from the sun. The issue is more complex in moist regions since agriculture can increase food energy while decreasing total captured energy insofar as a forest is often more effective than agricultural cultivation in biomass production. The search for a more sustainable type of agriculture thus necessarily involves an examination of the efficiency of agricultural land use in terms of biomass production, an issue which was of little concern in traditional systems. In addition, the availability of energy is a crucial factor for increasing resource substitutions, such as utilizing the phosphorous accumulated in oceans. In principle, all matter and all resources on our planet, except for energy itself, can be circulated if we have sufficient quantities of energy. In practice, however, there are always fractions of matter that cannot be circulated because of increased energy requirements, especially when the circulation distance is great.

The question of energy is both a complex and central issue in agricultural sustainability that is related to many other issues in other dimensions, including land cultivation, animal husbandry, inputs, processing, efficient nutrients circulation, and outputs. The land production of biomass energy, the energy used in biological processes, and use of fossil fuels are important aspects of energy flows in relation agricultural sustainability.

6. On-farm natural resources

Agriculture has involved the increasing utilization of local resources in order to increase food production. Land, water, biotic relations, and climate regime, which can be improved or degraded by human actions to varying degrees, are basic on-farm resources that determine agricultural production capacity. For example, crop rotation and the use of animal fertilizers improve soil structure and the availability of nutrients, while mono-cropping and excess tillage degrade the productivity of arable land. Many regions in the world, particularly in arid and semi-arid zones, are now suffering large-scale production losses because of damage to agricultural land, including erosion, compaction, contamination, acidification, humus depletion, and nutrients depletion. Climate changes can render both land and water use unsustainable, but it can also improve land productivity in certain regions by reducing constraints on photosynthesis. New or mutated pests can hinder or prevent certain types of production and require increased chemical usage. The protection of both land and water resources from degradation and depletion must then be important objectives in respect to agricultural sustainability. However, they cannot be adequately addressed on the local-regional level alone.

7. Off-farm resources

The use of off-farm resources in traditional agriculture was limited, primarily involving equipment and knowledge produced or gathered in nearby towns and cities. Modern industrial agriculture has become increasingly dependent both on external, non-renewable natural resources, such as fossil fuels and phosphorus fertilizers, and on industrial products, such as biocides. The direct and indirect dependence on fossil fuels is particularly widespread throughout the system of agricultural production and distribution. Many off-farm resources are not only directly responsible for extensive environmental degradations, they are also subject to long-term scarcity. Indeed, the issue of scarcity may soon become a relatively short-term problem as well in certain cases, particularly in respect to fossil oil. This dimension thus consists of important sustainability issues for agricultural systems throughout the world. It is worth noting that agriculture can produce bio-energy crops in order to replace, at least partially, fossil fuel energy.

8. Ecological system and environmental degradation

This dimension contains issues that are related to the degradation of the ecological system at the local, regional, and even global levels. It thus involves the welfare of people using many services provided by the ecological system. Some of the widely known ecological problems that have been created by modern industrial farming include nutrient leaching, the over-enrichment of water bodies, the spread of biocides beyond the farm, the depletion of biodiversity, greenhouse gas emissions, and the reduction of organic matter in soil. These issues are largely related to various issues in the preceding dimension, and most of them cannot be practically measured and used in local interaction processes. Selecting adequate principles of sustainability from the dimension of off-farm resources would thus largely cover most of the issues in this dimension as well.

9. Food safety and other health aspects

This social dimension of agricultural sustainable contains issues that are specifically related to modern industrial farming systems. Production methods and food content have become increasingly important for citizens and consumers in most countries. This is related to increased knowledge of the damage that can be done to human health in connection with the chemicals used in agricultural production and with food processing, whether it be on the basis of pesticide residues in food products, or the contamination of ground and surface water. However, knowledge concerning the effects of many pesticides, conservatives, hormones, feed supplements, etc., is far from sufficient. The development of resistant bacteria and other microorganisms in crops, livestock, and humans is also a growing health threat. There are even concerns that resistant genes can cause health problems when transferred through genetic engineering to plants and animals. While scant attention was directed to the side-effects of chemical technologies just a few decades ago, safe food has become an important demand of consumers and citizens. In general, health problems associated with food must be addressed by regulations concerning production methods. They are also related to issues in other dimensions of sustainability, particularly off-farm resources.

10. Food security and regional distribution

As was noted above, food security may be viewed as involving access by all people at all times to the food required for an active and healthy life. While it is possible for a country or a society to guarantee short-term food security by importing food, doing so on a long-term basis involves strategic risks and generates various ecological problems. Today's low food prices on the international market are likely to be relatively short-lived (Saifi 1997). However, high cereal prices may deprive the poor of the food they need, particularly if developing countries continue to be net cereal importers in the coming decades. Moreover, increased specialization in food production, both involving different societies and within one and the same society, will inevitably increase ecological costs for both importers and exporters because of nutrients imbalance and increased energy consumption. Being able to produce one's own basic food requirements is a primary security issue. In times of crisis affecting food production and availability, a community with a large area of agricultural land may very well manage better than one which is not so fortunate. In addition, issues such as energy flows and nutrient circulation consolidate not only food security on the national level, but also the regional distribution of food within a given society. Agriculture is the cornerstone of a secure and sustainable society since it provides not only food, but also important ecological services. The amount of arable land per person, balanced food production, and a high degree of dependency on local resources are consequently important issues in food security.

11. Farm economy

Even in a subsistence farm economy, which is less influenced by and less dependant on social structure and institutions such as food processing and the market, farming should provide farmers and their families with adequate living conditions. If this is not done, farming will be abandoned, moved onto new land, or conducted with different methods and on a different scale. A similar principle is also valid for modern industrial farming, with farmers being under constant pressure to rationalize their activities and attain a standard of living comparable with non-farm groups or otherwise leave the sector. It may be necessary in many countries and regions now undergoing industrialization to increase the productivity of both land and labor in order to supply the growing sectors of the economy with the food and labor force they need. It has already been noted that only a few percent of the total labor force are engaged in agriculture in many industrial and post-industrial countries. The economic factor plays a decisive role in farm management and practices and in farming continuity between generations. Today it has become closely connected with social conditions, particularly agricultural policies.

In order to determine principles of agricultural sustainability on the basis of the dimensions listed above, the issues must be examined in relation to a particular society or community. In addition, such principles are subject to facts and to discussion, and thus can be changed over time. For example, food security may not be an important issue for many societies today, but it may become very important indeed if difficulties develop with the global markets for food or vital inputs. In addition, certain principles may not only be valid for a number of different communities and societies, but also relevant to a number of different dimensions, such as is the case with the integration of crop and animal production. The principles and indicators of sustainability should thus be viewed as tools for ameliorating what we perceive to be the problems that agriculture faces today and will face tomorrow in a given community of society. The strengthening of local coevolutionary processes that is argued for in Section 3.2 may require additional special tools.

Since all of the above dimensions in agricultural production are inter-connected, promoting sustainable agricultural development cannot be based on principles that reside in only one or several of them. Moreover, the realization of these principles must be viewed as a long-term objective demanding that we both understand and influence the coevolutionary processes presented in Section 3.2. There will be both conflict and reinforcement between such principles even within a given country or a region, and it will be necessary to search for compromise solutions on the basis of people's concerns. There is an obvious conflict in most developing countries between, on the one hand, increasing food production and attaining food security and, on the other, increasing the use of off-farm resources in order to boost production and thereby undertake an unsustainable type of development. In most post-industrial societies there may only be minor conflict between these principles because of the stable, or even falling, food demand coupled with the ability to provide adequate financial support to farming for carrying out various improvements. In general, the development of technology and a stable food demand are vital for attaining the objectives we have been discussing. We do not know what technology and food demand will be in twenty or thirty years, but we can act today to influence their development. Just as vital are the immediate improvements that can be brought about by changes in production methods and land use that can be promoted by new agricultural policies.

3.4. Summary and Conclusion

Unlike the conventional approach that explains changes by stressing a number of causes, the coevolutionary approach views change as resulting from complex interactions between subsystems. The nature of the subsystems, the system itself, as well as the relations pertaining between them all change over time as they coevolve with each other. This type of thinking is rooted in the biological principles of mutation and selection. In biology the term coevolution describes the evolution of adaptation in terms of biotic interaction. Coevolutionary processes are evident in the agricultural systems of both developing and industrialized countries through the adoption of technological and institutional changes that are suitable in respect to the ecological system. Agricultural development can be viewed as continuous cultural adaptation in order to increase production from the environment in response to growth in population and increasing food demands, which in turn interact with this ongoing adaptation. In the pre-industrial period these changes comprised an inter-generational accumulation of knowledge based on long-term interaction with the environment and the resource base so that techniques, methods, and crop varieties could be adopted that would be characterized by long-term suitability. In contrast, modern agriculture, which emerged in relation to the domination of atomistic-mechanical science, rapid population growth, colonization, globalization, and the commercialization of agriculture, comprises large number of accumulative changes that have been adopted over a relatively short period of time, with little consideration being given to their long-term impact on the ecological system, the resource base, and society.

The view presented here concerning agricultural development and environmental history illustrates issues that are important for a system of sustainable agriculture. Agricultural development must be seen as consisting of coevolutionary processes involving the agricultural, ecological, and socioeconomic systems as well after the development of towns and cities. These processes are based on cultural adaptation in terms of trial and error, whereby efforts and gains are observed for both the short and long-term for the purpose of satisfying growing food demands. Forces influencing these coevolutionary processes have gradually widened to include higher level ecological and socioeconomic systems. In addition, certain adaptations not only increased food production for human beings through the application of knowledge, but also expanded the ecological system and increased its complexity by producing a greater quantity of biomass energy. Others, particularly in forested areas, increased the food available but produced less biomass energy than the initial ecological system. Both types of adaptation proved themselves suitable during the history of agriculture by selection for methods that partially integrate the ecological system.

The model of coevolution presented in Section 3.2, which reflects the influence of ecological problems on various part of the agricultural system, provides a framework for understanding sustainability and the processes involved. Furthermore, it also indicates various relevant factors and the type of principles one must search for as the basis of this understanding. In addition, it is necessary to influence short-term processes affecting production methods and land use as well as long-term processes affecting technological development, the value system, and the utilization of energy and resources in order to promote agricultural sustainability. Although such changes will take place by means of a combination of local interaction, national stimulus policies, and regulations, the history of agriculture suggests that the strengthening of coevolution at the local level is a pre-condition for sustainable development. The historical integration of the local community, agriculture, and the ecological system, which was dramatically weakened during the twentieth century, particularly in industrialized countries, appears to be an essential factor in the development of a sustainable system of agriculture.

The coevolutionary perspective reveals that agricultural sustainability must be understood in relation to the systems that shape agriculture, namely, the socioeconomic and ecological systems, the subsystems that comprise an agricultural system, and the processes of change in agricultural development. Any given agricultural system has been in a state of continuous development at varying rates of change. It can never become a static, finished product not only because the conditions that constitute agriculture are themselves in continuous change, but also because we can never fully predict all the consequences of change. In addition, it will not be possible to transform today's modern agriculture into a sustainable system in the foreseeable future due to various economic and social factors that hinder the resolution of the many complex issues involved. Furthermore, a sustainable system of agriculture is interconnected with a sustainable society, and not many societies appear to be prepared today to bear the associated demands and costs. But it is possible to enhance the sustainability of agriculture by strengthening coevolution on the local level in accordance with principles of sustainability that will be identified in the course of discussion. One obvious example of what could be done in this regard is to establish research institutes in which traditional agriculture can be developed to meet the challenges of nutrient deficits, new forms of pest management, and production increases without environmental degradation.

The coevolutionary perspective has two distinct but related implications for agriculture in developing and industrialized countries, primarily due to the status of food demand. The main selective pressure on agriculture in industrialized countries may well become the need to reduce agro-ecological degradation and resource depletion, while in developing agriculture it could be to promote sustainability by means of policy interventions that affect important aspects of food demand and production. The main selective pressure on agriculture in developing countries is currently to increase food production. But since certain environmental problems have a negative impact on agricultural production capacity, there is also a growing pressure to reduce ecological degradation. Cooperation between industrialized and developing countries concerning research and investment and greater research into technologies that are suitable in respect to agricultural sustainability are important factors for the reduction of resource depletion and the promotion of agricultural sustainability.

The model presented in Section 3.2 describes the relations pertaining between the agricultural subsystem and the ecological and socioeconomic systems as agriculture coevolves in response to various ecological problems and to the requirements of the socioeconomic system. This model identifies eleven dimensions of sustainability in respect to agriculture. In order to bring about improvements in accordance with the principles and indicators that can be derived from these dimensions, it is necessary to influence the course of development in technology and value systems, and also to influence agricultural production through short-term stimulus or regulatory policies. In addition, since a sustainable path of agricultural development requires the participation of many different actors in society, including farmers, politicians, consumers, scientists, environmentalists, and citizens, and since the issues involved are both multiple and complex, a basic consideration in our search for principles and indicators of sustainability is that they be readily understandable by the general public and applicable to a broad range of concerns and issues pertinent to the question of sustainability.

The principles and indicators of agricultural sustainability must be specified in relation to a particular society or community. They need to be based on the agricultural history of the community in question, including the problems it has encountered in the past and the problems it anticipates in the future. These principles are not to be viewed as absolute components of a system of sustainable agriculture, but rather as measures that can help reduce agricultural non-sustainability, particularly by enhancing local coevolutionary processes. In addition, the principles selected are subject to facts and to discussion, and thus can be changed over time. Certain of them may not only be valid for a number of different communities and societies, but also relevant to a number of different dimensions, such as is the case with the integration of crop and animal production. Finally, addressing agricultural sustainability at the local-regional level while integrating issues concerning sustainability at the national and global levels is proposed as the most practical way for dealing with the difficulties that are associated with the existence of multiple levels of analysis.

4. The Conditions for Sustainable Agriculture in Sweden

A framework for understanding and promoting agricultural sustainability was presented in Chapter 3. Important processes and subsystems in agricultural development that led to increasing non-sustainability, as well as those that may lead to increasing sustainability, were discussed. Before depicting certain principles and indicators for Swedish agricultural sustainability (Chapter 6) and examining agricultural sustainability and coevolutionary processes in respect to the Municipality of Uppsala (Chapter 7), it is necessary to address the conditions that affect the strength of sustainable development in both Swedish (Chapter 4) and global (Chapter 5) agricultural systems. Chapter 4 relies primarily on three works. Section 4.1, which draws on Conditions for Environmentally Friendly Agriculture: An Analysis of Development Trends and External Factors (Saifi and Drake 1990), briefly discusses how Swedish agriculture became dependant towards the end of the twentieth century on society as a whole through such issues as policy, environmental concerns, energy, and technological development, some of which are regionally and internationally influenced as well. Section 4.2 proceeds from Economic Rationale for Environmental Policy in Swedish Agriculture (Saifi 1993). It argues that an environmental policy of conditional support can improve agricultural sustainability and economic efficiency. Section 4.3 relies largely on The Greening of Agricultural Policy in Industrial Societies: Swedish Reforms in Comparative Perspective (Vail et al., 1994). It presents the position that Swedish society has a great interest in and commitment to preserving its historical heritage of farming and agro-ecology. In addition, the political system has developed various policy measures in reaction to the rapid increase in environmental demands during the 1980s. Section 4.4, which concludes the chapter, discusses the implications of such matters for agricultural sustainability.

4.1. Agricultural Development Trends and Environmental Concerns

About 90% of the Swedish population were engaged in agricultural activities until the middle of the nineteenth century. Subsistence agriculture was the norm, and population size in various districts was closely related to agricultural production capacity. In spite of the declining role of agriculture in the national economy over the last two centuries, the Swedish population has still remained located primarily in agricultural areas. During the 1980s about 90% of arable land was within a 30 km radius of cities and towns with more than 10,000 inhabitants (Renborg 1988).

The structure and production forms of agriculture have fundamentally changed during the twentieth century such that specialized commercial farming is now the principal provider of food to society while employing only 2-3% of the work force. As Flygare and Isacson (2003) observe, the agricultural sector in Sweden during the second half of the twentieth century succeeded in satisfying the rapidly growing food demand, although the wide-spread use of chemical fertilizers and biocides and the large-scale production of meat, milk, and eggs have come under criticism in the last twenty years.

Changes in the agricultural sector, especially during the last century, were related to changes in Swedish society as a whole, and both were influenced by changes and events that occurred internationally. For example, population growth and rising living standards have necessitated increased food production, especially such animal products as milk and meat. Technological developments, international regulations, and trade agreements also influenced Swedish agriculture both directly and indirectly. In addition, the dominant role of agricultural policy in shaping agriculture became even stronger in recent decades. Moreover, the many issues that influence agricultural development, including agricultural policy, have become largely integrated both regionally and globally. Consequently, it is important when assessing the conditions for environmentally friendly agriculture to address developmental trends on both national and international levels, together with the structure and potential of the sector. Although important changes occurred during the 1990s, the judgment is that Saifi and Drake's (1990) analysis, namely, that there is a growing possibility to improve agriculture's environmental record, remains largely valid.

Changes in agriculture

During the first half of the twentieth century, the amount of land under cultivation in Sweden increased only marginally to 3.7 million hectares in 1951, but crop yields and livestock productivity increased substantially. While the number of farms remained roughly unchanged at around 400,000, the number of those involved in agriculture decreased to about one-fifth of the total workforce in the country. Most farms remained mixed, cultivating cereal and lea in rotation and integrating animal and crop production. During the second half of the century, about one million hectares of arable land, primarily less productive and marginal land in forest districts and in Norrland, were removed from the sector, and crop yields and livestock productivity increased at a much higher rate than previously. The size of the agricultural work force further decreased to less than 3% of the total, and the number of farms fell to less than 100,000. This strong rationalization, which also involved a growing reliance on machinery as well as the use of mineral fertilizers and chemical agents, led to growing food surpluses during the 1970s and the 1980s since food demand had leveled out and farming remained reasonably profitable due to price subsidies. It is noteworthy that about one-third of the remaining farms were small, using less than four hundred hours labor annually, with diverse types of production.

This new situation eventually led to four structural changes that had unforeseen effects on the environment. First, there was an increase in farm specialization and the separation of crop and animal production. Between the early 1950s and the late 1980s the number of farms with cattle decreased from about 90% of the total to approximately 30%, while specialized crop production became established on about one-third of the arable land. Second, farming was shifted to the plain districts in spite of efforts to preserve farming in areas with less favorable climatic and soil conditions, primarily because of decreasing transport costs. 55% of the Swedish population lived in the southern plain districts in 1988, which comprised 63% of the total arable land, 92% of food grain land, and 68% of feed grain land. Third, the increased surpluses were exported at a significant loss to society. For example, the sector produced 174% of domestic wheat consumption and 115% of domestic butter consumption in 1986. Fourth, there was a marked increase in pollution and a decrease in farming amenities, including nutrient leaching, the spread of biocides, a growing destruction of agricultural landscape, and a decrease in biological diversity.

There are three important aspects of the present structure of agriculture that may serve to promote environmentally friendly farming in most regions of Sweden. First, the dependence on income from regulated products is relatively low in comparison with total income, with most farmers receiving various monetary as well as non-monetary support. In addition, most farming households receive more net income from non-farm activities, such as services and retirement benefits, than from directly farm-related activities. Moreover, there is a lifestyle dimension to farming, and farmers do not expect full compensation for their working hours. A large share of farm work can be considered as leisure time, especially on small farms. Second, the high cost of food processing and large-scale distribution chains indicate that an increase in primary production costs in connection with more environmentally friendly methods of production may not increase consumer prices significantly. This could also encourage more on-farm processing, the development of new products, and direct marketing, especially if the policy of price supports is replaced by a policy of direct support, such as an acreage subsidy. Third, Swedish agriculture still remains distributed throughout the country, and most farms still have the ability to integrate crop and animal production. This can enable the sector to meet society's growing interest in agricultural landscape, reduce the burden on the environment, and promote regional balance. It is worth noting that if the appreciation of farming is positively related to population, then farming in regions with a small ratio of arable land per resident deserves higher subsidies than elsewhere (Drake 1992).

International development

An analysis of issues related to agriculture reveals an international trend towards integration and less regulation, especially in respect to such market distortions as the dumping of products. The resulting increased free trade in agricultural products, which mostly occurs within such blocks as the European Union, has an impact on Swedish agriculture directly, through the prices of agricultural products and inputs, and indirectly, through agreements, technological developments, and attitudes. However, completely free trade in agriculture should not be expected for various reasons, such as food security, environmental issues, energy issues, the uncertainty of future supply, and the special status of farming in most countries.

There was a doubling of world food production between 1950 and 1990 accompanied by a fall in prices. This was made possible not only through the introduction of new, inexpensive arable land, but also because the negative environmental impact was not factored into the price structure. An additional doubling of production by the middle of the twentieth-first century, which seems to be demanded by population growth and rising living standards, is much more problematic, not least of all because it will demand vigorous agricultural development. Brown et al. (1989) identify the seriousness of the problems facing humanity in this regard. While it is still possible to increase productivity and cultivate new lands, doing so may in fact be limited by an increasing demand for land for other purposes as well, such as for forest areas and conservation, and by environmental degradation, such as soil erosion and climate warming.

Technological developments, the question of energy supplies, and environmental and ethical concerns are other global issues that influence Swedish agriculture. There was intensive technological development after the World War II involving biology, chemistry, and machinery that boosted food production and raised productivity. However, substantial knowledge has been accumulated since the 1970s concerning its unexpected and unwarranted negative results. In From Farming to Biotechnology Goodman et al. (1987) express their expectation that genetic engineering will radically change how our food is produced. They put forward two possible paths of development, namely, appropriation and substitution. The former involves genetic transfers between species and cultivars in order to expand biological capacity, while the latter involves the replacement of many of today's agricultural products, such as milk, with fabricated products based on organic raw materials. However, there is strong and growing resistance to the increased usage of GMOs, especially in Europe.

World energy consumption is still increasing and becoming ever more dependent on fossil fuels since the initial promise of nuclear energy has proven to be unmerited. Prior to the 1980s our main concern regarding fossil fuel resources was depletion, but it has since switched to their impact on the environmental, especially climate warming. During the next decade we are likely to face squarely both the problem of depletion, due to a decreasing output/input ratio, as well as accumulated environmental problems. Chandler (1985) argues for investing heavily in order to increase energy efficiency so that we may reduce both energy usage as well as the related pollution. Moreover, if fossil fuel prices would include their environmental costs, then the competitiveness of environmental friendly and renewable energy sources, such as solar power, wind, and biomass, would increase substantially. The development of sustainable energy systems would likely have a very great impact upon agriculture because of the increased prices of fossil fuels and mineral fertilizers and the increased profitability of on-farm energy production.

Growing environmental awareness and ethical concerns at the global level may have a profound impact on Swedish agriculture, particularly in regard to reforms in agricultural policy and the development of farming methods that are in accord with public demands. The Brundtland report (WCED 1987) not only expresses these global concerns, but also encourages international agreements and directives that embody them. The environmental, social, and ethical costs of food production render the concept of comparative advantage in respect to agricultural products rather abstract and difficult to apply. The uncertainty regarding future food production, technological developments, and environmental and energy problems may well encourage countries with high-cost food production, such as Sweden, to maintain at least a certain “insurance” production capacity.

Agriculture from a societal perspective

Swedish society influences and shapes agriculture through a number of factors, including consumption, environmental awareness, ethics, attitudes toward agriculture, technological development, energy consumption, and agricultural policy. Not only do these factors interact with each other, they are also influenced by international developments.

Because Swedish agriculture at large is unable to compete internationally, it is crucial to change patterns of consumption. Certain changes tend to support domestic production, while others do not. Since Sweden is characterized by marginal population growth and an already high standard of food consumption, it is reasonable to expect that there will be only a marginal increase in food demand in relation to an increase in income. The current trend in consumption is towards quality and diversity, and consumers’ awareness of the relationship between food and health is growing steadily. Cosmopolitan food habits, a desire to be free from food additives, ethical influences, especially regarding the treatment of animals in production, and a commitment to preserving the environment increasingly influence food consumption patterns. The demand for other agricultural goods and services is also growing, such as tourism and the preservation of the countryside (Saifi and Drake 1990).

There is no doubt that the awareness of citizens and politicians concerning the physical environment in Sweden increased significantly in the 1980s. Indeed, opinion polls reveal that the environmental question became the most important issue for the population as a whole. Agriculture’s positive contribution to landscape conservation also became more clearly appreciated than ever before, and people’s willingness to pay for the agro-ecological landscape can generate an income stream that is potentially not much less than net farm income from regulated products (Drake 1992). However, agriculture began receiving open and strong criticism during the 1980s for its negative environmental impact. The working group on environment and agriculture (Miljövårdsberedningen 1989) discussed major environmental problems associated with modern Swedish agriculture, including nutrient leaching, eutrophication, pesticide spread, landscape transformation, the depletion of many species related to the historical development of agriculture, as well as the reduction of various other valuable elements in agro-ecological systems. Animal welfare in agriculture also became widely discussed at that time and new directives have been established to improve conditions.

In many respects the 1980s marked a turning point in relation to society's new demands upon and attitudes toward agriculture (Drake 1989). On the one hand, the increasing costs of exporting food surpluses became unacceptable. According to the OECD (1988), the total subsidies paid to Swedish agriculture, as measured in producers' subsidy equivalent for regulated production, almost doubled between 1978/79 and 1985/86. This not only constituted a large economic loss for consumers and taxpayers alike, it was also problematic in respect to the developing countries and to international trade agreements concerning agricultural products, both of which demanded lower subsidies. On the other hand, it became clear that society wanted more than food production from agriculture, and that food had to be produced in ways acceptable to society and without serious environmental problems. That the political system was responsive to such issues was indicated by the fact that a number of policy measures were introduced in order to rectify the problems that arose from the intensive type of farming associated with the policy of high prices for agricultural products.

In short, agricultural policy based on high food prices was revealed during the 1980s to be inadequate in respect to certain basic objectives of agricultural policy, such as food security, farm income, regional distribution, and consumer welfare. Emerging trends in respect to international agricultural development as well as societal demands concerning agriculture make it necessary that policies based on price supports and a high degree of regulation be replaced with policies based upon direct support for environmental and regional objectives. While this should lead to fewer farming regulations, it should also encourage stricter environmental and technological controls. In addition, this type of policy should stimulate environmentally friendly farming along with the utilization of resources, particularly arable land and labor, for the development of new products (Saifi and Drake 1990).

4.2. Economic Rationale for Environmental Policy in Swedish Agriculture

Demands for environmental improvement have steadily grown in recent decades in respect to the production of goods and services as well as the conditions of human settlement. At the same time, agriculture has received substantial financial support in industrialized countries in spite of the associated economic costs and the advocacy of free trade. The issue of agricultural sustainability, which has also been increasingly emphasized in recent years, involves the protection of the ecosystem, the circulation of nutrients, and a reliance on renewable resources. But the trend in Swedish agriculture has, on the contrary, been towards increasing specialization and the concentration of food production on the most productive land. This section argues for an agricultural policy that includes the social costs and benefits of agriculture by paying farmers for their positive services on the condition that they implement certain measures that decrease environmental degradation and reduce costly exports.

Paying farmers for environmentally friendly production was practiced in the EC on many occasions (Harvey and Whitby 1988), and such practices as taxing the use of fertilizers and pesticides have been carried out for many years in Sweden. There are also various alternatives to CAP price policy that can improve environmental impact and reduce production surpluses, such as input taxing (Harvey 1989). A less attractive practice was the EC's land set-aside program, which reduced surpluses but hardly affected intensification. A more attractive possibility involved the reduction of production surpluses in the EC through environmental measures (Weinchenk 1990).

Welfare economic theory views environmental issues as side effects or externalities. They require policy intervention by the state so that their negative effects can be reduced or eliminated and their positive effects enhanced or maintained. The fact that the exact values of environmental costs and benefits cannot be determined in most cases implies that the importance of an environmental policy resides in whether it improves the situation, not in whether it defines the optimal solution. It is important to note in this regard that consumers' reactions to unacceptable methods cannot be equated solely with purchasing power. As citizens, they may very well be able to affect such issues as how farm animals are treated.

The lesson of agricultural supports

It is difficult to see any economic rationale underlying many of the farm commodity support policies typical of the industrialized world. This is particularly the case with price subsidies, whether in the form of import levies, or in that of deficiency payments. For example, the World Bank (1986) argues that the price support policies of industrialized countries have had a minimal long-term effect on farm income while at the same time being expensive for consumers and taxpayers and depressing international prices. Winter (1988) argues that less expensive policies may very well be more effective in meeting many of the stated objectives of various OECD countries, which are essentially economic in nature. Hayami (1986) points out that an increase in agricultural protectionism, including price supports, is a common phenomenon in countries whose agricultural competitiveness is declining. Both Winter and Hayami demonstrate that agricultural subsidies are in fact related to the vested interests of farm organizations, bureaucrats, and politicians. But regardless of the specific reasons behind increasing agricultural protectionism, one may conclude that agriculture provides certain services that become more important when the relative size of the sector decreases.

In the EU in general, and in Sweden in particular, the protection of agriculture through price subsidies and import levies has brought about a troublesome increase in food surpluses and has led to environmental degradation. And when food surpluses must be exported at subsidized prices, it is difficult to justify income redistribution to farmers by means of price subsidies, not least of all because a great deal of such support goes to non-farmers (input sellers and land owners). It is thus necessary to search for policy instruments that reflect social benefits and costs, reduce the negative effects of price supports, and effectively promote agricultural sustainability.

From the point of view of welfare economics, and assuming no external benefits and costs, optimum price and production levels should lie at the equilibrium point where supply and demand curves intersect. When prices are set at a too high level, production will increase and demand decrease, leading to surpluses that must be exported at international market prices minus transport and other costs. The case with agriculture, however, is much more complex. For example, underlying the supply curve are thousands of supply curves arising from individual farms, some of which have higher than average production costs. This can be the case for many reasons, including regional, climactic, and soil factors as well as the use of less "rational" production methods due to habit, a lack of knowledge, environmental concerns, or even limited financial capability. This can have important consequences for the environment insofar as practices with a positive environmental impact, such as crop rotation, mixed crop and animal production, the preservation of traditional landscapes, and the restricted utilization of pesticides and mineral fertilizers, are common among relatively high cost farms.

The plain, forest, and northern Swedish agricultural regions have different cost structures, with the lowest being associated with the plains and the highest in the north because of the differing climatic and soil conditions. Given food surpluses and low transport costs, an internal free market system within Sweden would lead to prices that are not sufficiently high to cover production costs in most of the northern districts and in many of the forest districts as well. A policy of higher prices would thus be important if it is desirable to maintain farming in high-cost regions. However, this would also stimulate more intensive farming in low-cost regions, with its attendant problems. Jonasson (1989) demonstrates that lowering the prices of Swedish agricultural commodities through deregulation would reduce production intensity and lead to certain environmental improvements, but that it would also drastically reduce agricultural services, especially in Norrland and in the forest districts. Much of the reduction in production would come about through the rendering of certain agricultural lands unprofitable, but many relatively more environmentally friendly farms would also disappear.

The conventional approach of reducing prices, introducing direct payments for various non-market services, and levying direct taxes for environmental pollution could provide a solution to such problems. But this would be much more complex than it may at first appear not only because of the complexity of agricultural services, but also because subsidies paid to a given group of farmers actually affect other farmers as well. For example, paying certain farmers for what is considered to be their more valuable landscape means that certain other farmers may well have to go out of business. Hasund (1990) suggests that payments for landscape services be based on the relative value of each segment of landscape. Although this approach is in principal correct, it is difficult to see how it could be practical in light of the necessary costs associated with detailed planning and the required organizational structures. Taxing farmers for the negative environmental effects of production would be even more complex and costly.

The Swedish agricultural policy reform of 1990 (Ministry of Agriculture 1989) introduced some degree of price reduction; offered relatively large payment for planting forest on arable land, thereby taking relatively large areas of arable land out of production and reducing the agricultural labor force as well; and created special subsidies for northern areas and for highly valued landscape. But the lands transferred into forestry may well be needed in the future since such global environmental problems as land degradation, air and water pollution, and climate warming may substantially decrease future world agricultural production (Chapter 5). Moreover, agriculture in Sweden stands to face improved conditions in the future, especially in relation to increased photosynthesis and the use of biomass in energy production. This implies that the present excess capacity in terms of arable land and labor may acquire a new importance in the future. One might argue that these resources could be brought back into production when needed, but this could well involve very high costs, especially when there are no longer farmers in a particular area to cultivate the land. This does not indicate that agricultural land and farm labor should be protected at any price, but it does mean that decisions to retire such resources must be based on social costs and benefits, and future expectations, not just private considerations.

An alternative solution that will be discussed below is to introduce conditional support on the basis of agro-environmental considerations. This involves paying farmers for the positive services they provide, such as landscape amenities, on the condition that they implement certain measures that both have a positive effect on the environment and also reduce production. This type of approach may in fact prove important in the process of steering agriculture towards sustainability. It can also be combined with price reductions and a certain level of imports, but this comprises a topic for further discussion elsewhere.

Social benefits of an environmental policy in agriculture

In a narrow consideration of the economic benefits of an environmental policy, it should be noted that neoclassical economics maintains that environmental improvements should be carried out as long as their marginal benefits exceed their marginal costs to producers. The usual market solution for an environmental problem involves an equilibrium between marginal social costs (MSC), which rise as environmental degradation increases, and the marginal producer costs (MPC) for reducing degradation, which rise as the level of improvement increases.

If the level of environmental degradation is greater than the point of equilibrium, then the marginal benefit to society for reducing this level exceeds the marginal costs that would be incurred by producers to do so. A policy that reduces environmental degradation to the "optimal" level would thus result in social benefit, assuming zero transaction costs. And even if taxpayers pay for such improvements in the form of compensation to farmers for the costs they incur, there would still be a net benefit to society. We should note here that it would not be appropriate to accept a reduction in environmental pollution that does not sufficiently protect the interests of future generations, account for risk and uncertainty, address accumulation degradation, and prevent irreversible change (Section 2.2).

A growth in awareness, education, and income, along with the possible accumulation of environmental damage, may increase the marginal social costs of degradation in the long term. In addition, technological innovations, which can be induced by regulation, information, and economic incentives, will decrease the marginal production costs of reducing environmental problems. The point of equilibrium thereby becomes associated over time with a decreased level of environmental degradation. This lends support to the argument that economic incentives to improve the environment should now be introduced, even if the present level of pollution is at a point where MSC is lower that MPC.

It is not possible in reality to identify MSC and MPC for every environmental problem in agriculture because of the complexity of the issues involved. Nevertheless, it appears likely that measures adopted to reduce environmental degradation, such as the reduction of nutrient leaching, an increase in carbon deposits, or a decrease in pesticide usage, would also reduce crop production. But in a country having higher than international prices and with surpluses that must be exported at prices lower than production costs, as has been the case in Sweden, particularly during the 1980s, implementing these types of environmental policies would generate additional welfare benefits since the deadweight losses incurred from the maintenance of high prices would be reduced. Since agriculture supplies many important services to society without payment, including food security and landscape, compensation for the increased costs associated with environmental measures can be replaced by payment for such services. In addition, such payments can be conditioned upon environmental improvements. For example, farmers can be offered compensation per hectare or even per animal upon the condition that they adopt measures that reduce production as well as environmental damage, such as using legumes for rotation, not cultivating certain areas, and not using certain methods.

In principle, significant economic benefits thus follow upon the implementation of a policy that would pay farmers for their social services upon the condition that they adopt certain measures that reduce environmental degradation because of the subsequent reduction in export subsidies as well as the social benefits brought about by environmental improvement. (Important issues such as transaction costs and other countries' reactions are not considered here.) Although the export of surpluses is now regulated by European agricultural policy by virtue of Sweden's EU membership, and while certain food products that were in surplus during the 1980s are now imported, such as meat, this argumentation remains sound.

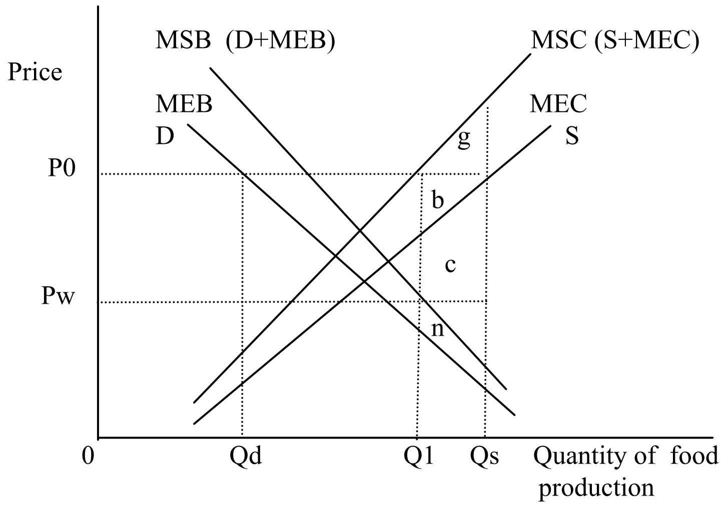
The social costs and benefits of agriculture

Other approaches may also be used in analyzing the positive welfare effects associated with the implementation of a policy of conditional support, such as relating external costs and benefits to the supply and demand curves of agricultural production. The aim in this regard is to illuminate differences between farms having different environmental records.

In Figure 4.1, the marginal external costs of environmental degradation (MEC) are added to the marginal private costs of food supply (S) in order to determine the marginal social costs (MSC). The marginal external benefits of environmental services or benefits (MEB) are added to the marginal private benefit of food demand (D) in order to determine the marginal social benefits (MSB). The slope of MSC is steeper than the supply curve because marginal external costs increase as production increases. The slope of MSB is steeper than the demand curve since marginal external benefits decrease as production increases. At Qs production level, marginal external costs are thus likely to be greater than marginal external benefits, especially when total external costs are not substantially lower than total external benefits. Stated otherwise, decreasing the level of production would result in external welfare improvement as long as MEC is greater than MEB. Similarly, increasing production from a low level, such as Qd, would result in external welfare improvement as long as MEB is greater than MEC.

An exhaustive examination of "optimal" price and production levels in respect to Figure 4.1 is unfortunately beyond the scope of the present discussion, not least of all because of such problems as the differing levels of external costs and benefits among farmers. For example, one could argue, given domestic deregulation, that optimal price and production levels are located at the equilibrium point where MSB and MSC intersect. This assumes that each farmer were paid and taxed individually for positive and negative externalities respectively. In light of the impossibility to meet this assumption at reasonable costs and the fact that low or very low product prices, for example international market prices, may render food production in many communities or municipalities unimportant, it may be useful to address the issue in different or complementary ways. The following analysis assumes high prices for agricultural commodities and the existence of some surpluses, like milk, or potential for future surpluses due to technological development and stagnant or degreasing demand in order to present some important points in relation to macro level analysis and the problem of aggregation. The purpose is to highlight the usefulness of the policy of conditional support within the context of a sustainable path of agricultural development, not as an alternative to the policy of taxing pollution and paying for services but rather as complementary instrument that could be useful for strengthening local coevolutionary processes and improving the principles of sustainable agriculture depicted in section 6.4, especially regarding crop rotation and integrating animal and crop production.

Figure 4.1 Improving economic welfare through decreased food production



If P0 is the present price level for farmers and Pw is world market prices, decreasing production through a policy of conditional support, such as from Qs to Q1, would result in the following welfare changes (assuming 0 policy costs):

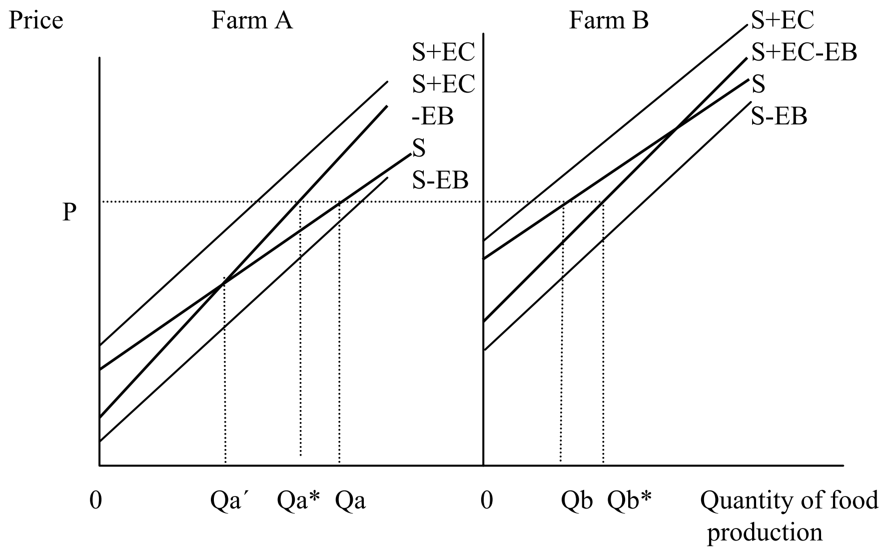
consumer surplus	= 0
producer surplus	= -b
external social benefits	= -n
external social costs	= +b +g
export subsidy	= +b +c
net welfare	= +b +g +c -n

And since (n) is assumed to be relatively small (low marginal external benefits when production is high), decreasing production would clearly lead to welfare improvements. But in order to attain such welfare benefits without any farmers and consumers being worse off (no consideration is given to the losses of other groups), it is necessary to compensate farmers for their losses, which are indicated by (b). It would not be necessary to compensate consumers for decreasing external benefits (n) if the latter are lower than the external gains (b+g), and if the same consumers gain and lose. However, this may very well not be the case in reality, especially if the reduction in production is concentrated in particular regions and/or based on reducing the area under cultivation rather than reducing intensity.

Most of the external benefits in Sweden arise from the cultivation of land in areas throughout the country, while most of the external environmental costs stem from production “rationalization” and increased intensity. It thus follows that there will be greater benefits from a decrease in external costs if reduction in production is primarily based on reducing intensity rather than the area cultivated. This implies that the compensation paid to farmers must be greater than (b) if production is to be reduced to Q1 and if the reduction in external costs is larger than the reduction in external benefits (b+g > n). The supply curves of the more environmentally friendly farms lie in the upper range of curve S in Figure 4.2, while those of less environmentally friendly farms lie in lower range.

Looking at these issues at the level of individual farms may help clarify this important point. In Figure 4.2 we represent the sector by two farms (or two types of farms) with differing production costs and external side effects. This reduces the sector's supply curve, along with both MEC and MEB, to the farm level. Farm A produces at level Qa in response to the given price P, where marginal external costs are higher than marginal external benefits. MEC is added to the supply curve S in order to determine the curve S+EC, and MEB is subtracted from S in order to determine S-EB. External costs exceed external benefits at a production level higher than Qa´. The net of external benefits and costs is represented by the curve S+EC-EB. Farm B produces at the level Qb, where MEB is greater than MEC.

Figure 4.2 A reduction in food production with an increase in net external cost and benefits



A reduction in farm A's production would thus result in positive net external costs and benefits. On the other hand, a reduction in farm B's production would result in negative net external costs and benefits. This implies that in order to reduce total production under the condition of b+g > n, as in Figure 4.1, we must concentrate the reduction on farm A's production, i.e., on farms with negative net external costs and benefits. The theoretically optimal reduction should be based on the farm's marginal costs plus the marginal external costs and benefits (S+EC-EB). However, not only is it in fact impossible to obtain the required accurate data for each farm, it is evident that such an attempt to reduce production would involve unreasonable costs. Nevertheless, this type of logic must be followed when implementing a policy to reduce production, particularly when some data concerning external costs and benefits are available on the regional level. Additional difficulties arise if the price level P in figure 4.2 is related to price P0 in figure 4.1 since choosing the initial price level become problematic and net prices become differential. These arguments reveal that connecting agro-ecological problems and services to production level is not problem free approach, especially when we have a number of products some of which, like lea, have no established or regulated market.

Sustainable agriculture and conditional support

One could argue that it is more rational in economic terms to pay farmers individually for their external services and tax them for their external costs than to base policy on the net benefits and costs of external effects at sector level insofar as the former produces incentives to reduce external costs and increase benefits (Drake 1994). If such a policy were to be followed in respect to Figure 4.2, farm A would decrease production to level Qa* and farm B would increase production to level Qb*. Moreover, farmers' reactions become important when the payments/taxes involved are substantial, particularly in respect to their attempt to reduce environmental taxes and increase payment for agro-ecological services by improving environmental performance. This implies that including the social costs of environmental degradation as well as the social benefits of agricultural landscape would radically alter the profitability of various Swedish farms and define production alternatives. However and as shown above translating this logic to optimal price and production level is problematic.

If farmers were taxed for damaging the environment, they would have a strong incentive to reduce the practices involved. This could result in reduced intensity, a more efficient use of pesticides and nutrients, crop rotation, taking certain areas out of cultivation, etc. But since such taxes, which may be quite large, are neither realistic, nor feasible for many reasons, not least of all our inability to measure accurately the costs involved, it appears more reasonable to request that farmers take such measures voluntarily. In order to facilitate this, one could provide financial support conditioned upon external benefits. If most farmers would accept such terms, the environment would improve and production would decrease. This would reduce both pollution and export subsidy costs.

It is clear that agriculture's external costs and benefits are issues directly related to sustainability that cannot be merely resolved in a mechanistic and reductionist fashion since not only are they also related to many other issues, no optimal levels can be identified. As revealed in section 2.3 in a sustainability context the costs and benefits of improving an environmental problem is important for determining the level of the improvement but as important is changing the conditions that constitute costs and benefits so that more improvement become feasible. Chapter 3 postulates that a system of sustainable agriculture comprises processes of changes that link the ecological and social systems at both local and regional levels and lead to a reduction of what a given society perceives to be unsustainable. In addition, the pace and strength of this development must be contextual and related to a society's appreciation of, commitment to, and demand for agricultural services accompanied by a reduction in undesirable effects. A policy of conditional support can provide the economic basis for a reasonable or feasible level of change through a consideration of the costs and benefits of positive and negative "externalities." Moreover, indicators of ecological and economic sustainability complement each other since both are needed to promote sustainable development (Rennings and Wiggering 1997). Ecological sustainability determines physical constraints and the direction we should take, while economic sustainability determines how far we can proceed in this direction.

The realization that Swedish agriculture must sooner or later be driven towards sustainability raises the need for suitable policy instruments. And since there is no operational definition of sustainable agriculture yet available, we have no choice but to understand the issue as consisting of processes of change that both reduce environmental degradation and facilitate the implementation of such crucially important practices as the recycling of nutrients and the use of renewable energy. The flexibility inherent in a policy of conditional support may well make it capable of responding to changes in technology, values, and degree of commitment to sustainability such that it promotes agricultural change of the type we have been discussing through alterations in payment amounts and conditions.

Three important issues should be mentioned at this point, particularly in relation to the processes of change that lead to sustainability. The first is importing food from other regions or countries, which becomes more feasible as environmental regulations (conditions) are introduced without compensating farmers for the costs incurred. The second is the increased excess production capacity that results from technological innovation and from stagnation in food demand. This increases both the pressure to remove resources from the sector, as well as the prospect of taking further steps toward sustainability. And the third is the possibility of a declining reliance upon environmental ethics as environmental taxes are introduced. Frey (1992) illustrates how environmental taxes tend to crowd out environmental ethics while regulation and subsidization tend to support them.

Conditional support for agriculture can play an important role in responding to the growing demands to improve the environment and decrease production surpluses, and may even strengthen environmental ethics. It has the advantage of having relatively low administration costs since only sample control is required. It is also capable of flexible response to local requirements and changes in conditions, can serve inducing certain characters such as crop rotation, responds to import competition, and maintains a portion of excess land and labor resources in the agricultural sector. Yet it should not be seen as alternative to the principle of paying farmers for agro-ecological services and taxing them for environmental problems, but rather as an important complementary instrument that could be useful for addressing complex and diffuse problems or services, especially in strengthening local coevolutionary processes within a context of a sustainable path of agricultural development.

4.3. The Greening of Swedish Agricultural Policy

The greening of Swedish agriculture in terms of reducing agro-environmental problems is not isolated from the general environmental movement in countries throughout the world. As Section 2.3 observed, the latter began to develop with the emergence of post-modern societies in the 1960s and eventually became a mainstream social and political issue in the 1980s. Environmental organizations together with the mass media brought to the public a picture of global as well as local problems. As a result, politicians changed their political platforms in order to convince voters of their environmental commitments, while corporations redesigned their public relations strategies in order to create environmentally friendly images of them selves. The greening of agricultural policy, particularly in industrialized societies, and its transformation into the general goal of developing a system of sustainable agriculture, in fact arose upon the problems accumulated since World War II by virtue of the previous policies that had been implemented (Goodman and Redclift 1991; Vail et al. 1994).

Vail et al. (1994) view crises both as conditions arising from the past, and as processes leading into the future. From this perspective they demonstrate how the agricultural crisis that intensified during the second half of the 1980s in relation to increased food surpluses in industrialized countries, depressed international food prices, and the growth of environmental concerns transformed the basic concern in respect to agriculture from food production to the provision of a broad range of social services. Decades of agricultural protection and support on the basis of state budgets and high consumer prices had led to chronic surpluses in food commodities. This changed the EU from being a major importer of food into a major exporter competing on the international market with heavily subsidized prices. Moreover, this increase in production was associated with accumulated pollution and resource depletion because of the constant need to adopt new chemical, mechanical, and biological techniques. And as the WCED (1987) urged industrialized countries to help developing countries follow a sustainable path of agricultural development, subsidized exports put many farmers in the same countries under continuous pressure from low-priced imports. It must be noted that this agricultural crisis is directly related to the international expansion of the capitalist system, particularly in agro-industrial activities. Goodman and Redclift (1989) illustrate that the “Food system in the post-war period has been increasingly internationalized as a result of the closer interaction of national markets, common technologies, more uniform patterns of food consumption and the overarching strategies of international agribusiness” (p. 3). This system must change because of the weight of its internal contradictions, and also in light of the growing criticism of modernity and globalization (Bonanno and Constance 2001).

Like many other industrialized countries, Sweden introduced various measures during the 1980s in order to reduce surplus production, such as the set-aside program and milk quotas. Other measures were also implemented in response to environmental concerns, such as taxes upon the sale of mineral fertilizers and biocides and the provision of financial support for conversion to organic farming. These agro-environmental measures are not isolated from prominent structural changes in agriculture since late 1940s, such as increasing farm size, specialization, capital accumulation, the growing use of technologies and external inputs that increase production and save labor, the consolidation of farmers' organizations, the consolidation of agricultural policy, and the shift of farming to plain regions. During the 1970s farmers enjoyed very favorable conditions that stimulated increased production and food surpluses. Both high international food prices and domestic retail food subsidies were behind what has often been called the golden age for farmers. During the 1980s, consumption and export subsidies became unrealistic and problematic due to falling international food prices and the increasing budget burden.

The relative priorities of agricultural policy have varied during the twentieth century as the internal and external conditions of agriculture have changed and as the public willingness to support both farmers and policy has risen and fallen (Vail et al. 1994). The modern policy of variable import levies and market regulation took shape during the 1930s in response to the need to provide farmers with an adequate income that was comparable with non-farm wages. Society in general and the state in particular had already long been involved in increasing food production and food security. During the 1950s the rationalization of agriculture in order to provide adequate farm income and free up labor for non-farm sectors were the main aims of agricultural policy. During the 1980s important policy objectives came to include food safety, consumer welfare, regional balance, and agro-environmental issues (Ministry of Agriculture 1989). Although food security had been the main objective in agricultural policy throughout the twentieth century, the vulnerability of the sector in fact substantially increased between 1940 and 1990 by virtue of dependency on mineral fertilizers, biocides, and imported fossil fuel and fodder (Andersson and Brorsson 1991). Since the 1980s it has become a burden on society to increase food production, but food security has remained a major objective of agricultural protectionism.

The emergence and development of Swedish agricultural policy can be more adequately articulated by reference to the concept of "negotiated economy," which asserts the role of state-led negotiations with interest groups in decision-making, than in respect to public choice theory, which asserts the role of farmers' organizations in policy decisions that economically favor farmers (Micheletti 1987; Vail et al. 1994). Swedish reality is distorted in many ways by the argument (Bolin et al. 1986; Winter 1987) that the formation of agricultural policy is closely related to the vested self-interests of farm lobbies, bureaucrats, and politicians. Agricultural policy in Sweden is in fact formulated through a multi-stage legislative process that involves even consumer delegates and encourages public debate. In this respect it should be noted that the Social Democratic Party, which primarily represents Swedish workers, played a leading role in formulating farm policy throughout the twentieth century. Such issues as the living countryside, open landscape, food security, food safety, and price stability for both producers and consumers are real issues of concern for society as a whole that cannot be created merely by farmers and their representatives. Most Swedish politicians as well as people in general have a strong attachment both to the countryside and to farmers, who are viewed as carrying a valuable historical heritage (Vail et al. 1994).

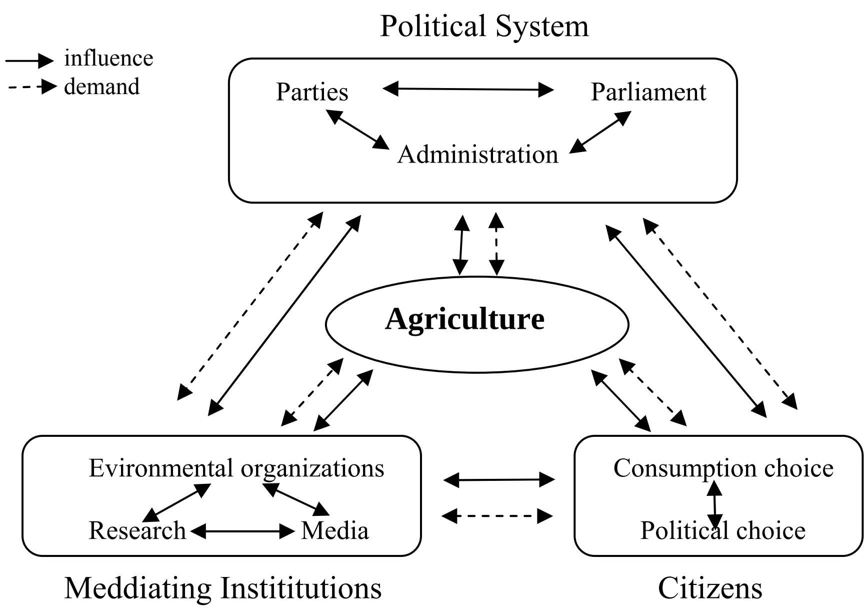
The negotiated economy consists of four evolving and interacting institutions that shape resource allocation and income distribution (Vail et al. 1994). Three of these, namely, competitive markets, representative government, and administrative rules and regulations, are institutions common to most contemporary mixed economies. The fourth institution, which in Scandinavian countries has played a decisive role, particularly in agriculture, involves state-directed negotiations between interest groups that have conflicting economic interests. State-initiated negotiations between tenant and landlord organizations and between trade unions and employer federations arose even before the development of modern parliamentary democracy and representative government, at least in Sweden. This institution has weakened in recent years as competitive markets have gained ground and as Sweden has become an EU member. It still exists, nevertheless, and may even come to influence decision-making procedures within the EU.

Changes within Swedish agriculture during the twentieth century, including the evolution of policy, have largely been based upon the modern view of development described in Figure 2.1, in which rational scientific analysis and design are considered to be the best means for identifying solutions and optimizing well-being. Natural and social scientists in fact continue to play important roles in decision-making regarding agricultural policy. Although the role of experts in policy implementation has also been large, especially in relation to their significant independence in carrying their duties as civil servants, their role in policy making has been subordinate to the negotiation institution, which includes the agricultural marketing board, farmers' organizations, and consumers' delegations. The resulting interaction involving experts, politicians, and interest groups has contributed to the formulation of a generally balanced farm policy that has been responsive to the changing economic, political, and social conditions. Most of the many modifications in agricultural policy during the twentieth century can in fact be attributed to changing conditions. For example, not only do the substantial policy changes of the late 1980s clearly reflect changes in economic realities in terms of the increased costs of food exports and the need to restrict state spending in order to curb inflation and reduce food prices, they also reflect the social reality of increasing environmental awareness. These realities influenced, and were to some extent influenced by, new political alliances and agendas.

The increased environmental demands placed upon agriculture during the 1980s arose in relation to the interactions between four major groups of forces, namely, mediating institutions, the food production system, citizens, and the political system (Vail et al. 1994). Figure 4.3 can be seen as an expansion of the model presented in Chapter 3 (Figure 3.1) in order to illustrate the growing awareness of agro-environmental problems and the increasing demands for green measures from the socioeconomic system. Although Sweden is now more affected than before by European agricultural policy, Figure 4.3 is still useful for identifying ways to influence future changes in Sweden and other EU countries. For example, the Swedish position that environmental conservation should play a greater role in CAP (Ministry of Agriculture 1997) may eventually lead to increased national responsibility concerning the impact of agricultural methods upon the environment.

Concern about agro-environmental problems has a history of over one hundred years in Sweden, beginning with the voices raised in the late nineteenth century against the large-scale state-led drying of wetlands. Criticism during the 1950s and the 1960s against the loss of agricultural lands and the use of hazardous chemicals led to directives to protect agricultural land and to the eventual banning of DDT during the 1970s. During the 1980s a long list of environmental problems was placed onto the political agenda, and environmental protection, which involves the reduction of pollution, the protection of agro-ecological systems, the prudent use of non-renewable resources, and the humane treatment of animals, then became a major objective of food policy. Figure 4.3 depicts the process in which an awareness of environmental problems can eventually lead to the demand for appropriate measures to reduce them that involves the major institutions and actors who contribute to food politics. Concern about a given issue may initially begin with any one actor, but only interaction among a number of actors makes it possible for such concern to lead to measures for dealing with it.

Figure 4.3 Forces and interactions in the greening of agricultural policy



Source: Based on Vail et al. (1994)

The structure and development of modern agriculture, which is based on the survival of the cheapest with no integration of positive and negative environmental, economical, regional, and social effects, has been subject to the criticism of mediating institutions, the political system, and citizens. This has also included interaction involving research institutions, environmental organizations, and the mass media, the size and the role of which have increased dramatically in post-industrial societies. In addition, growing affluence, knowledge, and contact with various institutions have motivated people to place new demands upon the agricultural sector that are much more complex than the sheer need for food. For example, citizens and consumers have brought pressure to bear upon the farming system to deal with environmental degradation, ecological amenities, food safety, regional distribution, and the proper treatment of animals in all aspects of production. Politicians and administrators have also become engaged in bringing about change on local, national, regional, and global levels in response to these increased demands, and policy changes have become based on both self-interests and moral commitment.

A new view of the function of Swedish agriculture began to develop in the 1980s. Whereas the emphasis had earlier been upon food security and regional development, it has now shifted to the reduction of negative externalities, the maintenance of the agro-ecological landscape, the recycling of nutrients, the production of renewable bio-fuels, and the use of less hazardous production methods. A number of measures were taken to reflect this shift as early as the second half of the 1980s, including the taxation of fertilizer and biocide use, regulations to improve manure management, subsidies to organic farming, nutrient-catch crops, bio-energy production, animal protection laws, and payment for the maintenance and improvement of areas judged to be of high agro-ecological value. These measures, which Vail el al. (1994) describe as piecemeal responses to increasing green demands with no coherent underlying strategy, were clearly experimental attempts to reduce agro-ecological problems associated with the industrialization of farming. They have been subject to change as people have learned from their own and other's experiences.

Vail et al. (1994, table 7.5) assess the direct performance of the major agro-environmental policy measures of the 1980s in terms of goal attainment and cost effectiveness. In addition, they do so in relation to four major objectives of greening, namely, the reduction of environmental pollution, agro-ecological conservation, sustainable resource use, and animal welfare. They conclude that while the measures in question have contributed significantly to goal attainment, certain of them, including the increase in manure storage capacity and organic farm support, have not been cost effective. However, five significant weaknesses can be identified in their analysis, some of which they themselves recognize. First, indirect and psychological effects can be both large and difficult to assess, especially in the long run. Second, pluralistic democracy cannot be subject merely to value-laden standards of economic efficiency. Third, the ways in which a given policy measure avoids or reduces certain costs must be included in the assessment. Fourth, the initial cost of any project is greater than what it would be in the long run. Fifth, such complex issues as support to organic farming cannot be reduced to simplistic cost/benefit analysis, even though cost effectiveness must always be considered, as Section 2.3 discusses. Such issues may in fact help explain why organic farming expanded to about 10% of arable land in 1999 and is projected to increase to 20% by 2005.

4.4. Implications for Agricultural Sustainability

Chapter 3 serves to support the key argument that a strengthening of local coevolutionary processes is likely a pre-condition for developing a system of sustainable agriculture. This conclusion contradicts historical development in Sweden since the 1950s, in which linkages between towns/cities and agriculture have steadily weakened. Such linkages were food-based and very strong in traditional agriculture, which coevolved with the nearby city or town. However, certain important features of ecologically sustainable traditional agriculture, such as animal and crop integration and the rotation of crops and lea, are still practiced on large portion of farmland. Agricultural lands also remain relatively well distributed throughout the country. In addition, interest in non-marketed agricultural public goods and services, particularly the agro-ecological landscape, has grown in recent decades. If people are willing in sufficient numbers to pay for such services, a strong case can be made for replacing linkages based on food production with linkages based on agro-ecology. Nevertheless, linkages involving local food production and consumption may need to be strengthened in the near future because of anticipated world energy shortages.

When agricultural sustainability is addressed in a more holistic way, costs and benefits are merely elements of the agricultural system that are related to values in a particular time and place. Values and technological changes, which are key issues for long-term development towards sustainability, are also important system elements that cannot be taken as given. In fact, many of the trends discussed in Section 4.1 are related to changes in values and technology, both of which have been influenced by abundance and scarcity in respect to resources. If we expect that there will an increasing shortage of energy, especially fossil fuel energy, then we should also expect that values and technology will develop in a manner that both stimulates and enforces a more prudent use of energy resources. Such a direction of development is decidedly different than the one associated with the period of industrialization. Similar arguments also hold true for the use of other resources and for environmental degradation as well. Two important consequences follow from this pattern of reasoning.

First, the costs of enhancing sustainability will decrease over time while the benefits will increase. Building a system of sustainable agriculture is clearly a costly project, but as Section 4.2 discussed, gradual improvements in respect to sustainability may very well entail only small costs, and possibly even net benefits, if social costs and benefits are considered. Costs and benefits understood in a broad way may indeed be moving to support measures that strengthen agricultural sustainability.

Second, today's high farming costs in Sweden should not be permitted to dominate agricultural development by driving the production of cheaper primary foods, the implementation of greater intensity, and the abandonment of large areas of arable land, especially in less productive regions. It is time to take advantage of the current potential to improve agricultural sustainability and invest, at least partially or experimentally, in a type of development that is responsive to the rapidly growing shortages of various natural resources. This can provide Swedish society in general, and agriculture in particular, with knowledge and experience important for steady development towards sustainability.

Sections 4.2 and 4.3 have brought to our attention the usefulness of the policy instrument of conditional support for improving agro-environmental policy measures. Indeed, there may be no practical alternative, especially in the short term, to conditional support in efforts to strengthen coevolutionary processes on the local level, which is argued for in Chapter 3. Chapter 3 also argues that it is necessary to alter production methods and land usage as well as technology and values in order to develop appropriate short and long-term responses to today's challenges. Such strategic choices need to take into account the fact that changes in environmental policy arise out of interactions between citizens, mediating institutions, the political system, and agriculture itself, as Figure 4.3 depicts.

The modern food system in industrialized countries emerged through and has been enforced largely by policy interventions beginning in the 1930s. These have encouraged the industrial sector to act as the driving force for a continuous restructuring of agriculture around the industrial production of food for mass consumption (Goodman and Redclift 1991; Vail et al. 1994). Policy intervention is also capable of dealing with many of the environmental and social contradictions that industrial farming has created, even if doing so may involve both financial and political expenses. The present chapter argues, however, that the expenses associated with pursuing a path of sustainable agricultural development may in fact be relatively low in Sweden. On the one hand, public interest in farming is strong in three major respects, namely, reducing environmental degradation, maintaining a viable countryside and agro-ecological landscape, and having safe and high quality food. With some 20% of disposable income spent on food and a farming workforce of only 2% of country's total, the ability to pay farmers for improved agro-environmental management, including food safety and the humane treatment of animals, should be very large. On the other hand, Swedish political institutions function reasonably well in translating public demands into policy intervention. All parties represented in parliament have placed the environmental issue on their political platforms, and many non-governmental organizations have assumed important roles in the formation of environmental policy.

5. Environmental Degradation and Future Global Agriculture: Implications for Agricultural Sustainability

5.1. Introduction

It becomes necessary at this point in our discussion to investigate the extent to which environmental degradation and resource depletion may affect global agriculture in the future. Our examination of this problem will draw upon Environmental Degradation and Future Global Agriculture (Saifi 1997) insofar as this work provides insight into the current possibilities for promoting a system of sustainable agriculture in Sweden and also addresses global issues that need to be considered in this regard. It also discusses the implications of the model developed in Chapter 3 for a projection of future food supply and demand.

It has become obvious that land and water degradation, climate warming, water scarcity, air pollution, and the reduction of biodiversity will significantly affect global agricultural production capacity. But we also need to quantify the effects of environmental degradation on global food production and prices in order to obtain information needed for decision-making on many levels. The coevolutionary model of agricultural development presented in Chapter 3 is not entirely appropriate for application at the global level because of the existence of a multitude of diverse agricultural, socioeconomic, and ecological systems. Nevertheless, certain global issues can be clarified through a widening of coevolutionary processes in relation to the globalization of food systems. Of particular importance are the constraints imposed on food production systems by the sum of ecological systems, or the biosphere. And even though this model does not rely upon static cause and effect relations, it does enable us to discuss in a critical fashion possible future developments by means of a reductionist perspective.

Alexandratos (1988) and the FAO (1993) emphasize the importance for agriculture of resource degradation, but they did not incorporate this problem into their projections of increased costs or reduced production. Although Crosson and Anderson (1992) discuss land degradation and climate warming as they address the prospect of meeting cereal demand in 2030, they do not integrate it into their analysis. On the other hand, Harris (1990) incorporates environmental degradation into his projection of demand-driven production by compensating for constraints upon land resources with an increased use of fertilizers in order to satisfy future demand. But all such demand driven studies have two shortcomings. The first is that they do not include the direct effect of reducing agricultural production capacity, with a consequent rise in food prices, upon future food supply. The second is that they exclude various interactions involving a number of factors and processes that determine important parameters of future food supply and demand

(Saifi 1997). We must then look for an alternative to this type of study since it remains necessary to establish a framework for understanding the nature of various environmental problems and estimating their impact upon agriculture.

Figure 3.1 describes interrelations between the agricultural subsystem and the ecological and socioeconomic systems in order to depict how agriculture coevolves in response to various environmental problems and to the requirements of the socioeconomic system. Production and consumption activities in the socioeconomic system are the primary cause of environmental degradation, which may have a significant negative impact upon agricultural production capacity. If we can estimate this reduction in food production and integrate our findings into demand/supply functions, then we may be better able to grasp the magnitude of the problem in question in relation to future food prices and availability. In addition, environmental degradation may seriously affect the health and well being of present and future generations. Awareness of the problems caused by environmental damage, including resource depletion, increases pressure upon the socioeconomic system to respond in an appropriate manner, even though certain forces may resist necessary changes. The changes within the socioeconomic system in respect to demand, input and output prices, regulations, policies, technology, and institutions that are necessary to alleviate environmental degradation, and which arise from complex processes that reflect differing material interests, knowledge, moral convictions, and macroeconomic efficiency (Vail et al. 1994), will have a significant effect upon agriculture.

Section 5.2 attempts to determine the extent to which certain environmental and resource problems have a negative impact on global agricultural production capacity. Section 5.3 constructs a scenario for future cereal production and consumption in 2030 using simple reductionist trends. This scenario does not include the effect of environmental degradation upon the reduction of future production. Section 5.4 integrates the estimated reduction in production capacity discussed in Section 5.2 into the scenario developed in Section 5.3. Section 5.5 presents a coevolutionary critique of this analysis and discusses various implications for future production and consumption. Section 5.6 concludes the chapter.

5.2. Major Environmental Problems Affecting Global Agricultural Production

The amount of remaining virgin land has decreased over the last one hundred years as a result of the tremendous expansion of agriculture in response to population growth and increased per capita food demands. In addition, the implementation of numerous large and small-scale irrigation projects, along with the need to satisfy both industrial and domestic requirements, has increased water usage many times over. Indeed, the demand for water is still increasing rapidly, particularly in developing countries. Such factors have led to a scarcity of land and water resources in many areas, with a consequent increase in related marginal investment costs. While it is still possible in varying degrees to increase water and land usage for agriculture in most regions of the world, these constraints certainly increase investment costs (WRI 1990; FAO 1993).

Environmental degradation and resource depletion will clearly have a negative impact on production in the coming decades. In this regard, and upon the basis of available studies that have been examined in more detail in Saifi (1997), the present discussion will address land degradation, climate warming, air pollution, water scarcity, and loss of biodiversity in order to estimate the magnitude of possible damage each of these may cause. While no consideration is given here to eventual efforts to mitigate these problems, any such measures that might be taken will incur additional expense and often reduce production capacity. A clear example of the latter is the set-aside program involving marginal land in the United States that has been implemented in order to reduce land erosion.

Land degradation

Erosion, salinization, water logging, and alkalinization have substantially degraded the biological productivity of arable land throughout the world, especially in more arid areas. The related annual losses in production capacity, which have been roughly estimated at 0.3-0.5%, are equivalent to 5 million hectares of arable land. Losses of this scale over a period of forty years would result in a 13-22% reduction in production (WCED 1987; Oldeman et al. 1991; WRI 1992). It should be noted that the loss of cropland to human settlement may even exceed these estimated annual figures.

Climate change

Average global temperature may increase by 1-2 ^{o}C by 2030. This is roughly half the increase projected to occur when a doubling of the carbon dioxide equivalent (2*CO2) is reached towards the end of the twenty-first century. It is currently not possible to make reliable estimates concerning how this will effect agricultural production, primarily because the impact at the local level is affected by changes in precipitation and various other climatic factors. However, there will be an impact on production potential in four general ways, namely, a positive effect from carbon dioxide enrichment, a negative effect from the loss of land in coastal areas due to a rise in sea levels, a positive effect in regions currently with a thermal deficit if no moisture deficit occurs, and a negative effect in many areas presently suffering from excess heat and moisture deficit if there is no adequate improvement in the balance of precipitation and evapo-transpiration. Reduced production in a 2*CO2 climate may be estimated at 5-20%. Consequently, there may be a 2-8% reduction in production in 2030 based on the average of the above range, of which some 20% might be eliminated through various cost-free or low-cost managerial adjustments (Rosenzweig and Parry 1994; IPCC 1996).

Water availability and degradation

We can identify three major causes of increased irrigation costs (decreased water availability). The first is the growing demand for water by agriculture, industry, and households. The availability of fresh water for human exploitation is limited, especially in relation to geographical and seasonal fluctuations in rainfall. The second is the contamination of river water in many areas, particularly in relation to increasing salt concentrations. This degrades land and reduces production. The third is the fact that past agricultural expansion was in certain cases based on non-renewable ground water. A consequent decrease in production of 2-4% by 2030 may be a reasonable estimate (La Riviere and Maurits 1989; WRI 1990).

Air pollution

The major negative effects of air pollution on crop yield stem from increased soil acidity, rising ozone concentration in the troposphere, and increased UV-B radiation. Present ozone levels have probably caused a 5-10% decline in agricultural production in industrialized regions. Moreover, air pollution may well increase dramatically in the coming forty years if no controlling measures are taken. We may thus assume a 2-4% reduction in global food production in 2030 due to air pollution (Mackenzie and El-Ashry 1989; WRI 1992).

Biodiversity

Since plant-based genetic material has contributed substantially to increased crop production in the past, then future yields may well be negatively affected by the possible extinction of certain relevant species and cultivars. But since many wild plants are now being placed under conservation in genetic banks and protected areas, the estimated loss of production in this respect should be rather low in 2030, perhaps 1-2% (WCED 1987; Myers 1989).

Production reduction and price level year 2030

The above discussion provides a rough estimate of a 20-40% reduction in crop production in 2030 if no measures are taken to mitigate the problems in question.

Land degradation	13-22%
Climate warming	2-8 %
Water availability and degradation	2-4 %
Air pollution	2-4 %
Loss of biodiversity	1-2 %
Total	20-40%

This reduction can be expressed in terms of decreasing production at a given price, i.e., the supply curve in 2030 will shift to the left. A more intense usage of technology and fertilizers may slow the rate of decline on degraded land, but the unit production costs will continue rise until further production eventually becomes unprofitable. Subsistence agriculture will also be affected since farmers will be forced to abandon land that has become unproductive and move cultivation elsewhere. Even if new resources are available to compensate for those that have been degraded, it will not be possible to avoid increased production costs.

5.3. A Scenario for Global Supply and Demand in 2030 with No Consideration of Environmental Degradation

Unforeseen developments in such important determinants as technological innovation, environmental impact, and changes in preference make it difficult to provide reliable projections for decades into the future, particularly when it concerns such a complex issue as global food production. The method used here to estimate production and consumption in 2030 is rather simple insofar as our discussion is focused solely upon the effects of resource and environmental degradation. This is problematic concerning supply because past production trends include the effects of environmental degradation and declining prices during the 1980s. In addition, our estimates of cereal demand are based on projected population growth along with an assumption of increased income in developing countries and a subsequently larger portion of animal products in the diet.

The basic simplifications in our estimates are as follows:

1. Taking cereals to be representative of overall food production. Cereals are the basis of world diet, directly as food and indirectly as feed. Approximately two-thirds of all arable land is used for cereal production.
2. Assuming there will be a competitive world market in cereals with food prices that reflect short and medium-term marginal costs. Today, on the contrary, the agricultural sector is highly regulated and prices reflect a thin international market affected by subsidies.
3. Projecting increases in cereal supply and demand at real 1990 prices in a competitive market. Such prices would be higher than international prices in 1990, although lower than domestic prices in most industrialized countries.
4. Assuming that land and water prices are endogenously determined, and that prices of off-farm inputs, such as energy, fertilizer and machinery, follow past trends.
5. Anticipating a relatively high price demand elasticity of -0.5 and a high price supply elasticity of 0.8. The reasoning behind this is that global prices in a competitive market have a greater effect on national and regional production and demand than those in a less competitive market, especially in the long-term (Brown 1993; Haung and David 1993).

The assumption that fossil fuel and fertilizer prices will follow past trends is probably unrealistic and needs to be discussed further. This will be done in Section 5.5 below.

Future food supply

Extrapolating the future supply of cereals on the basis of historical developments provides a less reliable projection since a number of important parameters are likely to change. For example, there are various limitations on the amount of land that can be cultivated and the size of possible yields. In addition, historical trends may reflect how specific factors, such as a fall in prices, concrete policies, and environmental degradation, have affected cereal production during the 1980s. Nevertheless, adjusted trends will be used in conjunction with a discussion of the complex nature of cereal production in order to analyze both qualitatively and quantitatively various scenarios that incorporate the direct effects of resource and environmental degradation as well as the impact of policy measures taken to improve the situation.

The long-term production of cereals (Qs) can be depicted as a function of cereal prices (p), which in turn is a function of the quantity and the quality of the land under cereal cultivation (A), climate regime (C), irrigation (W), labor (L), technological change (T), environmental and resource degradation (E), institutional arrangements (I), capital investments (K), fertilizer (F), equipment and machinary (M), pesticides (Pe), and energy (N).

$$Qs = f(p(A, C, W, L, \quad T, E, I, K, \quad F, M, Pe, N))$$

It is very difficult to analyze these factors quantitatively because of the interactions that take place between them. The first four can be generally considered as on-farm, internal, or immobile resources. The second four are socioeconomic factors that are mainly affected by choice and policy. The third group consists of external inputs that are more or less globally determined in price, although their prices can be changed at the national level through taxes and subsidies. While the environmental factor has a negative impact on the productivity of resources and on production as a whole, most of the other factors have a positive effect on production when they are employed. The difficulties associated with estimating future supply by means of this function are thus very large indeed. It is more reasonable to instead use a reductionist approach that is based on past production trends without environmental degradation.

The environmental factor has an impact on agriculture in two distinct ways. The first is to reduce production because of land and water degradation, climate change, air pollution, and the depletion of biodiversity. This has already been estimated in Section 5.2, and the results of that discussion will be integrated into our projections of future supply in Section 5.4. The second involves efforts to alleviate environmental problems by means of policies implemented within the socioeconomic system, some of which may even act at the global level. This will be discussed in Section 5.5.

According to the FAO, global cereal production increased substantially during the 1950s, 1960s, and 1970s due to increasing yields and, to a less extent, larger areas harvested. However, the rate of growth slowed during the 1980s, particularly during the second half of the decade (Table 5.1). Important contributing factors for this change included falls in prices, set-aside programs, particularly in Europe and North America, and environmental degradation. For example, international farm commodity prices declined approximately 40% during the decade, most of which occurred between 1984 and 1989 (WRI 1992, p. 97). The slow growth in cereal production between 1985 and 1990 is thus largely related to the decline in cereal prices and the set aside programs, and the decline in cereal area during this period supports this conclusion.

Table 5.1 Annual growth of global cereal area, yield, and production 1948-52 to 1988-92 (five year average)[1]

	Area %	Yield %	Production %
1950-1960	0.8	2.4	3.2
1960-1970	0.6	2.0	2.7
1970-1980	0.4	2.3	2.7
1980-1990	-0.4	1.9	1.5
1985-1990	-0.4	1.5	1.0

Sources: Based on FAO Production Year Book (for several years).

This means that it is more appropriate to use the trend in production from the first half of the 1980s (2% annual increase) than from the second half in projecting future cereal supplies. There are still large areas of land that can be brought under cultivation, particularly in Africa and South America, even though doing so faces various limitations related to water supply as well as physical and chemical constraints (WRI 1990, Table 18.2 and 18.3). However, the effect upon future production of the eventual decline in the possibility to exploit new land must be taken into consideration. Similarly, as cereal yields continue to increase, the potential for future increases in yields declines. This also needs to be taken into account in supply projections.

[1] According to the FAO (2000) cereal production in 2000 was 1,852 million tons, which is almost equal to the average production between 1988 and 1992. This is interpreted in reference to changes in the system for estimating production. Extending such calculation to include development during the 1990s would require a substantial amount of work.

Assuming the existence of competitive markets and the absence of any environmental impact on agricultural production, it would therefore be reasonable to conclude that cereal supply at real 1990 prices will grow by 2% annually during 1990-2010 and by 1.6% during 2010-2030. At these rates, cereal production would increase from 1,877 million tons in 1990 (1988-92) to 3,832 million tons in 2030. This projected trend identifies a point on the 2030 cereal supply curve, enabling us to estimate price and production levels in relation to demand function with the assumed elasticity in supply.

Assuming no reduction in production capacity due to environmental degradation, as well as no increase in production costs due to resource degradation and scarcity, we may conclude that cereal production would measure approximately 4 billion tons in 2030 in light of decreasing costs and higher yields due to technological changes offset by increasing unit costs due to a declining return of inputs. This interpretation implies that if cereal prices rise/decline, a larger/smaller quantity would be produced. It also implies that real off-farm input prices will follow the same historical trend. If they rise due to environmental degradation and resource scarcity, there will be a smaller supply of cereal at 1990 prices.

Future food demand

Two major factors must be considered in estimating food demand in 2030. The first is the projected global population, which is expected to continue increasing throughout the twenty-first century at a rate lower than the 1.7% of the 1990s. The World Resources Institute (1992) and the World Bank (1992) project world population in 2025 at 8.5 and 8.4 billion respectively. If we add 0.5-0.6 billion as population growth for the period 2025-2030, we receive a projection of 9 billion for 2030. The second factor is increasing per capita cereal demand due to increasing per capita calorie consumption as well as increasing needs for animal feed. World per capita food consumption increased between 1961-1963 and 1983-1985 from 2,316 to 2,665 calories per day, with the change in developing countries being from 1,957 to 2,434 calories per day (Alexandratos 1988, p. 300). 38% percent of world grain production was used as animal feed in 1990, with the figures being 60% for Europe and 16% for Asia (WRI 1992, p. 276). We can thus project a substantial increase in cereal demand as the demand for animal products rises in response to rising income.

The annual world per capita consumption of cereals (including seeds, industrial uses, and losses) was 355 kg in 1990 (total production of 1,877 million tons and a population of 5,292 million). If we assume the per capita demand will increase annually by 0.5% in 1990-2010 and by 0.3% in 2010-2030, the annual per capita demand will be 417 kg in 2030, with a total global demand of 3,748 million tons. This demand-side projection assumes food requirements will be met even if local or regional cereal deficits occur. It also assumes changes in diet patterns similar to those experienced in the past. The figure of 3.8 billion tons is considered in terms of 1990 prices, with growth in both population and income. If the cereal price rises/falls, demand will decrease/increase. This projected demand in terms of 1990 prices determines a point in the 2030 cereal demand function, and with the assumed demand elasticity we will be able to estimate production and price levels in relation to the above estimated supply.

Balancing supply and demand

At 1990 prices cereal supply in 2030 will be 3,832 million tons and cereal demand will be 3,748 million tons. If environmental effects are not taken into consideration, this implies lower production, higher consumption, and some price reduction. With a demand elasticity of -0.5 and a supply elasticity of 0.8 at the equilibrium point, prices will fall by approximately 2% and the equilibrium production/consumption level will be 3,780 million tons. This result is arrived at from the following two equations:

$$(3{,}832 - Y)/Y = 0.8\,X$$
$$(3{,}748 - Y)/Y = -\,0.5\,X$$

where Y is the production/consumption equilibrium and X is the rate of price change. While this estimate does not differ substantially from those of other studies (e.g., Crosson and Anderson 1992), a different picture emerges when effects on the environmental are also taken into account (see Table 5.2).

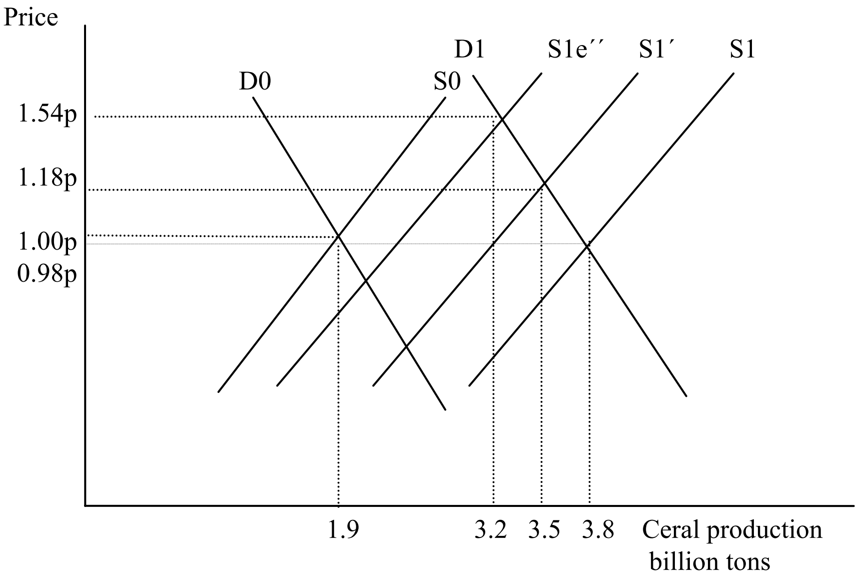
There are weaknesses in the above analysis of projected cereal production in 2030, particularly in respect to the assumption of growing supply and demand at 1990 prices and the estimated supply trend. An alternative approach would involve equalizing cereal supply with the cereal demand of 3,748 million tons in 2030 at 2030 prices and thereafter consider the effects of environmental degradation. However, it is reasonable to continue with the first approach without referring to 1990 prices in light of the changes in cereal prices and production for 2030, (see Figure 5.1).

5.4. Incorporating Environmental Degradation into Future Agricultural Production

The above discussion indicates a doubling of cereal production by 2030. The supply curve in Figure 5.1 moves from S0 (for 1990) to S1 (for 2030), and the demand curve moves from D0 to D1 respectively. The effects of environmental degradation may be understood as a continuous increase in production at the annual trend of 1.8% reduced by the effects of reduced yields and production and the increased costs of internal resources.

The reduction is expressed in shifting the projected supply curve for 2030 from S1 to S1e' and S1e'' for low and high estimates of environmental degradation. If production falls by 20% at a price of 1.00p with a demand elasticity of -0.5 and supply elasticity of 0.8, the price level will rise by approximately 18% in comparison with 2% in the base scenario and the production level will decrease to approximately 3,486 million tons. If production falls by 40% at a price of 1.00p with similar supply and demand elasticity, the price level will rise by approximately 54% and production will decrease to approximately 3,191 million tons. Cereal prices would be 20-56% higher in comparison with the base scenario.

Figure 5.1 Projected cereal supply and demand in 2030 with and without environmental degradation integrated into the supply function



Source: Saifi 1997

Table 5.2 displays price and production/consumption levels for different elasticity settings. Small changes in production equilibrium and large changes in price equilibrium are observed with a supply elasticity of 0.6 and a demand elasticity of -0.4 instead of 0.8 and -0.5 respectively. In our analysis cereal prices are assumed to reflect short to medium-term marginal costs in a competitive market. The present reality, which to some degree may continue into the future, indicates that short-term international cereal prices are more related to the export of surpluses and the import of deficits than to total production and consumption. This gives rise to highly variable international prices. However, the general long-term trend in international prices cannot deviate greatly from that of local markets in open economies, even though the current elasticity values in international supply and demand appear to be lower than those used in the present study. It is also important to note that domestic prices in industrialized countries do not include various direct and indirect subsidies.

Table 5.2 Cereal production and price levels in 2030

	Without env. deg.	Incorporating environ. degradation[1] low	medium	high
Basic scenario[2]				
Production/consumption (million tons)	3780	3486	3338	3191
Price level (1990=100)	0.98	1.18	1.33	1.54
Low elasticity scenario[3]				
Production/consumption (million tons)	3782	3475	3322	3169
Price level (1990=100)	0.98	1.25	1.47	1.84

1. low=20% reduction in food supply, Medium=30%, High=40%.
2. Supply elasticity of 0.8 and demand elasticity of –0.5.
3. Supply elasticity of 0.6 and demand elasticity of –0.4.

Sources: Saifi (1997)

The above results are based on an assumption of unchanged trends in non-farm input prices, the use of which will increase substantially in order to increase production and compensate for degradation. For example, Harris (1990) projects a doubling of fertilizer use by 2010 and another doubling by 2050 in order to meet global food demand. This implies large costs in terms of the environmental degradation and resource depletion that are associated with such levels of mineral nitrogen use. In the short to medium term, increased demand for these inputs may not result in large price increases because of various market forces, particularly since scarcity and environmental damage may become evident only over a longer period of time. But substantial price increases could result from the awareness of such future problems and from various policy measures. Prices of on-farm resources, such as land and water, will increase significantly in relation to product prices, but these are integrated into the market model. However, additional price increases, which are not included in the above analysis, should be anticipated in relation to increasing demand from other sectors. One possible, or perhaps likely, development of increasing input prices would thus result in even higher cereal prices than those anticipated in the above analysis.

In estimating food demand, it is assumed that the world community will not allow large-scale famines to occur. Many developing countries currently face difficulties in paying for food imports and millions of their citizens live in extreme poverty and deprivation. We can assume that many of them will in fact have to increase such imports since almost all the projected increase in demand will take place in the developing world, where the effects of environmental degradation are also expected to be more severe. Not only would allowing 200-500 million people to starve reduce demand by only 1-2%, the associated social and environmental costs would be extreme.

Farmers by themselves can do little to deal with most of the problems we have discussed. Not only is government intervention needed, it is reasonable to assume that various measures will in fact be implemented, either at local, national, or global levels. Some resources have already been invested in order to decrease environmental degradation, even though they aresmall in comparison with the scale of problems. While the above quantitative analysis has various shortcomings, particularly in respect to the remedial measures that may be implemented, it is important to note the negative impact, upon both agricultural production and the environment, of more land being degraded, more carbon being emitted, and more nutrients being leached from the soil.

In summary, if measures are not introduced to reduce resource degradation and depletion, particularly in respect to land and water, and control environmental degradation, particularly climate warming and air pollution, there will be a substantial reduction in cereal production in the coming decades. Furthermore, there is a serious danger that damage to the environment will be in the higher range of estimated values. This will increase the vulnerability of agricultural production, raise food prices, and make it more difficult for developing countries, whose financial, technological, and institutional resources are much more restricted than those of the industrialized countries in both relative and absolute terms, to feed those with low incomes. The need for industrialized countries to become more involved in dealing with such problems cannot be over-emphasized. This is not only a moral issue, it is also an issue of their own long-term self-interest.

5.5. The Coevolutionary Perspective and Future Global Agriculture

The coevolutionary perspective presented in Chapter 3 illustrates how agricultural systems can change in response to environmental degradation due to an increasing awareness of the damage caused, primarily by means of various indications and incentives from the socioeconomic system. The interaction of the agricultural system with the socioeconomic system on the boundary of the ecological system may give rise to new preferences as well as an ongoing adoption of techniques and methods in order to reduce environmental degradation. The major obstacles to rapid adaptation in this regard are increasing food demand, a lack of willingness to commit the needed financial resources, resistance from certain economic interest groups, a rigid research system, and a perceived loss of international competitiveness. However, such obstacles can be reduced by an increased participation of concerned citizens and organizations and by global cooperation between nations.

As was discussed in Section 5.3, future cereal supply is a function of various complex and interacting factors, including the implementation of various measures in order to reduce environmental degradation. The rate at which damage to the environment could be reduced depends on the choices society makes and the objectives that are established in socioeconomic systems on both national and global levels. While there would be some reduction in agricultural capacity and a slowing of growth in production if we move rapidly to reduce degradation, the alternative of opting for a rapid growth in production would cause extensive damage to the environment. Although we cannot provide a detailed account of the impact on all relevant factors of efforts taken to reduce environmental degradation, it is clear that the implementation of measures in this regard would restrict the growth of future food supplies in three major ways. First, trends in food production would change in consequence of new types of technological development. Second, the use of off-farm inputs would decrease. Third, a degree of agricultural capacity would be allocated for energy production. However, future food demand could also be reduced by a slowing of population growth and a smaller than projected increase in per capita cereal consumption.

The first impact on food supply involves technological change and different patterns of resource utilization. If substantial resources and technological innovations were made available to developing countries, and if we were not faced with environmental degradation and problems of scale, there would be a higher growth in production than the rough estimate of 1.8% annually given in Section 5.3. But reducing environmental degradation would imply that an increased share of resources and technology be employed for such purposes. For example, protecting biodiversity, which provides genetic materials that are necessary for technological development, demands the conservation of many ecological systems over large areas. In order to decrease land erosion, we may well have to forgo cultivating vulnerable land. In addition, technological development would have to be directed towards both solving and avoiding environmental problems, not just increasing the productivity of unit resources. Instead of searching for varieties that produce higher yields but require greater protection and nutrient nursing, we would have to identify varieties that give a reasonable yield but also have genetic properties that are appropriate in respect to the immediate environment. Such changes would tend to slow the growth of production.

The second impact on future production involves reducing the use of certain off-farm inputs that are associated with environmental damage and/or long-term scarcity problems. Fossil fuels and mineral fertilizers, both of which are non-renewable resources, are the most obvious examples. Increasing fossil fuel prices would indirectly influence the price of many other agricultural inputs, including fertilizers, equipment, machinery, and biocides. The use of many such inputs can be reduced by means of increased prices (taxes), technological developments that increase their productivity, regulation, education, circulation, and the use of substitutes.

The third impact involves the allocation of a degree of agricultural capacity to energy production and reforestation. We may have no choice but to rely increasingly on renewable energy sources in light of the problems associated with the use of fossil fuels. It is reasonable to expect that land would be diverted from food production for this purpose even though much of the land used could be retired land, i.e., either marginal land more suitable for forest, or excess arable land in industrialized countries.

Because of the consequent restrictions on future production, cereal supplies may not grow adequately to meet the increasing demand. And in light of the likely rise in cereal prices that would follow, the ability of the poor to purchase any needed food requirements would be severely affected. In Section 5.3 the demand for cereal was estimated to reach 3.8 billion tons in 2030. However, the chief factors underlying this estimate, namely, population size and per capita cereal consumption, can be influenced and reduced to a substantial degree. This would lead to a reduction in demand.

The rate of population growth can be decreased by investing in programs that reduce the fertility rate. For example, when China's leaders realized how limitations on natural resources could compromise their ability to satisfy the food requirements of the growing population, radical population control was enforced. Similarly, reasonable efforts in family planning, economic development, education, especially for young girls, and improvements in women's working conditions could significantly reduce the projected population of 9 billion in 2030. On the other hand, widespread economic mismanagement, environmental destruction, family insecurity, and social /national conflicts could substantially increase population size.

In addition, annual cereal consumption need not increase to the estimated per capita level of 433 kg in 2030. Between 1970 and 1990 the amount of grain consumed in the world in animal production remained at the same level in comparison with total consumption, namely, 38% (WRI 1992). In the United States and United Kingdom, however, the share of grain fed to animals actually declined from 80% to 70% and from 59% to 50% percent respectively. Diet experts and health organizations strongly recommend reducing both the amount of animal fat and total calories in the diets of wealthy countries. If preferences are in fact changed in line with such recommendations, including food patterns in the developing countries, and if the conversion efficiency of cereals is increased, it could be possible for the per capita consumption of cereals not to exceed the present level of 355 kg, which is comparable to the levels in Japan and Italy today. And if world population increased to only 8 billion, cereal demand in 2030 would reach only 2.8 billion tons, which is about 25% lower than the total estimated in Section 5.3. Cereal production/consumption in 2030 would thus be much lower than the projections given in Figure 5.1 and Table 5.2, and prices would consequently be lower as well.

According to the FAO (2002), world cereal production increased by about 1% during the 1990s. Cereal prices increased sharply in the middle of the decade, but later fell back to their 1991 levels. The fact that production grew more slowly than was predicted by various studies, such as those of the FAO (1993), Crosson and

Andersion (1992), Harris (1990), as well as Section 5.3 above, deserves a detail analysis that is beyond the scope of this chapter. However, it does confirm the complexity of the issue and the level of difficulty associated with projections of future food production. The low growth in cereal production during the 1990s is in fact comparable with the reduction in future cereal production that would result from environmental degradation along with the various measures that might be taken to alleviate it..

Modern industrial agriculture, powered by output stimulating policies, brought about environmental degradation, high budget costs, farm concentration, “unhealthy” food, and trade disputes, among other problems. These problems may shape the agricultural policy in the industrialized countries insofar as they have produced social resistance that is evident in the growing concerns of consumers concerning food content and production methods. Such problems have also given rise to the emergence of environmental organizations that support environmental friendly agriculture and the preservation of the traditional countryside (Goodman and Redclift 1991; Vail et al. 1994). These trends have in turn been followed by counter-measures from agro-businesses that are manifested in segmentation strategies and advertising campaigns.

The export dumping of agricultural commodities and the subsequent rapid decline in international prices in the mid-1980s became connected with rising costs for consumers and taxpayers. This encouraged an important breakthrough in CAP policy reforms and in GATT negotiations involving reduced farm support and the decoupling of subsidies from output. European agricultural policy has shifted in recent years towards acreage and environmental supports, and it will likely increasingly emphasize environmental improvements. This can decrease costly surpluses, as was discussed in Section 4.2 above. With a stable demand for food and a growing demand for environmental services, industrialized countries now have the opportunity to direct technological development towards the reduction of environmental problems, not increased production. The main selective pressure on agriculture in industrialized countries may thus come to be the need to reduce environmental degradation and develop a system of sustainable agriculture.

The OECD (1994) recommends that its member countries promote market liberalization and reduce economic distortion. It also encourages the implementation of direct support for the stabilization of farm income, disaster relief, a minimum income, and the provision of environmental goods and services. It is significant that these are inherently long-term policies, and that they serve to protect agriculture as well as reduce damage to the environment. With food being basic for human survival and agriculture having a variety of social functions, further liberalization and free trade may well become associated with the harmonization of environmental policy and food production in relation to a range of social costs and benefits (Chapter 4). Free trade and a competitive global market are in conflict with various legitimate local and national interests, particular in respect to food safety, agricultural services, moral convictions concerning production methods, and environmental degradation. Furthermore, international free trade in agricultural commodities with no consideration of environmental degradation would intensify the destruction of many ecological systems insofar as market forces in and of themselves would press for lower production costs at the expense of increasing environmental and social costs. A pertinent example of this is the growth of meat exports from the tropical rain forests of Central and South America, which has pushed poor farmers onto marginal land and has damaged fragile ecosystems.

The main problem facing developing countries is the anticipated negative impact of environmental degradation on agricultural production capacity at the very time when there is an increased demand for food. Although many developing countries may enjoy a competitive advantage in certain types of agricultural production in the coming decades, and in spite of their great potential to increase production further, they are projected to import some 160 million tons of cereal by 2010 (FAO 1993). For Africa to achieve self-sufficiency in cereals by 2030, a 5% annual growth rate in production may be needed. This will be a rather difficult task not only in light of the past record (Saifi 1995), but also because of the particular effect on developing countries of global environmental damage.

The main explanation for why the decline in per capita cereal production during the last two decades has not led to a steady increase in prices is the low purchasing power of the world's poor. The current character of income distribution on both national and international levels has caused a large percentage of the world's population to live in poverty and food insecurity. There are two essential elements in food security: food availability, and people's ability to acquire control over food by means of production, wages, trade, or transfer (Sen 1981). The analysis presented in Section 5.4 coupled with the interpretation and critique from a coevolutionary perspective presented here indicate that developing countries should not expect that there will be long-term availability of food on international markets at declining prices, regardless of historical experience. The sharp rise in cereal prices during the middle of the 1990s (FAO 2002) should be seen as a warning by those countries that depend heavily on the global cereal market. As a consequence, the strategies of lower population growth and balanced diet patterns may indeed become necessary in order to increase food security and reduce resource degradation, although investing heavily in agricultural development must remain a basic priority. The main selective pressure on agriculture in developing countries is thus to increase food production and achieve food security in the long run by protecting the natural resource base and building upon the traditional knowledge they have developed.

Alleviating global environmental problems implies a substantial transfer of resources and technologies to poor people. Without this, not only will the projected rise in prices increase the number of people in need of food support for survival, the resulting human suffering and environmental destruction will be great. And since national and international policies for the promotion of agricultural research and development are essential to increasing the rate of growth in output (Ruttan 1991; Schuh and Norton 1991), with many developing countries experiencing severe limitations on their financial and technical resources, the role of bilateral and multilateral assistance is crucial. Such assistance from industrialized nations and international organizations could be utilized efficiently in development on a broad scale, particularly in connection with increasing long-term production capacity, decreasing environmental degradation, and helping countries become self-reliant in food production (George 1990).

In a world governed by short-sighted national economic interests, however, it may be difficult to convince industrialized countries and donors in general to assist developing countries in establishing secure food supplies. External commitments to support agriculture in developing countries in fact declined in real terms by 42% between 1986 and 1992 (FAO 1994). Nevertheless, long-term interests in creating trade opportunities, protecting important resources from rapid depletion, avoiding large-scale instability, and reducing global environmental degradation should encourage industrialized countries to provide an adequate level of support. In addition, such interests are buttressed by a growing public awareness of the critical state of affairs in respect to environmental damage. But although the United Nations and a number of prestigious international gatherings have put forward recommendations and guidelines for promoting sustainable development and environmental conservation, such as Agenda 21, the political will to implement them is still lacking.

5.6. Conclusion

In conclusion, the current state of environmental degradation will cause a substantial loss of agricultural production capacity, which may increase cereal prices by 20-56% in 2030 and lead to global instability in food security. Prices may be even higher if the cereal price elasticity is lower due to a less competitive market and/or rising input prices due to environmental degradation and resource scarcity. Despite the weaknesses inherent in any long-term projections of future food supply, the present analysis demonstrates that declining food prices, which were experienced in the past, should not be expected in the future. There is clearly an uncertain future regarding the prices of food commodities, on-farm resources, and external inputs as well. This situation may have a devastating effect on the world's poor.

Measures will undoubtedly be implemented to decrease environmental degradation and resource depletion, but their strength and effectiveness will depend on political will and on a commitment to allocate adequate resources, particularly in industrialized countries. Such measures will affect future food supplies in three major ways, namely, by affecting technological development, by reducing the use of off-farm inputs, and by allocating a share of agricultural capacity to energy production. They could also affect future food demand in two major ways, namely, by limiting population growth along and by restricting per capita cereal consumption. Reducing cereal demand would not only reduce future prices, it would also increase the possibility to reduce environmental degradation instead of increasing production.

The coevolutionary interpretation of how environmental degradation affects global agriculture reveals that there can be no reliable prediction of future supply and demand because of the many complex and interacting factors involved, most of which can be influenced by social choice. And since environmental degradation will have increasingly serious negative consequences if no steps are taken to alleviate it, industrialized countries must take the lead in adopting measures to protect the natural resource base for food production and to develop food systems that are suitable in the long-term in relation to the larger ecological system. In doing so they will serve their own short and long-term national interests as well as global concerns, and also uphold a moral commitment to agriculture, the environment, and poor people.

The type of strategy industrialized countries must adopt has two dimensions. Its national dimension involves the protection of basic agricultural resources while developing sustainable production methods. Its international dimension involves encouraging global cooperation in order to harmonize efforts to protect the environment, reform and expand food aid programs to help poor people protect their own resource bases, and assist developing countries in following a path of agricultural development that is more viable in the long-term than modern industrial agriculture.

The coevolutionary model presented in Chapter 3 reveals how interaction between the socioeconomic and ecological systems on a global level may have a serious impact on agriculture. Of particular importance are three constraints on food production systems that may arise from the sum of ecological systems, or the biosphere. The first is the limitation of on-farm resources, especially land and water. The second is the depletion of certain crucial off-farm non-renewable natural resources, such as fossil fuels and rock phosphate. The third is the degradation of the biosphere itself by such factors as global warming and the depletion of atmospheric ozone. Pursuing a path of sustainable agricultural development must involve efforts to confront and alleviate such problems.

6. Principles and Indicators of sustainability: Strengthening Local Coevolutionary Processes In Swedish Agriculture

6.1. Introduction

Operational definitions of sustainability are related to space and time and thus subject to change. An analytical framework that consciously reflects the nature of agriculture as a coevolutionary process involving the agricultural sector, the socioeconomic system, and the ecological system may be useful for understanding and promoting agricultural sustainability (Chapter 3). In this respect, the present chapter puts forward a definition of agricultural sustainability for Swedish society at its present stage of development and investigates various issues concerning this question as well as the relations between them. This serves to identify certain principles and indicators that can assist in strengthening coevolutionary processes on the local level. This constitutes an important step forward in inducing a system of sustainable agriculture. As Chapter 4 argued, there is a large potential in Sweden to move in this direction, but we need to have a comprehensive vision of what sustainable agriculture in fact is if we are to realize it.

Section 1.1 indicated the thirteen agro-environmental areas that the OECD (1997) suggests must be taken into consideration when discussing the meaning and content of sustainable agriculture, along with the additional four proposals put forward by the Swedish Environmental Protection Agency (SEPA) (Naturvårdsverket 1997). Each of these problem areas contains a number of issues that need to be examined, with a potentially large number of associated "operational" indicators that could be identified. Large number of indicators, some of which may be difficult to measure and understand, is not appropriate for facilitating communication, especially on local level and when involvement of many actors is required. In addition, it is necessary not only to address the roles that food demand and the value system play in respect to sustainability, but also to understand the historical development away from a system of sustainable agriculture.

The objective of this chapter is to search for principles and indicators of sustainable agriculture relevant to present Swedish conditions that are in accord with the coevolutionary model presented in Chapter 3, which identifies the strengthening of local coevolutionary processes as key to the development of a sustainable system of agriculture. While these principles must reflect the complexity of the agricultural system, the indicators derived from them must be easy to understand and apply in a variety of areas, periods, and production systems in order to facilitate the changes needed to promote sustainability. The principles will be sought in the dimensions of sustainability that were identified in Section

3.3. Chapter 7 will apply the coevolutionary model, along with these principles and indicators, to an analysis of agricultural sustainability in the municipality of Uppsala during the twentieth century.

It must be emphasized that it is necessary to relate these principles to local conditions and to examine them within the context of a given system of production. Furthermore, the principles we identify should be viewed as practical characteristics of sustainable agriculture on the basis of our present knowledge, not as absolute criteria. For example, the awareness and understanding of environmental problems, as well as plans to resolve them, have undergone changes in both the research community and in society as a whole, and they will continue to change in the future (Svedin 1988).

Section 6.2 proposes a definition of sustainable agriculture within the Swedish context in order to provide a framework for identifying the principles and indicators in question. This section is essentially an elaboration of the general argumentation presented in Chapter 3. Section 6.3 further investigates and discusses the eleven interrelated dimensions of sustainable agriculture presented in Section 3.3. These are then related to the Swedish conditions discussed in Chapter 4 and the international developments discussed in Chapter 5 in order to locate the essential issues and the connections between them. Section 6.4 utilizes the mapping of issues and relations presented in Section 6.3 in order to identify principles that reflect the major issues concerning agricultural sustainability. It then provides practical, measurable indicators that can be used to indicate the degree of deviation in a particular system in respect to these principles. The aim is to choose principles and indicators that support the strengthening of local coevolutionary processes that is argued for in Chapter 3. The adequacy, measurability, and ease of understanding concerning these principles and indicators are examined throughout the course of discussion. Section 6.5 summarizes the findings and recommendations of the chapter as a whole.

6.2. A Meaning of Sustainable Agriculture

Agricultural sustainability should be understood in relation to the systems that shape agriculture, namely, the socioeconomic system, the ecological system, the subsystems that form a given agricultural system, and the processes of change within agricultural development (Chapter 3). Agricultural systems have always been in a state of continuous development, although the pace has historically varied, and they will never become static, finished works because the conditions that constitute them continually change. The coevolutionary model emphasizes that it is necessary to understand the various processes at work in agricultural development when addressing the issues of sustainability. Chapter 3 argues that policies implemented in order to promote a system of sustainable agriculture must strengthen interactions between people, agriculture, and the ecological system on the local level. They must also address changes in production methods and land use as short-term responses while viewing technological development and changes in values as long-term responses.

In promoting agricultural sustainability it is important to utilize three interconnected processes that influence change. These are 1) local interaction involving farmers and citizens in respect to production and consumption; 2) the regulation of inputs and production methods at various levels in society; and 3) analysis at the national level of problems, the provision of sufficient economic support, technological change, and the development of an appropriate value system. In this regard, the discussion in Section 3.3 goes on to reveal that it is not possible to provide a detailed and comprehensive description or operational definition of sustainable agriculture that is valid for most regions and into the future. We must instead approach sustainability on the basis of a broad, general definition using principles and indicators that are specific to a given country or region at a particular point in time. These principles and indicators should thus be viewed as tools that are useful for promoting sustainability, or reducing unsustainability, and not as absolute measurement of sustainability.

Section 3.3 broadly defines sustainable agriculture as "a system capable of satisfying the food requirements of the present generation without compromising the ability of future generations to satisfy their own." It then examines this definition in respect to the function of agriculture, the level of analysis, the meaning of food requirements, and the future time-frame we must consider. A further elaboration of these four issues in relation to Swedish conditions is essential if we are to derive some major principles and indicators concerning agricultural sustainability in Sweden.

First, the primary historical function of Swedish agriculture has been to provide food for farmers and for other people in society. This has also been the case for most if not all countries. Producing fiber for cloths and other uses as well as hides for leather were formerly important agricultural functions that have almost completely disappeared in recent decades. Food security has in fact been the main objective of agricultural policy since early in the twentieth century. However, agriculture now has a complex role in Swedish society. The preservation of cultural heritage, the maintenance of a living countryside, the preservation of open landscape, and the protection of agro-ecological biodiversity have become widely appreciated agricultural services. The importance of agriculture for services other than food production has thus changed significantly in recent history, and it may well change substantially in the near future. For example, we should anticipate that nutrients circulation and fuel production will become important functions of a system of sustainable agriculture. Both are already practiced on a small scale, such as by spreading sludge waste on farmland and by cultivating forest energy. These and other related measures need to be addressed within a comprehensive framework of sustainability.

Second, sustainability must be analyzed on local, regional, national, as well as global levels, and each level should integrate important issues from the others. This type of approach, which was suggested in Section 3.3, is already widely accepted and practiced in Sweden. For example, the sustainability indicators discussed by the SEPA (Naturvårdsverket 1997) are in fact related to a number of analytical levels. Many Swedes also implicitly support the integration of global issues into individual and local choices concerning production and consumption. Moreover, decision-making power concerning the management of natural resources has been increasingly delegated in Sweden to the municipalities. This practice supports the idea that we should in fact take the municipality as the basic level of analysis, into which we should integrate issues from other levels.

Third, food requirement is considered to be more significant in respect to sustainability than food need or food demand. In Sweden since the 1950s, as in other industrialized countries, food demand has developed into the excess consumption of "unhealthy" foods as the percentage of animal products in the typical diet has substantially increased, most of which are produced using cereals, at least partially, as feed. Livsmedelverket, the Swedish authority responsible for safe and healthy food, instead recommends a diet that consists of fewer total calories and a reduced amount of animal products, especially meat and fat, than is presently the case. Food consumption in Sweden thus now exceeds the food requirement, which is defined as the quantity and quality of food needed for a healthy and active life. Changing the diet structure to reflect the above recommendations and reducing the amount of cereal uses for feed would reduce resource use and increase agricultural sustainability.

Fourth, we propose a time frame of one thousand years for measuring sustainability insofar as agriculture has survived for this period of time in most Swedish regions, albeit in continuous change. There are no reasons to expect major geological and climatic changes during this period except for the dangers presented by current man-made global warming. Although the latter will likely improve the productivity of Swedish farming because it may reduce thermal constraints on photosynthesis and increase carbon dioxide enrichment (Chapter 5), it is a serious problem for the world that directly affects the possibility of developing a system of sustainable agriculture. In addition, if we want land deposits of phosphates and fossil fuels to last for another one thousand years, Swedish agriculture will have to substantially restrict their use. But in light of the present excess of arable land and the large potential for nutrients circulation, it should not be very difficult to do so.

On the basis of such considerations, the model of coevolution can assist us in deriving principles and indicators capable of providing reasonable guidance for the development of a system of sustainable agriculture in Sweden. Such principles and indicators are subject to discussion and change in the light of various social requirements. Transforming these principles into reality may not be feasible in the short-term due to various economic and social factors, but we can direct agriculture towards sustainability by implementing particular policy instruments that reflect them and by following a path of development that strengthens local interactions.

6.3. Dimensions of and Issues Relevant to Sustainable Agriculture

Section 3.3 briefly discussed eleven dimensions of agricultural sustainability in relation to the model of coevolution presented in Section 3.2. It was argued that each country and ultimately each community can derive their own appropriate principles and indicators from these dimensions. We will now further discuss them in relation to Swedish conditions.

Problems related to agricultural sustainability have been widely discussed in Sweden (Miljövårdsberedningen 1989; Naturvårdsverket 1997; SCB and Naturvårdsverket 1994, 2000). In addition to the environmental problems that have been discussed by these works, Björklund et al. (1999) identify many important services associated with Swedish agricultural ecology, such as net photosynthetic capacity, soil fertility, nutrient circulation, and biotic regulation, and they estimate their value in both qualitative and quantitative terms at the national level during two periods of time. However, most of the issues addressed are not useful for a strengthening of local processes in order to promote sustainability since they are both difficult to measure and understand on the part of local actors.

Principles and indicators relevant to agricultural sustainability in Sweden can be found in relation to various interconnected issues within the following dimensions:

1. Value system and ethics

The value system within a socioeconomic system interacts with knowledge and policy and is the main source for short and long-term responses in respect to agricultural sustainability. Swedish experience shows that knowledge about environmental degradation has increased public concern and led to the implementation of policy measures intended to reduce problems at a relatively rapid speed (Chapter 4). During the 1990s, for example, the growing concern about agricultural sustainability shaped both public policy and consumer preferences, particularly in respect to food labeling and organic foods. The system of research and education could play a key role in accelerating the pace of this development, but it must be said that methodological pluralism, which constitutes an important value issue concerning science and research, is badly needed for advancing sustainability (Norgaard 1989; Section 2.1 above). In this respect, traditional agriculture and the knowledge it embodies has a proper role to play in addressing agricultural sustainability. Not only has this type of agriculture shown itself to be adapted to the environment, modern science will never be able to exhaustively know all the facts within an agricultural-ecological system. Animal treatment in agriculture is another ethical issue within the value system that is growing in importance among the public and changing policy. A large number of recent Swedish agricultural regulations are in fact intended to improve the well-being of farm animals.

As Section 3.3 observed, the value system is related to all other dimensions of agricultural sustainability, and yet it cannot be directly and explicitly outlined as a principle of sustainability. The relationship between values and the economy, technological development, and food consumption demands special attention because of the extent to which these three factors are capable of directing agricultural development towards sustainability. First, the willingness to accept additional costs because of environmental and ethical considerations in food production will determine how far Sweden can go in this direction. Since regulation will likely increase on-farm production costs, there will be a conflict concerning sustainability on economic grounds if compensation is not available to farmers, resulting in an increase in local or national imports. Second, directing technological development towards meeting the increasing environmental and ethical concerns of society would reduce the costs of pursuing a path of sustainable agricultural development. Third, developing healthier food consumption patterns would reduce pressure on the ecological system and increase the potential for a faster development towards sustainability.

2. Traditional agriculture

Most Swedes made their living from traditional agricultural activities for centuries prior to 1900. This type of agricultural system, which developed through coevolution with the ecological system at the local-regional level insofar as constraints arising within the ecological system determined farming practices, was clearly characterized by long-term sustainability. An important feature of this historical development was the creation of agricultural landscape with its related ecological system and biodiversity. The obvious local connection in this respect emphasizes the role of the local community in preserving and developing it further.

As in most agricultural regions of the world, the interconnection between land cultivation and animal husbandry by means of nutrients and feed was realized at an early stage of Swedish agricultural development. This direct and indirect circulation of nutrients was effectively used not only to increase food varieties and availability, but also to maintain soil productivity (Larson et al. 1997). A thousand years of various types and degrees of technical improvement in agriculture strengthened this interconnection. Although modern industrial agriculture weakened this relation by importing nutrients for plant cultivation and providing feed to animals from other areas and regions, Swedish agriculture still combines grain and animal production to some extent.

Traditional agriculture cannot provide an alternative to the present system of industrial agriculture, at least in the foreseeable future, for reasons related to nutrient circulation, fuel consumption, plant and animal protection, social conditions, and the agricultural labor force. For example, the mechanization of certain agricultural activities using internal combustion engines may remain unavoidable for most agricultural systems. Regardless of the ecological advantages in using horse traction instead of tractors powered by non-renewable fuel (Rydberg and Jansén 2002), it is presently unrealistic to consider the use of this feature of traditional agriculture as a principle of sustainability. In addition, certain production methods in traditional agriculture, particularly those related to the treatment of animals, would not be considered acceptable today. Nevertheless, the knowledge embodied in traditional agriculture can indicate a number of points of reference concerning sustainability, such as crop rotation, the combination of crop and animal production, biological pest management, and nutrient circulation. Much of the detailed knowledge of traditional agriculture has faded away, but it could to a large extent be resurrected through research into existing systems that still have the above features. It should be noted that these features are likely related to all of the ecological issues in agriculture.

3. Food demand and diet structure

Food demand and production were largely connected at the local level in the historical development of Swedish traditional agriculture. Using trial and error, people chose a particular manner of food production methods that was adapted to the local environment in a situation of relatively low and stable demand. Sweden could not satisfy its food demands today through traditional "sustainable" agriculture, not least of all because the population has increased from 2.4 million in 1800 and 5.1 million in 1900 to 8.9 million in 2000 (SCB). Traditional agriculture met the doubling of food demand in the nineteenth century by cultivating a larger area of land and utilizing a higher level of integration in respect to crop and animal production. Food demand measured in cereal tonnage doubled another two times during the twentieth century due to population growth and increased cereal consumption as animal feed. The agricultural sector succeeded in meeting this increased demand first by refining the traditional system that existed in the previous century and then by moving to a modern industrial system of production. This new system managed to produce surpluses during the 1980s even when there was a decrease in arable land.

The possibility to implement changes that promote the long-term survival of the agricultural system, which is already substantial, has begun to grow due to stable, and even declining, food demand. As Chapter 3 illustrated, this is perhaps the most important condition for developing a system of sustainable agriculture since it permits changing the selective pressure on agriculture from increasing production to improvements related to the survival of the system in the long-term. But reducing food demand, whose primary components are population size and per capita consumption, may actually increase the non-sustainability of agriculture if it leads to increasing concentration and intensity and drives environmental friendly farms out of business. The population of Sweden is now stable, but patterns of food consumption are not favorable to rapid agricultural development towards sustainability. In the 1990s, livestock feed was responsible for approximately two-thirds of total grain consumption, and the share of animal products in the diet was much higher than what health authorities recommended. It is obvious that less feed and other inputs would be required if the consumption of meat and animal fat that are based on cereal feed was reduced. In turn, this would facilitate the reduction of intensity in agricultural production. There are thus two paths of change in food preference that would support a greater degree of sustainability in agriculture. One is to have a balanced diet, and the other is to favor products that produce less ecological distortion and more ecological services.

4. Technological development

Throughout the history of Swedish agriculture certain methods were abandoned while others developed further (Myrdal 1997). Important elements in this process include climate, soil structure, and social conditions, which have always shaped farming practices in the various Swedish regions. In relation to industrialization, research and training centers were steadily developed and enlarged throughout the twentieth century in order to base change on technological improvements instead of the trial and error method farmers had previously used. This was associated with a new emphasis on increasing production and factor productivity that gave scant consideration to the consequent effect on the environment. Beginning in the 1950s, the success of new mechanical, biological, and chemical technologies led to the abandonment of traditional agriculture, which was deprived of any further technological development.

However, agricultural institutions in general, and the agricultural university in particular, now face an increasingly more complex task, particularly in relation to what society views as acceptable in respect to production methods and the level of sustainability. As Chapter 4 illustrated, food surpluses combined with an increasing concern about agro-ecological problems have led to a rethinking of technological development since the 1980s. It is now considered necessary to integrate the impact on the environment and social concerns into technology as well as accept pluralism. Diversity in technological development is in fact a likely pre-condition for sustainable agriculture (Chapter 3). For example, the SEPA (Naturvårdsverket 1997) anticipates two types of technological development. One (Pathfinder) builds on traditional agriculture, which is presently named ecological agriculture, while the other (Taskminder) develops modern industrial agriculture in a way that resolves environmental degradation and resource depletion. Such diversity in thinking needs to be expanded to include food processing and distribution as well. The development of competitive techniques for small scale food processing and distribution may not only strengthen farm economy, but also decrease ecological stress and increase social benefits.

While technological development creates both problems and solutions, we are able through social control to reduce the negative effects and enhance the positive contributions. For example, Ehrlich et al. (1999) emphasize the role of public policy in technological development for the purpose of sustainability. In order to determine whether or not a specific new technique, such as better manure management or an improved crop, is sustainable, we need to bring its relations with other dimensions into the discussion. Within the framework of sustainable production, the success and adoption of a new technique cannot be dominated by profit maximization with little or no consideration of its eventual effects on the environment, as has been the case during the development of modern agriculture. An important element in the development of a system of sustainable agriculture is that we direct technological development towards the resolving of existing ecological problems, avoiding them in the future, increasing resource productivity, and providing agricultural services. This type of development requires coevolutionary feedback from policy makers, the scientific community, citizens, and farmers.

5. Energy use and biomass production

The energy question is the most important sustainability issue in Swedish agriculture. This refers to the use of different input forms as well as to the production of biomass and food. Energy is an important and complex link between nature and humans that relates to almost all other sustainability issues. Agricultural systems are basically ecological systems that have been transformed in order to produce a greater amount of food energy for people. If an agricultural system captures more solar energy than the natural system upon which it is based, then it is clearly ecologically sustainable and there is a positive human contribution to the ecological system. But not only is this type of analysis difficult, most agricultural systems, especially those in forested regions, probably produce less biomass than the natural system. The conclusion in Chapter 3, however, concerning the sustainability of traditional farming systems was based on local coevolutionary processes that impose constraints arising from the ecological system on both the agricultural and socioeconomic systems. When fossil fuels are not used, these processes select for the high production of direct food (cereals) and of animal feed in order to generate animal products and power farm activities. The production of biomass thus powered the production of food as well as feed. However, this chain has been broken through the industrialization of farming, whereby farm activities have become increasingly powered by external inputs that are dependant on fossil fuels both directly and indirectly.

In both traditional and modern industrial farming, the increased land production of biomass energy remains the core objective of cultivation. In this regard, the better utilization of solar light by crops from early spring to late autumn is an important challenge in Swedish agricultural development (Ebbersten 1988). But if biomass production is to serve as an indicator of sustainability, then we must deduct the external input of energy embodied in the various activities and materials related to its cultivation. Combustion based mechanization, mineral fertilizers, and the chemical protection of crops are the most important activities in this respect that demand large quantities of external energy, particularly fossil fuels. Three levels of analysis must be involved if we are to determine the energy production of farming systems within the context of sustainability. The first is the net total energy produced on agricultural land. This must include all the harvested crops, the biomass remaining in crops left above and in the soil, the biomass in non-crop plants, and the biomass produced by crop and non-crop plants that is consumed by insects, animals, and bacteria. The second is the energy in harvested crops that farmers further process into food and feed. This has been a major concern of agriculturists, but it is clearly related to the first level. The third is the energy in food, either in cereal and other crops or in animal products. Large quantities of food energy are lost at this level when cereals are converted into animal products. Since Swedish agriculture is dominated by land cultivation, which has the primary function of producing biomass energy, our focus in searching for principles and indicators of sustainability should be on the first and second levels of energy analysis. The third level is indirectly and implicitly addressed in other dimensions and issues, such as food demand and the structure of a balanced diet.

6. On-farm natural resources

The historical development of Swedish agriculture can be viewed as an increasing utilization of local resources in order to increase food production. This has emphasized increasing the area of land under cultivation, improving its productivity, and improving livestock management. Arable land, soil type, precipitation patterns, biotic relations, and the climatic regime are basic on-farm resources that determine agricultural production capacity, the first of which can be improved or degraded by human action to varying degrees. For example, crop rotation and the use of animal manure improve soil structure as well as nutrients availability, while mono-cropping and excess tillage degrade the productivity of arable land. Climatic conditions are relatively stable, and farmers adjust their practices to them and to their annual fluctuations. Protecting agricultural land from degradation, which can take such varied forms as soil compaction, contamination, acidification, and the depletion of humus and nutrients, should be an important objective of sustainable agriculture in Sweden. Other important degradations that reduce agricultural production capacity are air pollution and the depletion of the ozone layer.

But it is not feasible to focus any of the above on-farm resource degradations as a principle of sustainability. Not only do farmers have only a limited ability to influence such issues as ozone layer depletion, biotic relations, climate conditions, and air pollution, the difficulty of taking accurate measurements also constitutes an obstacle in this regard. On the one hand, soil compaction is related to the use of heavy machinery, is difficult to measure, and is probably best addressed through regulation. On the other, soil contamination with cadmium and mercury, the level of humus and nutrients in the soil, and acidification are issues likely worth considering as sustainability principles and indicators. But even they can be better represented indirectly since all of them are related to other issues and not easy to monitor continuously on the local level. For example, the main sources of cadmium pollution are mineral phosphorous and air pollution. While the first of these has decreased substantially in recent years and can be eliminated through farm regulation, the second cannot be locally controlled. Mercury accumulation is mainly related to pesticide use and thus could be dealt with through proper use and appropriate regulations. The levels of soil nutrients are related to crop rotation and the use of animal manure, but acidification is mainly caused by air pollution and synthetic nitrogen. We may therefore allow principles from other dimensions to represent various issues in this dimension.

7. Off-farm resources

Modern industrial farming has become increasingly dependent on external natural resources. Some of these, such as fossil fuels and mineral phosphorus fertilizers, are nonrenewable resources, while the production of mineral nitrogen fertilizers is in turn heavily dependent on fossil fuels. The use of such inputs has caused serious environmental problems. For example, nutrients leaching and the over-enrichment of water bodies are closely connected with the continuing use of mineral fertilizers (Fleischer 1988). However, their consumption can be reduced substantially by increasing the local circulation of organic waste from both urban and rural populations to agricultural land. And although fossil fuels provide power for many activities in agricultural production, agriculture can produce bio-energy crops that can replace them. Machinery and biocides are other important inputs in modern agriculture that increase the productivity of land and labor, but not without environmental and resource degradation. The benefits and costs, taken in a broad sense, of using these resources are important factors in agricultural sustainability, especially when labor rationalization is no longer needed and ecological degradation has already reached substantial levels. Many issues in dimensions six and eight relevant to sustainability are related to off-farm resources.

The use of mineral phosphorus, fossil fuels, mineral nitrogen, and biocides constitute some of the most important sustainability issues in this dimension. Scarcity and long-term supply are basic problems concerning the first two, and all of them cause a number of environmental problems both directly and indirectly. Pesticide use may face growing number of problems associated with increased complexity and costs due to the development of pest resistance and the increased public awareness of the environmental damage it can cause. While problems associated with fossil fuels concern the socioeconomic system as a whole rather than agriculture alone, farming has the potential to reduce the use of fossil fuels by producing its own fuels, at least for traction and heat. The use of these resources is a key issue in respect to agricultural sustainability because of scarcity and their impact on the environment, and each of them is connected to various important issues in other dimensions. Pesticide use, for example, is related to various health and ecological problems. The role of technological development in finding feasible alternatives to the use of these off-farm resources must be emphasized.

8. The ecological system and environmental degradation

This dimension involves the various degradations that affect the ecological system at local, regional, and even global levels. Today the welfare of people who use the many services provided by the ecological system is declining. In addition, the local agro-ecological systems that were shaped by traditional agriculture, and which are highly appreciated by both urban and rural populations, have been negatively affected by decades of agricultural modernization and rationalization. The Baltic Sea, for example, faces serious ecological problems due to nutrients leaching and water over-enrichment. Agriculture is also a major source of increasing levels of atmospheric methane, carbon dioxide, and nitrous oxide, all of which are important agents in climatic warming. Alleviating the problems of biodiversity depletion, eutrophication, pesticide spread outside the farm, air and water pollution, and increased carbon deposits in soil are important sustainability issues. Another aspect that needs to be considered is the capacity of the ecological system to assimilate various inputs insofar as the environment can be negatively affected by the excessive use of off-farm resources, the long-term impact of which is highly unclear. Although the issues associated with this dimension are important in respect to sustainability, it may not be necessary to take them as principles and indicators since they are largely embodied in issues in other dimensions, especially off farm resources, that are easier to measure and understand. A clear example is the extensive leaching of nutrients, which is largely caused by the excess use of mineral fertilizers and inappropriate practices.

9. Food safety

The industrialization of farming and food processing along with the weakened connection between food producers and consumers have entailed increasing control by agricultural, environmental, and health authorities concerning how food is produced, processed, and maintained. Such matters as production methods, dates, and food content are becoming increasingly important to citizens and consumers. This is largely related to the prolongation of the time span between production and processing and consumption. It also is affected by increasing public knowledge concerning the immediate damage to human health caused by the use of chemicals in production as well as by toxic residues in food and the contamination of ground and surface water. In spite of the tremendous technological advances of the last one hundred years, knowledge concerning the effects of many biocides, hormones, and additives, including the radiation treatment of foods, is far from adequate. The development of resistant bacteria and other microorganisms in crops, livestock, and humans is another growing health threat. There is also a certain concern about the possible negative impact of GMO crops in that resistant genes may cause health problems when transferred into plants and animals. The safety of animal products is threatened by such troublesome issues as additives, feed content, excess medical treatment, feed contamination, and the spread of disease, including salmonella and BSE. Although the issue of health is an important social dimension of agricultural sustainability, it is related to issues in other dimensions of sustainability, particularly biocide usage.

10. Food security and regional distribution

Understanding food security as access by all people both now and in the future to the food required for an active and healthy life implies that Sweden as a country, as well as its local and regional communities, should be able to provide for future food requirements. Today it is possible for Swedish society to attain "short-term" food security by importing food at lower than domestic production costs. Doing so, however, entails both strategic risks and also various ecological problems. While the currently low prices on the international market are unlikely to last in the long-term, land productivity in Sweden may in fact increase in relation to a reduction in thermal constraints and increased carbon dioxide enrichment. However, increased specialization in food production both within a given society and between different societies will inevitably increase ecological costs for importers and exporters and also increase the danger posed by future crises affecting food production and availability. Being able to produce basic food is a primary security issue, and a community with a greater amount of agricultural land is clearly in a better position to manage with such difficulties. In addition, energy savings and nutrient circulation consolidate both food security on the national level and also its regional distribution within the society. Moreover, transferring food production to the most productive land in southern Sweden would not be compatible with achieving food security. The distribution of agricultural production throughout as many Swedish municipalities as possible provides the basis for a secure and sustainable society since it provides not only food but also important ecological services, not least of all because highly valued agro-ecological systems cannot be maintained and the management of nutrient waste would be more problematic without farming. The amount of arable land per person, the integration of food production and consumption at the local level, and high degree of agricultural dependency on local resources are important issues for food security and agricultural sustainability.

11. Farm economy

Agriculture cannot be sustained if farmers cannot live from farming at a standard that is comparable with other groups in society. That Swedish farmers have a multiple of objectives in respect to their occupation is well documented (Nitsch 1982). Nevertheless, the economic factor has to a great extent played a decisive role in farming continuity between generations and also in farming management and practices.

Farm economy is a vital dimension of agricultural sustainability that is closely connected to macroeconomics and societal views, especially agricultural policies. Compensating farmers for practices that improve sustainability is an important policy measure that could improve, or at least not deteriorate, farm economy (Chapter 4), and improving labor productivity and rationalization may also be needed in many countries and regions. However, it is difficult to see the merit of the latter in Sweden, which has about 2% of the working force involved in primary agricultural production, an unemployment rate of about 5%, and an important level of public interest in preserving a viable countryside and protecting ago-ecological systems. Indeed, it could be argued that many of the new tasks that might be assigned to Swedish agriculture in relation to services and sustainability would require an expansion of the labor force.

Since measures that increase agricultural sustainability entail additional costs, and since it is crucial that the competitiveness of local agriculture not deteriorate, society must cover the costs involved by means of a policy of conditional support, as Section 4.2 argued. In a world with low transport costs and independent national governments, not all local authorities are capable of protecting agriculture in their regions from internal and external competition. Direct financial support to farmers for their ecological and social services will likely be inevitable if Sweden chooses to follow a path of sustainable agricultural development. Since different farmers provide different levels of ecological and social services, such intervention would favor certain farmers more than others. But this is exactly the point when the intention is to introduce sustainability into farm economy. The principle of economic compensation for agricultural and environmental services should be viewed as a desirable institutional arrangement that would strengthen local coevolutionary processes, particularly if detailed management is delegated to the municipalities. However, the possibility of following such a policy arrangement at the local level depends on higher-level decisions, including the national and EU levels. Even though consumer choice, individually and by means of private and official organizations, could play an important role in farm economy, it is affected by prices. We obviously cannot avoid the collective nature of sustainability.

The awareness of problems associated with modern industrial agriculture has increased in recent decades. This indicates that a new path of agricultural development is already under way. A sustainable path of agricultural development requires contributions from many actors in society, such as farmers, consumers, politicians, reporters, scientists, environmentalists, and citizens in general. Their contributions will be more effective if there is some common understanding of what sustainability means, including its principles and indicators. This is particularly true for the local level insofar as the strengthening of coevolutionary processes involving farming and society is a key issue in agricultural sustainability. Realizing the types of principles we have been discussing is a long-term objective that would bring agriculture closer to sustainability.

This section has presented issues concerning sustainability that are connected with each other at various degrees of complexity. Such inter-connections may enable us to select or construct a limited number of principles capable of representing these issues reasonably well, and that can serve to strengthen coevolutionary processes and promote sustainability. For example, cadmium in cereal is an issue within the health dimension that is related to the issue of cadmium accumulation in the soil within the on-farm resource dimension. This in turn is related to the issue of mineral phosphorous use within the off-farm resource dimension. The latter, which involves the issues of resource depletion as well as increasing energy usage for recovery, particularly from the oceans, is also connected with phosphorous leaching within the ecological dimension. Consequently, if we present the low use of mineral phosphorous as a principle of sustainable agriculture production, we illustrate a point that is connected with the situation of many important issues in addition to a higher degree of phosphorous circulation.

6.4. Principles and Indicators of Sustainable Agriculture

Many of the above issues concerning sustainability, such as animal treatment and the use of hazardous chemicals and hormones, have to be managed through regulations. These may take the form of government directives, or that of organizational trademarks indicating ecologically-friendly food production. However, the qualitative aspects of agro-ecological systems may not only be difficult to measure, it may also be difficult for involved actors to understand them. Such important issues as animal feeding and food safety also reveal the limitations involved in assigning certain measurable indicators for sustainable agriculture. It is clear we have to examine the connections between the various issues involved if we are to determine principles of agricultural sustainability from the above discussion.

Regardless of the particular principles put forward, they are subject to change over time. For example, food security is currently not a significant issue for many societies, but its level of importance can readily change if global food markets become unstable or shortages appear in the supply of vital inputs. In addition, certain principles may not only be valid for different communities and societies, but also relevant to a number of the above dimensions, such as combining crop and animal production. Because of this interdependency of the issues involved, it is possible to use a more limited number of principles both to reflect the meaning of sustainability and also to influence the various development processes that promote sustainability.

Instead of a detailed examination of the linkages between the above issues, it may be more fruitful to present certain principles, discuss their relevance and importance, and derive practical indicators from them. The choice of the particular principles given below is thus made in relation to a more holistic perspective from which the issues discussed in the preceding sections are viewed as inter-connected. An indicator is derived for each principle on the basis of measurability and practicality. The primary objective is to derive indicators that have a practical usefulness for local interactions, but their usefulness on other levels is also taken into account. These principles and indicators are selected in light of three considerations that are related to the strengthening of coevolutionary processes on the local level. The first is the comprehensive representation of the most important issues in respect to sustainability. The second is their usefulness in a process in which people as consumers and citizens are also involved. The third is the possibility to utilize measurable indicators in comparative studies involving different time periods, geographical areas, and production forms.

The following is a list of the principles and indicators proposed:

1. High production of energy in terms of biomass

The principle of a high level of photosynthesis is important in two ways. The first is that it provides biomass energy to the ecological system. Even though Swedish agriculture often transforms less solar energy into biomass than natural land or forest, the agro-ecological systems created by agriculture are largely dependant on the biomass produced through land cultivation. Many non-crop plants and non-farm animals associated with these systems are dependent on agricultural practices and production. Our concern in this respect is thus with the qualities of new ecological systems that cannot be measured merely in terms of maximum captured energy. However, the total biomass produced by photosynthesis in crop and non-crop plants must be considered in this type of analysis, even though it is difficult to measure and comprises a concept difficult to understand.

The second is that it produces energy in the form of biomass for direct human utilization or indirectly through livestock, which has historically been the basic function of agriculture and has driven its development. This will likely include a future increase in biomass demand in order to provide fuel (Eriksson 1988). In agriculture certain crops and animals are protected and nourished at the expense of others, but even these become part of the ecological system, particularly in relation to providing energy and nutrients to other species both in and above the soil. Even with the mono-cropping of cereals and no animal production, there is a large share of biomass that benefits the surrounding ecological system. An increased share of energy benefiting the ecological system would then be associated with feeding harvested crops to nearby livestock, particularly in farming that integrates crop and animal production. Given this complexity, it is reasonable for our purposes to concentrate on land productivity in terms of energy in harvested crops, not on the total biomass produced through photosynthesis.

An important issue that must be addressed concerns the quantity and quality of energy used to produce the harvested crop. There are many internal and external sources of energy that can be identified as inputs in crop production. It is not possible to quantify these inputs accurately in light of the many complex processes involved, some of which require value judgments. Emergy analysis (Rydberg and Jansén 2002) is probably the only method that could address energy complexity, system multi-functionality, and energy quality as well, but it is far too complex to be practical for our purposes. Furthermore, we should exclude the energy embodied in the labor force from our calculations (Jansén 2000) since all external inputs comprise a long chain of embodied energy in respect to their production and transportation, including energy consumed by labor. In addition, on-farm livestock can be multifunctional, thereby contributing to crop production in various ways. For example, if horses are used for field work, then it is a value judgement whether we consider their contribution in terms of crop share as feed or as energy required for their maintenance. It is also significant that much of what they eat goes into the food web for other organisms. Finally, even if a crop is used to fuel agricultural machinery, it is not correct to consider this use as an energy input that should be deducted from harvested energy insofar as not all the energy in the crop is harvested and not all the energy in the harvested crop is used for combustion.

The increasing use of non-renewable energy is the most important sustainability issue facing contemporary societies. The external non-renewable inputs in agriculture are primarily in the form of fossil fuels, mineral fertilizers (especially nitrogen), tractors, and other machines. We should thus consider net energy production as harvested crop minus external non-renewable energy in the form of fossil fuels and synthetic nitrogen fertilizer. Energy spent on producing tractors, equipment, buildings, and machines is excluded for reasons of simplicity. In addition, most of the current production forms in Sweden will have to utilize these for many years to come. It is not difficult to measure and understand the net energy production of crops, as defined above, per hectare of arable land as an indicator of agricultural sustainability. This implies that our main concern is the harvested crop regardless of its utility forms as either direct food, feed for animals that produce milk and meat, or energy. This same indicator can be used for analyses at both farm and national levels. An appropriate unit of measurement is mCal, where m is million and Calorie is one thousand calories. This is more suitable than kWt or joules since the basic concern is food production and consumption, which is often measured in daily Calories per capita. Net primary production in kilogram per hectare can also be used after certain modifications that facilitate its application in analysis at farm and local levels. A sufficient annual quantity of food for human consumption is approximately one mCal.

2. Combining animal and crop production

The historical development of Swedish agriculture was based on combining crop and livestock production, which could readily be expanded and was of benefit to both farmers and other people. This principle is also related to many other important sustainability issues. For example, its contribution to the ecological system and to the landscape is highly recognized and appreciated. In addition, crop production cannot be sustained without the nutrients provided by livestock and other animals in the surrounding ecological system if no external fertilizers are used. When crops and livestock are integrated on the farm level, an effective system of nutrient circulation with minimum energy requirements can be developed. But if the net nutrient flow in and out of the farm is notably negative, then even combining crop and animal production would not be sufficient for sustaining soil nutrients, especially phosphorous. Another important linkage is associated with cultivating a variety of crops that produce both food and feed, thus involving crop rotation. Swedish farmers in traditional agriculture employed a symbiotic, coevolutionary process involving crops, livestock, and humans on the basis of trial and error such that all three expanded. We may never fully understand the complexity of this system, but its merits have been widely recognized.

There is a great potential in Swedish municipalities for a substantial improvement in this practice since most farms either maintain some level of animal production, or are often close to farms that do. This implies that we can increase the flow of crops and nutrients by means of policies that encourage the coordination of animal and crop production. An appropriate indicator for this principle would be the unit number of animals per hectare of arable land. This indicator is obviously reasonable when used at the farm level, but it has important weaknesses when used at the municipal and national levels due to higher animal concentrations in certain region and on certain farms. At these levels we could use "percentage of farms with 0.6-1.2 unit of animals per hectare of arable land" as an indicator for this principle.

3. Crop rotation with lea

The benefits of this principle for sustainable agriculture extend from a variation in food and feed, to pest management, increased biodiversity, improved soil structure, and the provision of nutrients. The importance of lea cultivation in agricultural sustainability is widely acknowledged (Ebbersten 2002). For example, legume crops fix nitrogen in the soil and provide high protein food and feed, while lea and green forage are basic cattle feed that historically developed as an appropriate means for supplementing grazing. They also provide soil cover and reduce nutrient leaching, particularly nitrogen loss. Lea production also helps to control the creation of greenhouse gases since it increases soil carbon and reduces the use of mineral nitrogen, an important source of nitrous oxide emissions. The relation with energy production described above is particular important in light of the thermal constraints in Sweden since crop rotation can often provide a better utilization of arable land for photosynthesis. The value of crop rotation has been clearly demonstrated in traditional agriculture, and it is still recommended in modern industrial agriculture. We consequently cannot ignore this principle in an examination of agricultural sustainability in spite of its qualitative nature.

In order to derive a reasonable and easily used indicator for this principle, it is useful to keep in mind the principle of integrating animal and crop production. Lea is an important source of cattle feed, while legumes and cereals are important sources of both food and animal feed. We can thus view farms that maintain a balanced cultivation of cereal, lea, and legumes as having a good rotation system. Since not many farms in Sweden have an annual cereal cultivation that is less than 50% of arable land, an indicator based on land use for lea and legumes would reflect crop rotation reasonably well. The use of 40% of arable land for such crops can be judged to be a good standard at the farm level of analysis. Most crop farms would now have low scores in terms of this indicator, but this would be relatively easy to improve by coordinating land use between crop and animal farms. Analysis at the municipal and national levels could utilize the percentage of farms with 20-60% of arable land used for lea and legumes.

4. Limited use of mineral phosphorous fertilizer

The importance of this principle stems from the fact that known phosphate mining reserves on land will be exhausted in no more that two centuries. The use of ocean reserves will require a substantial amount of energy, involve large costs, and would not solve the problem of phosphorous enrichment in local and regional ecological systems. Phosphorous nutrients can accumulate in soil to a certain level, and even a low use of phosphorous can degrade soil if there is continuous deficit between total phosphorous input and output. Increasing phosphorous circulation is now the most feasible alternative for reducing its use in mineral form, and this would affect various other sustainability issues as well. For example, the integration of animal and crop production, which is the most important type of phosphorous circulation in terms of low energy requirements, also circulates other nutrients and provides many social and ecological services. The circulation of human urine, collected from urine separating toilets, can provide soil with nitrogen, phosphorous, and potassium, and it also reduces nutrients pollution from sewage plants (Saifi 1994). The use of sewage sludge in agriculture, after it has been cleaned of heavy metals, would also provide soil with important organic matter and solve the problem of sludge disposal as well (Hahn 1992). A limited use of mineral phosphorous can thus indicate many socially and ecologically sustainability benefits if it is not based on depleting soil deposit.

In order to derive a reasonable and easily used indicator for this principle, we need to compare the advantages and disadvantages of such possible measures as mineral phosphorous use per capita, per hectare arable land, per food unit, or per unit of energy produced. Phosphorous use per unit of energy produced in harvested crops appears to be the most reasonable measure since it is related to land production of biomass for human utilization, which is our first principle. It also produces fewer discrepancies. Kilograms of mineral phosphorous per mCal produced is thus proposed as a reasonable indicator. This indicator can also be used for analysis at both farm and national levels.

5. Limited use of mineral nitrogen fertilizer

The proceeding four principles render this principle somewhat less important since they all are related in varying degrees to the low use of industrial mineral nitrogen. The low use of mineral phosphorous is especially important because of the complementary natures of nitrogen and phosphorous use and circulation. Nevertheless, the limited use of mineral nitrogen is an important principle of sustainability since there are serious problems particularly related to the excess use of nitrogen, such as the enrichment of water bodies, the contamination of ground water, acidification, and the depletion of biodiversity. Furthermore, mineral nitrogen production demands the intensive use of fossil fuels. It is important to note that nutrients circulation and nitrogen fixing crops can substantially reduce the use of mineral nitrogen.

As is the case with mineral phosphorous use, kilograms of mineral nitrogen per mCal produced is a reasonable indicator for this principle. This indicator can also be used for analysis at both farm and national levels.

6. Limited use of biocides

This principle is related to many issues concerning sustainability insofar as biocide use has a wide range of effects on the environment, including the depletion of biodiversity, mercury accumulation in soil, and the development of pesticide resistance. The latter is already a source of increased costs to farmers because it leads to the increased use of increasingly sophisticated pesticides, while residues in food and the contamination of drinking water constitute health hazards. On the other hand, a limited use of biocides can conflict with many other principles, particularly by reducing crop photosynthesis. The role of technological development is crucial in reducing this conflict by providing new methods of crop protection. In addition, the role of national and international regulations in regulating the use of the literally thousands of chemical compounds in question is of crucial importance.

I have chosen "amount of active substance per hectare arable land" as an indicator for this principle for three main reasons. First, although "active substance" reveals little about the quality of chemicals, it is commonly used in statistics. Second, a large percentage of applied pesticide misses its target. Since the effect of this on the environment is more serious than pesticide residue in food, it is more significant to relate biocide use to the area of arable land than to the production unit. Third, although the number of applications is also at least as good as the above indicator, we cannot use it in historical comparisons. The chosen indicator is also useful for analysis on both farm and national levels.

7. Balanced food consumption

Balanced and healthy food consumption in Sweden would reduce food demand and promote a more rapid development towards the establishment of a system of sustainable agriculture (Chapter 3). A change in diet patterns in line with the recommendations of health authorities, along with improved animal welfare and a greater importance placed on ecological services, would make it possible to reduce the level of intensity in production and use less cereal in animal production. The total annual consumption of cereal per person is thus a reasonable indicator for this principle. An annual consumption level of 400 kg cereal per person, of which 200 kg is food and 200 kg animal feed, is a rough estimate of balanced food consumption at local and national levels.

8. Balanced regional distribution of agriculture

Local production and consumption made traditional agriculture ecologically sustainable on two accounts, namely, low energy requirements and high nutrients circulation. During the last century this production/consumption ratio was weakened as consumers moved to nearby towns and cities and to other regions regardless of the local ability to provide people with food. Such issues as the social services provided by agro-ecological systems, animal health, transport, and control over crop and animal production methods serve to strengthen the importance of the principle that agriculture should have a balanced distribution throughout the country. "Arable land per person in a municipality" provides a good indicator for this principle, and even though land productivity in Sweden varies from region to region, 0.3 hectares arable land per person may be taken as representing a balanced distribution of agriculture under present productivity condition. In regions with low land productivity this figures could be higher. This indicator is not valid for farm level analysis, but it is valid on the national level. A locally lower ratio of arable land per person indicates that there is a high potential for sustainability in terms of economic support for the farms in the municipality since there will be an increase in the value of services they provide.

9. Adequate income for farmers

Along with attitudes and values, farm economy has a great influence on the choice of production forms, managerial methods, and other practices. Farmers who utilize socially desirable but more expensive production methods should be compensated for the additional costs they thereby incur. Because of the complex nature of agriculture and the multiple objectives of farmers, it is difficult to determine the level of support needed as well as the level of farm income that is adequate for supporting sustainable development. Consumer demand and their willingness to pay a premium for a certain quality of food that is desired for moral, ecological, or health reasons also constitute an important stimulus for farmers who are willing to improve environmental and social services. In this respect, farmers' net income from farming in comparison with other groups in society is a reasonable indicator.

10. High degree of integration between farming and both rural and urban local populations

This principle is important not only because of its relation to many sustainability issues, from nutrients circulation to the preservation of a living countryside, but also because it is directly involved with strengthening coevolutionary processes at the municipal level, which implies a close interaction between farmers, other citizens, and the ecological system. For example, nutrients management and circulation from urban areas to arable land is an important condition for achieving the goal of maintaining adequate long-term food production (Drake 1991). There are also large economic benefits associated with using cleaned sewage sludge (Hahn 1992) and separated urine from toilet water in crop cultivation (Saifi 1994). Linking food production and consumption at the local level would also consume less energy in food transport. The energy used in transporting wheat from the US to Sweden is equal to approximately 40% of the energy content of the wheat itself, while the corresponding figure for local wheat transportation is only 2% (Brorsson 1991). Furthermore, public interest in agro-ecology and animal welfare is likely better addressed and managed at the municipal rather than national level and is directly related to food production and consumption.

Two issues are highly relevant to strengthening local coevolutionary processes. First, demand for basic food must be directed towards local/municipal production. Second, agriculture must be administered on the municipal level in a way that represents the will of local citizens through the political processes and is in accordance with the national directive delegating resource management to Swedish municipalities. It is not easy to find a reasonable indicator for this principle, particularly in respect to existing statistics, since much food processing takes place at a higher level. Moreover, there are currently no administrative bodies responsible for agriculture at the municipal level. The best indicator now available is probably the percentage of local production that is processed and consumed within the municipality or in nearby municipalities, but there still remains a need for supportive statistics and/or special studies. The percentage of biomass harvested and consumed within the municipality could be an alternative indicator, but this also needs appropriate statistics.

The principles suggested above cover a wide range of issues connected with agricultural sustainability and they complement each other as well. The relationships between them are both negative and positive, i.e., improvement in the realization of a given principle may lead to improvement and/or deterioration in the realization of others. For example, a reduction in biocide use may lead to a reduction in harvested energy, thus increasing the use of mineral nitrogen and phosphorous per unit of energy harvested. Such inter-relationships imply that agricultural sustainability cannot be based on merely one or few principles. While the principles we have chosen are valid for various types and levels of analysis, and for various forms of production in different places and in different periods of time, the indicators proposed may not be practical in all instances. They may thus need to be modified and changed in light of the particular situation and level of analysis to which they are applied. The statistics available may also hinder the use of certain indicators, not least of all because the type of statistics available today are not always suitable for analyzing the degree of sustainability in an agriculture system. An important additional issue is thus the need to generate statistics that are relevant to directing agriculture onto a path of sustainable development.

6.5. Summary and Discussion

Understanding agricultural development in terms of coevolutionary processes involving the agricultural, socioeconomic, and ecological systems is fruitful for addressing agricultural sustainability, particularly in relation to processes of change. Important elements of this view include the history of agricultural development, problems that have been encountered, and an awareness of likely future problems. This type of understanding reveals various dimensions of sustainable agriculture within which a number of principles and indicators can be found. Insofar as Sweden is characterized by a stable demand for food and a growing demand for ecological and social services by agriculture, the country is in a position to promote agricultural sustainability by strengthening the local coevolutionary processes that were weakened during the development of modern industrial agriculture.

There is no universal operational meaning of sustainable agriculture. The general definition that was proposed in Chapter 3, namely, "a system capable of satisfying the food requirements of the present generation without compromising the ability of future generations to satisfy their own," requires further elaboration. Under Swedish conditions it was found to imply the provision of food and other services, the integration of issues revealed on the global level of analysis, and the re-structuring of consumption patters to reflect the recommendations of health authorities. One thousand years was judged to be an appropriate time period for determining sustainability. A number of other significant issues in respect to sustainability emerged as we discussed the eleven dimensions of agricultural sustainability that were presented in Chapter 3 in relation to the Swedish conditions. Most of these issues were found to be related to other issues within the same dimension as well as in other dimensions.

Ten pairs of principles and indicators of agricultural sustainability that may be useful for strengthening local coevolutionary processes were derived from these dimensions. Many of the ecological problems examined were found to be related to the depletion of off-farm natural resources, particularly fossil fuels and mineral fertilizers, and to the failure to preserve important features of traditional agriculture that made it ecologically sustainable. It was proposed that an analysis of sustainability should focus on the local-regional level while integrating issues from the national and global levels. In order to facilitate interaction between the actors that are important for the development of a system of sustainable agriculture, the indicators should be easy to understand and use.

The following principles and indicators are suggested for local level analysis:

Sustainability principles	Derived indicators
1. High production of biomass energy	mCal net harvested crops per hectare
2. Crop rotation with lea	% of farms with 20-60 % lea and legumes
3. Combining animal and crop prod.	% of farms with 0.6-1.2 animal un. per ha
4. Limited use of mineral phosphate	kg P per mCal
5. Limited use of mineral nitrogen	kg N per mCal
6. Limited use of pesticide	kg active substance per hectare
7. Balanced food consumption	kg yearly cereal consumption per person
8. Balanced regional distribution	Arable land per person
9. Adequate income for farmers	Farmers' income/other groups' income
10. High degree of integration betw. farming and municipal populations	% of municipal production processed and consumed locally or regionally

These principles and indicators are to be viewed as suggestions based upon an understanding of agricultural sustainability that emphasizes process, history, and the involvement of farmers as well as other citizens. They do not replace other views and other levels of analysis, which are to be conducted in a more detailed manner. Utilizing only ten pairs of principles and indicators concerning sustainability is justified on practical grounds insofar as our aim is to promote sustainability by a strengthening of local coevolutionary processes, which implies interaction between many subsystems and actors. Realizing in practice the principles we propose requires both short-term regulatory policies that affect land use and production methods, as well as the long-term development of technology and value systems that support sustainability.

7. Coevolutionary Processes and Principles of Sustainable Agriculture in the Municipality of Uppsala during the Twentieth Century

7.1. Introduction

The model in Chapter 3 describes agriculture as a subsystem that coevolves with the larger ecological and socioeconomic systems. Various processes and elements that are in continuous but non-constant relationships with each other were identified as relevant to agricultural sustainability and future development. Within this framework, the present chapter will attempt to discover what can be learned from the historical development of Swedish agriculture. The focus will be on the twentieth century, when agriculture was transformed from a traditional system of locally based agriculture into a system of modern industrial agriculture that is interconnected with other systems on national, regional, and global levels. The indicators of agricultural sustainability that were proposed as useful for strengthening local coevolutionary processes (Section 6.4) will be examined in relation to agricultural development in the Municipality of Uppsala (within the borders existing in 2000) during the twentieth century. It is argued that such indicators must be understood contextually as reflecting what we now take to be important issues concerning sustainability. The changes over time in their values should be viewed as information that complements the larger picture concerning the evolution of the system, not as "absolute" measurements of agricultural sustainability in Sweden.

My interest is not to present a purely historical study on specific issue(s), such as Larsson et al. (1997) have done, or for a specific period of time, as Gadd (2000) did. I rather intend to examine agricultural development in Sweden in general, and in Uppsala in particular, within the framework of the model of coevolution in order to identify appropriate ways to direct future development towards sustainability. This involves three general lines of approach to the subject. First, statistics will be gathered and analyzed concerning agriculture in Uppsala during the twentieth century (Appendix A). The aim is to provide a picture of important changes in farming structure, which will then be examined in respect to the sustainability indicators proposed. Second, a study will be made of the pertinent historical literature to obtain information not provided by the official statistics. Third, the statistical and historical findings will be used together to paint a picture of clear and large-scale changes in Swedish agriculture. The aim is to provide an understanding both of agricultural sustainability and of the coevolutionary processes that have led to sustainable as well as non-sustainable development. The work that is presented in Appendix A shaped the structure and content of the chapter as a whole.

Section 7.2 briefly addresses important changes that took place prior to the twentieth century in order to provide a background to the further discussion. The evidence shows that comprehensive changes occurred during the nineteenth century that put agriculture on a new path of development. Section 7.3 outlines development during the twentieth century. It focuses on the changes and processes that led agriculture away from the path of sustainable development that it had shared with traditional agriculture. A specific path of development is identified for each quarter of the century. Section 7.4 estimates the values of the indicators of sustainability proposed in Section 6.4 for the five year periods that form the boundaries of the quarters. Section 7.5 presents observations that may be useful concerning a sustainable path of agricultural development. It also proposes a way to promote agricultural sustainability in the Municipality of Uppsala.

7.2. Agricultural Development prior to the Twentieth Century[1]

There are quite diverse natural conditions for agriculture within Sweden because of climatic differences influenced by latitude (58-69 degrees north), and also because of various factors related to geology, soil formation, and human practices. Areas of moraine, clay, and organogene soil with a growing season of 150-250 days gradually were transformed over millennia into important agricultural regions supporting people organized into villages. Early farmers came to Sweden from the south some five thousand years ago and brought with them domesticated cattle, sheep, and pigs, animal types which still form the bulk of current livestock. The practice for thousands of years was to leave livestock outdoors even in winter, albeit with some supplemental feed. Early land cultivation was based on the slash and burn method, which meant that cleared land could be used for cereal cultivation for only a several years before having to be abandoned because of declining fertility. This system was later used to support permanent cultivation, and was even occasionally practiced during the nineteenth century in spite of having been prohibited by the state (Fogelfors 1997).

By the middle of the first millennium AD permanent land cultivation for grain production was well established, along with the harvesting of meadows for feeding animals housed in stables or sheds during the cold winters. The Uppsala region, with its clay and silt soil and a growing season of about two hundred days, became an important agricultural center during the first and second millennia. It attracted early agricultural settlement, and later become the location of state and religious institutions. Much of today’s arable land in Uppsala was brought into production in connection with the rising level of the land and the consequent drying of wetlands and marshy meadows. Forest clearing was also an important means for claiming agricultural land, as has been the case throughout Sweden. Hunting, fishing, berry picking, and mushroom gathering were also historically important food sources, and they are still widely practiced today.

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[1] This section draws largely on Lantbruksstyrelsn (1990), Clason and Granström (1992), Larsson et al. (1997), Gadd (2000), and Morell (2001)

Towards the middle of the second millennium, and after more than a thousand years of relatively slow development, an increasing share of agricultural products were used to support the church, the nobility, and the state through taxes and rents. With the establishment of a powerful centralized state in the sixteenth century, particularly during the reign of Gustav Vasa, agriculture became increasingly affected by state involvement (Myrdal 2000). For example, an expansion of agriculture came about by virtue of the security provided by law and order and with the assistance of tax relief for claiming new arable land, which led to the development of a high food standard during the sixteenth and seventeenth centuries. It is clear from such historical facts that Swedish agriculture developed in a process of coevolution involving the ecological system and, later, the socioeconomic system as well.

The traditional agricultural system developed over a period of many centuries and survived in its main features into the nineteenth century. It was typically constituted around the village organization, arable land, meadows, and grazing lands (Sporrong 1997; Gadd 2000), and was dominated by family farming (Flygare 1997). Village centers were comprised of farmers' homes, each containing a house and an animal barn or shed. This was surrounded by fenced fields of cultivated lands and meadows and, further out, by grazing lands of open meadows and semi-forested lands (hage). The village order (byamålet), which determined each farmer's rights and duties according to his share in the ownership of arable land, and the village committee (byalag), which organized all types of production-related work, were the main governing institutions. Each farmer owned, or leased, and worked his share of arable land or tilled land, which was distributed as strips in each field and served as the basis for the village order and, later, for taxes. The arable lands were cultivated for cereal production, and the fields lay fallow every second or third year. Barn manure was used to fertilize the fields, where livestock were allowed to graze after the harvest in late summer. Fenced meadows were often not privately distributed, and the lea harvest was distributed according to the village order. The meadow lands were about three to five times larger in size than the tilled land, and they too were often grazed after the lea harvest. Grazing lands, water bodies, and forest were used by the village members in common.

The fact that this system of using natural resources survived for centuries, being applied in its main principles throughout the eighteenth century, is evidence of its sustainability. Nevertheless, it was not able to survive the pressure to produce sufficient food for the relatively fast growing population. One could argue that humans used no less than two hectares of agricultural land per person in this system, but many other species were also involved in the web chain of biomass energy that it produced. Natural ecological systems evolved with agriculture into agro-ecological systems with many new plants and animals. Approximately one thousand plant species were associated with this system of tilled lands and meadows, about one-third of which are now threatened because of rapid rationalization and the shrinking of their habitats (Larsson 1997).

Traditional farming in Sweden gradually became unsustainable during the eighteenth and nineteenth centuries as it increasingly interacted with the larger socioeconomic system, which began to undergo rapid and extensive change. The European scientific revolution and colonization of the world entailed changes involving knowledge, values, technology, and organizations that reinforced each other and led to a relatively rapid and fundamental transformation of agriculture. As was illustrated in respect to the model of coevolution that was presented in Section 3.3, a number of subsystems and elements are involved in the interaction between agriculture and the surrounding socioeconomic and ecological systems, each of which may effect others within the system as well as the system as a whole. When the system is stable, the sub-systems are locked to each other and little development takes place. But when the system is not stable, each sub-system can become an active force capable of changing other elements by virtue of their mutual inter-dependence.

There have been a number of such non-constant forces at work within Swedish agriculture since the eighteenth century, including; 1) population growth; 2) increasing state involvement; 3) technological change, 4) industrialization and the expansion of the non-agricultural sectors of the economy; 5) Changes in relative prices; 6) inducing "scientific" knowledge; and 7) changes in value system. These forces were interacting with each other and none of them can be singled out as having caused the changes in agriculture and in issues related to agriculture that are summarized in Table 7.1 and discussed below. However, they continue to influence agricultural development into the twenty-first century, albeit in different ways as they have changed over time.

A number of observations can be made concerning Table 7.1 in relation to the above seven forces. First, the forces driving modernization, such as the application of various scientific discoveries to improve health, education and production, were clearly dominant during the eighteenth century. Although, the reduction in the mortality rate due to better disease control resulted in relatively rapid population growth in the eighteenth and nineteenth centuries, food production was not able to cope with the resulting growth in food demand in spite of the substantial efforts that were taken, particularly in increasing the area of cultivated land. Consequently, living standards fell in terms of food quantity as well as quality. Hunger was common in poor harvest years, even when Swedish agriculture managed to stop importing rye and began exporting oats around the middle of nineteenth century. Such difficulties, combined with decreasing transport costs and increasing information about better living conditions in North America, led to periodic waves of emigration, and between 1861 and 1930 1.4 million people left Sweden, mainly for the United States (Morell 2001, p.76). Strong pressures were placed on the agricultural system at all levels to increase production as well as provide work for the growing rural underclass. Between 1750 and 1850 the number of what we may call the rural underclass (crofters, landless workers, servants) roughly quadrupled, the number of crofters, for example, growing from 50,000 to 190,000 (Isacson 1997). By 1900 only about one-half of farm labor consisted of farmers and their families. The old system was thus destabilized because of increasing food demand, social inequality, and the changes that occurred as a result of efforts to meet the demands of the socioeconomic system.

Table 7.1 Changes in Swedish agriculture during the eighteenth and nineteenth centuries[1]

	1700	1800	1900
Total population (m)	1.4	2.3	5.2
Rural population (m)	1.3	2.1	3.6
Arable lands (m ha)		1.4	3.5
Food standard	low	low	improving
	rye import	oat export	
Cultivation system	tilled land for cereal meadows for hay		rotation of cereal and lea meadows become ara. lands
Organization	village based management		individual farm mgmt.
Soil preparation	wooden plough		iron plough and harrow
Harvesting	sickle for cereals scythe for mowing lea	improved scythe	scythe for cereals and mowing lea
Threshing	flail	flail/threshing roller	threshing unit/plant
State involvement	science academy agricultural societies	agricultural academy	national board of agriculture
	veterinary and survey services		agricultural schools and research institutes
		cereal storehouse and trade	financial support
		law and directive changes and land reforms	
Farmers' position	medium	medium/strong	very strong
Farmers' ownership of farms	one-third	half	two-thirds
Tax bases	production/property	property	income
Rural landless	one-fourth	one-third	half

Sources: Author structuring based on Larsson et al. (1997), Gadd (2000) and Morell (2001).

1. The contents of the table are approximate. Most of them are related to the three mentioned years. Other are related to an approximate period and not a specific year. For example, the Academy of Sciences was established during the first half of the eighteenth century, in 1739, while the National Board of Agricultural was established in late nineteenth century, in 1890. The provision of financial support began around the middle of nineteenth century.

Second, state involvement in agriculture had many dimensions that were influenced by the domestic situation as well as by external forces associated with technological development, organizational change, and the conditions of trade. This fact illustrates that the state was largely responsive to the demands of the socioeconomic system as a whole. The state in fact undertook numerous efforts to modernize the agricultural system so that it would be capable of satisfying food requirements and employing more workers. By means of various measures and directives, including the reappropriation of arable land that had been distributed to nobles during the seventeenth century, farmers came to own approximately two-thirds of all farms by the end of nineteenth century. State-led land reforms combined with various supportive measures enforced the practice of rotating crops with lea on individual farms. The state also established various organizations during the eighteenth and nineteenth centuries that came to play an important role in developing and transforming agriculture. For example, the Academy of Sciences greatly contributed to animal disease control and land surveying. The semi-governmental county agricultural societies (Hushållningssälskap) served as powerful instruments for providing various services to farmers. Land survey offices were engaged in land reforms and in the construction of water drainage systems. The Agricultural Academy provided scientific advice for improving and changing agricultural practices. Agricultural schools along with research and field stations were widely used in the process of agricultural modernization. The National Board of Agriculture (Lantbruksstyrelsen) was established in 1890 to take charge of agricultural administration and extension services.

When the state decided in 1856 to allocate 20% of taxes collected from the alcohol trade to county agricultural societies, the involvement of the latter substantially expanded in many activities related to development issues, including collecting statistics, advising farmers on new techniques, improving animal production through imports and breading, and arranging meetings and competitions on various agricultural methods (Lantbruksstyresen 1990). The state also initiated a program to build cereal storage facilities and promote trade in many regions in order to control price fluctuations and guarantee a better distribution of food as needed. In addition, it contributed greatly in providing new arable land by regulating lake levels and drying wetlands, and to improving land productivity by ditching in order to remove excess water from the fields. Between 1881 and 1933 approximately 17,000 projects received state funding for ditching and for land reclamation (Håkansson 1997). It must be added that while forests became an increasingly valuable resource, marshes and bogs were considered to be worthless until their ecological functions were understood in recent decades.

Third, Sweden became able to satisfy its food requirements by the end of nineteenth century. The transformation that made this possible came about through increased knowledge, the adoption of new techniques and methods, particularly from England and Holland, and the establishment of domestic institutions in order to promote the needed changes. The tools, equipment, and system of cultivation in 1900 were substantially different from what they were in 1700. The most important technological adaptation was the system of rotating cereals and lea, which not only increased the area of arable land and the levels of crop production, but also decreased the need for fallow. Ditching and eventually covered water drainage was also an important contributor in increasing crop yields along with the area of land under cultivation. The adoption of the iron plough made it easier to use clay soils and substantially improved soil preparation in general. Improved equipment for harvesting and threshing saved labor during the autumn, when many activities demanded a large work force. Improvements in animal breeding and fodder also took place during this period. For example, annual milk production per cow increased from about one thousand kg to about two thousand kg. Such technological success was clearly connected with state involvement, the growing industrial sector, the replacement of traditional knowledge with expert knowledge, and the replacement of village-based farm management by the management of individual farms.

Fourth, the rapid development of industry and the growth in non-farm employment forced an increase in surplus agricultural production from farms. This both influenced and was influenced by improvements in nutrients management insofar as more nutrients began to be removed from farm circulation through the production of food surpluses. It also shaped and was shaped by specialization since industry served to rationalize labor as well as provide more adequate techniques and products. The once self-sufficient farm and village economy was transformed into a more specialized farm economy that was linked by the market with the economy as a whole. During the nineteenth century the household production of non-food products substantially declined, being moved into the expanding textile, leather, wood, iron, and equipment industries. In addition, even milk processing and butter production, which had been mainly on-farm activities even a few decades earlier, were transferred to the growing number of dairy plants by the end of the century. The latter numbered approximately 1,600 in the early twentieth century (Morell 2001).

The expansion of mining, ironwork, and lumbering into areas with less favorable conditions for agriculture stimulated increased trade in and the transport of food products. Together with the growth in urban population, this led to an increased amount of food stuffs and other nutrients being transferred from farms and rural areas into urban areas, and from regions with good conditions for agriculture into those that were less suitable. Furthermore, the leaching of nutrients from agro-ecological systems increased in relation to ditching and the drying of wetlands. New techniques and methods then had to be employed in order to maintain the fertility of the land and guarantee reasonable crop yields in the medium and long term. For example, the cultivation of clover-rich lea and legume crops, improved manure management, and the use of bone flour and limestone soil additives expanded during the nineteenth century.

Fifth, changes in relative prices, which had stimulated various changes in agriculture throughout the eighteenth and nineteenth centuries, continued to increase in importance throughout the twentieth century. Today they are probably the single most important factor influencing production mix and methods. For example, specialization and the transformation of subsistence farming into a more market-oriented type of production are rooted in the changing relative prices of outputs and inputs. The prices of many non-food farm products had already fallen before the beginning of the twentieth century because of industrialization, forcing farmers to abandon textile production and wood working for other activities, particularly forestry, that gave a better return. The movement of milk, cereal, and meat processing off farm was also influenced by the higher economic profitability of other farm activities.

Sixth, substantial changes in knowledge and technological development followed from the influence of the Enlightenment and modernization upon Swedish society during the nineteenth century. Various state-initiated organizations became the reference for decision-making and they took the lead in development. The centuries of on-farm trial and error that underlay traditional production methods gave way to "scientific" experimentation at the regional and national levels, with agronomists and other experts becoming more important in the new agricultural system than traditional knowledge. The basis of farmers' knowledge was thus moved from inter-generational learning that was passed from parents to children to specialized institutes where modern methods were taught. In addition, farmers became more aware of what was taking place outside of their own villages by virtue of improvements in communication. Such changes transformed agriculture by driving it to adopt new techniques.

Seventh, changes in the value system, which still continue today, have influenced agricultural development and led to rapid changes in farming practices. Modernity introduced a new world-view enforcing the belief that science should play a crucial role in development. Industrialization and capitalism also led to individualism and an awareness of class differences among farmers. For example, the "servants" who ate at the same table and slept in the same room as the farmer and his family during the eighteenth century ate and lived separately a hundred years later (Gadd 2000). Changes in food preferences, such as the preference for wheat bread instead of rye bread that emerged during late nineteenth and early twentieth centuries, provide another example of the effect of value changes on agricultural development, whereby the share of wheat in cereal production consequently increased from approximately 20% to over 90% during the twentieth century. However, this rise is also connected with technological developments and changes in relative prices. Modernization also generated both direct and indirect pressure that led to a change from the village management system to individual farm management. In addition, the increased importance of lumbering and coal production, along with the rise in individualism and growing problems associated with open access, undercut the old system of the common management and utilization of forests and grazing land in accordance with the needs of village members.

The operation of these interactive forces in altering the traditional system of arable land for cereal production, meadows for animal feed, and village-based farm management remained largely under constraints arising in the local ecological and socioeconomic systems. The increased food demand and production continued to be primarily integrated at the local level, extensive experimental and educational efforts were carried out on the same level as well, and the changes were largely voluntarily implemented. For instance, the new system of rotating crops with lea was largely developed from the old system by tilling meadows and enriching them with nitrogen fixing plants. In addition, the integration of animal and crop production through feed and manure management was stronger under the new system. Even the mechanical development associated with the new system remained largely locally-based insofar as it was muscle powered and fed by the agro-ecological system. The new system, which demonstrated its suitability during the first few decades of the twentieth century, may thus be termed to new system of traditional farming that evolved in interaction with the local ecological and social systems.

Three changes introduced towards the end of nineteenth century must be mentioned since they had a significant influence on subsequent agricultural development. These were the emergence of a new economic, social, and political position for farmers, the growing numbers of the rural underclass, and the encroachment of the free trade policy in agricultural goods. First, farmers came to dominate the second chamber of the Swedish parliament during the second half of the nineteenth century after new legislation granted voting rights to most farm owners but excluded workers as well as small and landless farmers. Second, the number of landless and unemployed increased significantly despite the emigration inside the country and to other countries. Third, as decreasing transport costs strengthened the competitiveness of American food products in Europe, Swedish oat exports sharply declined and domestic grain prices fell, threatening many grain producers. The protectionist group in the parliament won a majority voting for legislating import levies on cereals and other agricultural products. Growing competition in cereals and the introduction of import levies led to increased animal production. The latter produced greater value, provided a better nutrient balance, and employed more people in both rural and urban areas.

7.3. Agricultural Development during the Twentieth Century

The gap between the methods known to science and those applied at the farm level diminished substantially at the beginning of the twentieth century. But the practices adopted continued to be basically dependant on local resources, particularly nutrient flow, crop protection management, and the work force. Even the tools and equipment that farmers purchased were largely produced locally and regionally. Farmers had become literate, were freed from village production rules, and managed their own fields and forests. There was a chain of institutional arrangements at their service for increasing production and productivity, such as the county agricultural society, the county agricultural board, agricultural schools, research centers in Uppsala and Alnarp, credit facilities, cooperative arrangements, publications providing information on new equipment, better methods, and improved breeding and management practices, as well as well-defined rules concerning ownership, taxes, and trade. The new traditional farming system, which connected cereal with lea production through crop rotation and integrated crop and animal production more closely than before, not only dominated the agricultural sector, it had the potential to further improve and increase production. Food production had been increasing at a faster rate than population growth since the late nineteenth century, but it was still primarily related to local food demand. And since farmers now managed their farms individually, they were motivated to sell more food.

The century began with about two-thirds of the population engaged in farming activities and thus comprising the rural population, of whom about half were landless or working class. There were approximately 340,000 farms, about 80% of which were privately owned, cultivating about 3.4 million hectares arable land and some 1.4 million hectares of meadows (SCB 1903). Farmers and their families provided about half of farm labor (Morell 2001), with the remainder provided by the rural underclass, such as crofters, agricultural workers, and servants. This group had a low or very low standard of living, and many voices were raised to address this problem. Many people continued to emigrate insofar as population growth was still high. Since towns and cities were growing at a faster rate than the population as a whole, increasing food surpluses were demanded from the farms. There was thus strong pressure exerted by the socioeconomic system upon agriculture at the beginning of the twentieth century.

Before discussing the development of the agricultural sector during the twentieth century, it will be useful to mention two issues that may prove to be very important for any future development towards sustainability. The first is the fact that the new form of traditional agriculture not only was ecologically sustainable, but also had the potential for further sustainable development. The basic theme of this thesis is that people and the natural environment have coevolved with each other. The Swedish agro-ecological systems of the eighteenth and early nineteenth centuries were the outcome of such interrelations carried out over centuries. The new production system of late nineteenth and early twentieth centuries produced its own agro-ecological systems. This was realized in the 1930s by Mårten Sjöbeck, who argued that agricultural landscape and the related biological diversity are byproducts of farmers' practices in respect to food production (Gren 1998). While the landscape was substantially different in the new system in comparison with the old, a fundamental similarity persisted since land use remained largely the same on most farms, i.e., a combination of cereal fields, tilled and improved meadows (lea), and hagmark (even though the latter two had both been changed through efforts to increase food production). Tables 7.1 and 7.2 indicate that the new system had doubled food production twice by 1927. However, the system continued to be ecologically sustainable with its rotation of crops and lea and the integration of animal and food production. Indeed, Sten Ebbersten (2002) argues that maintaining soil fertility in this way, along with returning food-related waste from urban areas to the soil, are basic principles for a system of sustainable agriculture and for a sustainable society. It should be added that the sustainability of the new system was conditioned on consuming most of the food produced either on or close to farms. But even if most of food consumption were to occur in urban areas, the new traditional system had the potential for another doubling of food production if nutrients in urban organic waste were returned to the farm ecology.

The second issue is that good relations were maintained between farmers, people in other sectors, and the political system. Farmers enjoyed a strong political position in spite of the range of diversity among them, including small farms, large farms, grain producers in plain regions, and animal producers in forest regions. As a consequence of the reform that granted voting rights to all men at age 25, the middle farmers lost their dominant position in parliament in the 1911 elections. The party that made a breakthrough in that election, the Social Democratic Party, represented not only the growing industrial working class, but also rural workers and small farmers, particularly in the northern regions. There were conflicts between farmers and the working class insofar as the latter typically sought both inexpensive and higher wages for their agricultural members. In addition, the parliamentary representation of farmers steadily declined due to the shrinking numbers of farmers in society and the new voting rules. Nevertheless, the position of farmers remained relatively strong. The tradition of negotiations in the relationships between village members, classes, and parties contributed to this development (Vail et al. 1994; Chapter 4 above). The art of turning conflicts between farmers and other groups in society into cooperative solutions, which today involves public debate, commission reports, and parliamentary decisions in the formation of agricultural policy, is an important issue if Sweden is to follow a path of sustainable agricultural development. The crucial point in this respect is to pay farmers for certain measures that provide a greater return to society in terms of environmental and other benefits, such as the preservation of cultural and biological heritages and the management of nutrients circulation (Section 4.2).

Agricultural development during the four quarters of the twentieth century can be seen as having passed through four distinct phases, namely, refinement of the new traditional system, the adoption of motorized technology, the use of chemicals and restructuring, and the probable beginning of sustainable agriculture. Production and structural changes during the four periods, which are more or less valid for Swedish agriculture as a whole, are summarized in Table 7.2 for Uppsala Municipality. One important difference that needs to be pointed out concerns arable land per person, which was 1.1 in Uppsala as compared to 0.7 for Sweden as a whole in 1901. This difference leveled out to about 0.3 toward the end of the century since Uppsala's population grew at a faster rate than the average for Sweden.

The following brief account of agricultural development in each of the four quarters focuses on mutual influences involving various important forces in the socioeconomic system, particularly agricultural policies, and on processes leading to changes in sustainability.

Table 7.2 Major changes in agriculture in Uppsala during the twentieth century[1]

	1901	1927	1951	1976	2000
Arable land (ha)	62 220	64 303	62 090	54 279	50 279
Population	54 440	68 348	88 750	131 592	178 782
Populat. outside the city (%)	58	56	28	23	23
Number of farms	2 047	3 292	2 787	1 286	968
Crofters, other small farms	2 514	820	-	-	-
Farms without cattle (%)	< 7	7	23	43	66
Farms without lea prod.. (%)	< 7	< 7	< 23	37	33
No. of work horses and oxen	9 457	8 958	4 029	-	-
Number of tractors	-	101	1 722	2 606	2 400
Cattle units	26 789	30 130	25 903	14 555	12 186
Food cereal area (ha)	9 656	8 186	10 940	17 525	12 259
Feed cereal area (ha)	17 422	19 799	17 718	22 442	17 511
Lea and green fodder area (ha)	18 882	24 410	22 329	8 787	11 197
Fallow area (ha)	13 019	7 903	5 853	2 650	6 134
Food cereal yield (kg/ha)	1 351	1 804	2 307	4 486	4 870
Feed cereal yield (kg/ha)	1 350	1 841	2 033	3 666	3 751
Lea yield (kg/ha)	2 200	3 703	3 610	5 362	6 704
Fuel consumption (liter/ha)	0	2	63	105	109
Nitrogen consumption (kg/ha)	1	4	16	78	71
Phosphorus consumpt. (kg/ha)	4	5	11	21	7
Biocide consumption (kg/ha)	0	0	0.9	1.4	0.6

Sources: Appendix A

1. Judgment is used in deriving these estimates from various official statistics and individual studies. Crop yield and the use of fertilizers and biocides are based on a three year average. Statistics for arable land use in 1927 and 1951 are for farms with more than 0.25 hectares arable land. In 1976 and 2000 the statistics are for farms with more than 2 hectares arable land. This causes a minor error of 1-2%. See Posts Explanation and Sources in Appendix A.

The first quarter – Appropriating the new system of traditional agriculture

The state of agriculture at the beginning of the twentieth century is outlined in the third column of Table 7.1 above. Handicrafts and milk processing have largely been rationalized out, and forest work during winter periods provided important additional income. Food production was increasing at a higher rate than population growth and there were surpluses of butter for export. However, about 300,000 tons of cereal were imported in 1901-1902, mostly wheat and rye (SCB 1903). This accounted for approximately 30% of food cereal consumption, but for only about 15% of total cereal consumption. The food standard was improving, but it was still far from being sufficient for everyone. Both emigration and industrial expansion contributed to this improvement insofar as the former reduced food demand and the latter increased the ability to purchase food. Indeed, Häger et al. (1980) note that emigration had an important role in reducing both hunger and unemployment. Energy intake measured in calories per day increased from 2,300 in 1876-1885 to about 2,750 in 1896-1905, primarily due to an increase in annual food cereal consumption from 127 kg per person to over 160 kg (Morell 1997). Nevertheless, the low living standard among the poor, the preference against emigration, and costly imports maintained pressure on agriculture to produce more food and employ more people.

The nation's priorities during this quarter continued to be increasing arable land and raising production per hectare by crop rotation and other modern techniques. This is underlined by Counties' reports on land reclamation, acreage production, cultivation system, animal stocks, covered water drainage, and the wages of agricultural workers. The general goal was that each county should satisfy its own food requirements. The influence of the seven interactive forces behind agricultural development discussed in Section 7.2 indeed served to improve the productivity of land, animals, and labor. For example, the county agricultural society in Uppsala (SCB 1903) reported in 1901 that the supply situation of both cereal and animal products was good and that certain surpluses were available. Table 7.2 points out that production in Uppsala increased during the first quarter by about 50% for cereal and by more than 100% for lea, while the population grew by only about 25%. This indicates a substantial improvement in the per capita availability of both cereals and animal products. Cattle husbandry for milk and meat production was now considered to be an important component of the agricultural system, and efforts to improve productivity were expanded. This resulted in an increase in milk production per cow by about 40% during this quarter. An inquiry conducted in 1914 revealed that while regions such as Stockholm, Bergslagen, and Norrland needed to import cereals from other regions and from abroad, almost all regions succeeded in producing surpluses of butter and meat (Clason and Granström 1992).

People were beginning to consume more wheat bread and pork, especially in the growing towns and cities, and the sector responded by increasing the production of these products. Towards the end of the 1920s wheat cultivation dominated food cereals at the expense of rye cultivation and the number of pigs was doubled. In general, the consumption of meat, milk, and sugar rose substantially during this quarter. At the same time, the numbers of people belonging to the "underclass" group and emigrants leaving Sweden decreased dramatically. The sharp drop in the numbers of crofters and the increase in the numbers of farms during this period (Table 7.2) indicate a significant improvement in living condition for the landless. According to Morell (2001), the number of people engaged in agriculture fell during the first three decades of the century from 55% to approximately 40% of the total population, while those working in the growing industrial and trade sectors increased from about 35% to about 50%. The industrial sector provided ever more opportunities while the agricultural sector, with the help of state services and supports, freed ever more workers for industry due to its increasing productivity. Industrial production was also changed by the fact that work previously carried out on farms, such as food and dairy processing, was now transferred to factories. New industrial products were also called for, such as the tiles pipes that were used for covered water drainage.

Table 7.2 clearly indicates the most important achievement during this period, namely, the substantial increase in land productivity in spite of the small increase in the use of external inputs such as fertilizers. As cereal yields increased by about 40% and lea yields by 70%, the use of industrially-produced (commercial) nitrogen and phosphorous fertilizers per hectare of arable land increased to only 4 kg and 5 kg respectively. In addition, the average use of fossil fuels was only two liters per hectare. The increase in arable land, the numbers of livestock, the amount of lea cultivation (38% of arable land), and the domination of mixed farming (both crop and animal production) indicate that development during this period was basically an improvement of the agricultural system introduced and adopted during the nineteenth century. The basic principle of this system was the rotation of crops and lea and the integration of animal and crop production.

Support to small family farms, which was extensively debated before being implemented, was a particularly important state contribution during this period. The parliament in 1904, in which farmers were a majority, decided to engage state organizations to assist in the building of small farms for crofters, other agricultural workers, and forestry workers with the primary aim of improving living conditions for the rural underclass (Morell 2001). Laws were changed, new directives were issued, and substantial financial resources were allocated to encourage the establishment of new farms on crown lands and on large holdings. The Social Democratic Party also supported this program, as did the owners of large estates, who looked forward to a secured seasonal work force along with compensation for the arable land that they would have to sell under the new regulations. Small farms providing food and homes to forest worker, especially in Norrland, were also viewed as beneficial by forest owners. Many associations were established throughout the country to assist with the construction of farms and homes for their members. It was argued in support of this program that food production would increase and there would be better living conditions if crofters could use a larger area of arable land and came to own their own farms. It was also argued that small farms could manage animal production well by using the family work force. Between 1901 and 1927 the number of crofters and other small holdings in the rural areas of Uppsala Municipality consequently decreased from 2,514 to 820 units, while the number of farms increased from 2,047 to 3,292, half of which consisted of 0.26-10 hectares of arable land.

The implementation of technological developments continued to increase the productivity of land, animals, and labor. The pace of development was also speeded up by the further strengthening of state involvement and support, illustrated in Table 7.1, which continued throughout the century. The contribution of county agricultural societies in this respect was significant insofar as they served as middlemen between, on the one hand, the state and various state organizations and, on the other, farmers. They provided extension services, implemented many experimental projects, and provided educational services that were even extended to the parish level. Other important activities that led to the development depicted in Table 7.2 included better seed and animal breeding, improved soil preparation and manure management, sub-ditching, and the expanded use of labor saving equipment for harvesting and threshing. The ability of farmers to cooperate with each other in these matters, particularly in the acquisition of relatively expensive machinery and in the implementation of large projects of benefit to many, contributed substantially to development.

Although chemical fertilizers, biocides, and fuel driven machines were known during the second half of the nineteenth century, their use remained limited during the first quarter of the twentieth century. The emphasis was instead on methods that relied on local resources, including crop rotation, manure management, and horse driven equipment. For example, rotating cereals and lea improved the nitrogen content of the soil, facilitated weed management, and reduced the need for fallow land. It had long been known that manure could improve crop production. Modern science revealed that nitrogen, phosphorous and potassium are the basic elements in manure that are needed by crops and that new methods of storage and usage can preserve larger percentages of them. Manure content and manure management was thus an important component in the courses arranged by county agricultural societies. The 1927 census of agriculture in fact reported on the number of farms that had cement storage containers for manure and urine.

The use of labor saving implements powered by horses spread widely during this period. The expanded use of horses in plowing, transport, forestry work during the winter, grain harvesting, lea mowing, and raking increased in importance within the agricultural system. This led to a reduction in the use of oxen (from 957 to 36 in Uppsala) and a greater use of oats for feed. The increased use of mobile threshing plants powered by steam, and later by electricity, was influenced by cooperation between farmers as well as the better utilization of the available work force and improved finances. Large farmers and estate owners were the first to invest in new equipment and techniques because of their financial resources. They were also in a position to benefit more from a reduction of labor costs.

In 1914 Sweden exported butter and meat and imported wheat, oil, fertilizers, and concentrated fodder, but the country was not well prepared for war. After World War I broke out food prices sky-rocketed and there were eventually serious food shortages, particularly in the cities. The policy measures adopted to deal with such problems actually exacerbated the situation, such as when a potato price ceiling led to potatoes being used for pig feed. Food security thus became a central component in agricultural policy and agricultural development after 1918.[1] In addition, food imports began to decline (in 1927 food imports decreased substantially for a number of products). It should be noted that the number of sheep increased during the difficult years of World War I as well as World War II, indicating their suitability in respect to local and closed agro-ecological systems.

[1] After decades of affluence since the 1950s with no food shortages, the issue of food security has declined in importance in both public debate and agricultural policy.

The second quarter – motorizing agriculture[1]

The adoption of motorized technology dominated agricultural development during the second quarter. As we can see from Table 7.2, the number of tractors per thousand hectares increased from 2 to 35 and fossil fuel consumption per hectare increased from 2 liters to 63 liters. In addition, the area of arable land decreased by 3% and the number of farms decreased by 15%. Mechanization had little or no impact on increasing production and land productivity since crop production increased moderately despite the small decrease in arable land while the use of fertilizers and biocides increased substantially. But it did increase labor productivity, replacing more than half of horse work with tractor work. This led to a drastic reduction in the use of feed cereal and hay for horses, which may explain the reduced cultivation of feed cereal and lea. In terms of energy content, however, the savings in terms of fodder did not compensate for the increase in fossil fuel use.

The changes depicted in Table 7.2 were influenced by the interactive forces presented in Section 7.2 above. Before examining some important issues related to these forces, it will be useful to further discuss some important changes during this period. For example, regardless of Uppsala's attraction as one of the larger cities in Sweden, the population grew by only about 30% during the second quarter. The fact that the population outside the city decreased by 34% coupled with the declining number of crofters indicates the overall attraction of the growing sectors in the city. The production of food cereals increased by 29% in comparison with only a 10% increase in feed cereals. This is related to the increased utilization of winter wheat and increased fertilizer application. The use of industrial nitrogen, mineral phosphorous, and biocides increased to 16 kg, 11 kg, and 1 kg per hectare respectively. Farming specialization in respect to crop and animal production also expanded insofar as one-fourth of farms were without cattle in 1951.

The relatively low population growth led to lower food production and a decline in both arable land and animal units. No serious food shortages were experienced and the entire population enjoyed a relatively high food standard, even during World War II. The war did slow the rate of mechanization and the utilization of a number of industrial products, such as fertilizers and biocides. But immediately after the war agricultural industrialization accelerated, a process which continued without interruption for several decades. Tractors and milking machines were the main components in agricultural mechanization. Both went through decades of continuous development and modification that made using them both practical and economically feasible insofar as their prices fell. Technological development concerning farm implements and machinery, which was influenced by many factors, led to an increase in demand, improvements in quality, and reduced prices. This in turn led to more sales to farmers and further development.

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[1] The concept of motorization is used to indicate mechanization that is powered by fossil fuels.

An increase in labor costs beginning in the second half of the 1930s, the long and hard working hours in farming, and a general environment of enthusiasm for machines were important factors in the rapid mechanization of Swedish agriculture. As was the case in the United States, machine enthusiasts established the Motor Culture Association, which gathered together many agronomists, large farmers, and industrialists (Lantbruksstyrelsen 1990). The tractor almost completely replaced the horse, and implements that had been designed for horses were adapted for tractors. Indeed, by the end of the 1950s it was unusual to see horses being used for farm work. Milk machines replaced the heavy work that had mostly been performed by women, who began to leave farming at an early age and seek employment elsewhere, particularly in food processing and in services. It is estimated that wives on small farms in Uppsala had spent as average of two hours daily milking out of total working day of twelve hours at the end of 1930s (Morell 2001).

During 1928-1929 the price of food fell by some 20-30% and remained low for several years. This was accompanied by a general economic recession with increasing unemployment, especially in the cities. In what came to be known as the farm crisis of the 1930s, farmers, who comprised about one-third of both the work force and voters, faced economic devastation because of the combination of low food prices and loan burdens. In light of the increasing influence of Keynes' theory that aggregate demand influences the state of an economy, the coalition government consisting of the Social Democratic Party and the Agrarian Party launched a policy of income support to farmers (Vail et al. 1994; Anderson 1997). The threat that farmers might leave agriculture and thereby aggravate unemployment was seen as an acute threat that could be deterred through income support to farmers, which could also stimulate aggregate demand. Moreover, farmers' income was to be comparable with wages in other sectors, which was known as income parity support. A clear agricultural policy was thus established on the basis of import protection, domestic price supports, and domestic price stabilization, which implied a significant move away from free trade concerning agricultural commodities. This type of state involvement led to the establishment of a corporative agency that would set prices and consolidate the hundreds of marketing and input purchasing organizations into a national farming federation. The new policy was not a replacement for the old policy of production support but rather complemented it, having arisen from a new situation. Income support for farmers has remained an important policy objective into the twenty-first century.

Although support for the establishment of small farms was only abandoned in the late 1940s, the number of farms and the area of arable land in 1951 were substantially lower than in 1927. Population growth still provided increasing numbers of workers to the market, but the industrial, trade, and service sectors were growing at a faster rate than farming and offered both higher wages and an easier life. This development led to a further decline in the agricultural work force to about 20% of the total in 1950 as well as to increased purchasing power, which stimulated a larger demand for animal based foods.

Farming during the first half of the century had been hard and demanding work, even involving school children. Åke Smedbery (2000) relates in Hässja how difficult it was for him and other farmers' children to work day after day preparing hay while watching the children of summer guests playing and having a good time (p. 12-13). This type of situation gradually changed. As farmers became increasingly sales-oriented and responsive to policy, research, and development, the dependence of agriculture on other sectors as well as on the state increased both quantitatively and qualitatively. In addition, the character of development changed from being based on processes that were essentially locally and regionally oriented to those that were integrated with the national and global levels.

The third quarter – the chemicalizing and restructuring of agriculture

Agricultural development during the third quarter completed the process of industrialization. Mechanization expanded to include more tractors, better and larger milking machines, and the use of combine harvesters. In addition, crop breeding, combined with mineral fertilization and chemical crop protection, expanded the production capacity of arable land. Table 7.2 illustrates that the use of mineral fertilizers and biocides increased substantially, with the use of nitrogen quadrupling, while cereal yields per hectare almost doubled between 1951 and 1976 and lea yields increased by 46%. In addition, livestock breeding, coupled with veterinary services, greatly boosted animal productivity, with milk production per cow more than doubling. The expansion in milk demand could thus be met by a smaller number of cows.

This period of agricultural development was very much associated with the consolidation of the project of modernity that began some centuries earlier. The basic idea of this project, which came to dominate agricultural development, is that scientists are to provide knowledge concerning optimal farming methods and practices through detailed reductionist research. Policies are then to be based on these findings, and farmers are to react to these findings and policies according to the principle of profit or income maximization. The combination of education, access to information and services, and social and economic pressures to raise the standard of living led farmers to respond positively to the rationalization demanded by society as a whole. This forced many farmers to leave the sector, but those who remained substantially increased the productivity of labor and land by an increased use of external inputs.

In 1976 farmers produced twice as much biomass in crops as in 1951, but they also consumed twice as much fertilizer, fossil fuel, and biocide. Moreover, this was accomplished with less than half the number of farms, half the work force, and on 13% less arable land. Part-time farmers became common phenomena among those who survived the rationalization, particularly among those who abandoned animal production and expanded crop production since the latter required mostly seasonal work with modern methods. Hjelm (1991) describes this period in terms of the changing cost structure in agriculture. Labor costs declined by one-third to about 40% of total costs, while expenses for capital investments, such as machinery, buildings, and lands, and for variable inputs, such as fertilizers, fuel, feed concentrate, and biocides, increased substantially to 60% of the total.

There was a much weaker connection in 1976 than in 1927, and even in 1951, between crop cultivation, livestock husbandry, and food consumption at the local level. Of the major crops only lea was largely related to local consumption, especially on-farm. But since it was not feasible to market it within and outside the municipality, lea and green fodder cultivation decreased from 36% of total arable land in 1951 to 16% in 1976. Lea cultivation was thus adjusted to the new conditions of fewer milk farms, fewer cattle, increased yields, and the use of more cereal and concentrated fodder as cattle feed. However, the cultivation of food cereal was not adjusted to local demand, which could not have increased by more than 50%, since food cereal yields increased by 95% and the cultivated area by 60% (see population size in Table 7.2). What consequently took place in Uppsala also occurred in most other municipalities, especially in plain regions, namely, the excess production, mostly wheat, was channeled onto the global market. In light of the integration of the Swedish market, which was partly open to global market, along with lowered transport costs, the production of food was no longer related to local population.

Unlike the other forces discussed in Section 7.2, population growth had little or no direct impact on agricultural development during this period. One could argue, of course, that low population growth led to a slower increase in food demand and in the labor force, and thereby did in fact affect agriculture. However, food production increased more than food demand. If food production in Uppsala was indeed connected to the demands of its population, there would not have been such large food surpluses. In addition, the debate that arose during the 1980s at the national level on how to reduce food surpluses would have begun earlier and on the municipal level as well. We do not know what the outcome of such a debate would have been, but it would have been possible to opt for less intensive farming and, consequently, fewer agro-ecological problems. The point of this hypothetical discussion is that events and choices are contextual, and even though we cannot predict future development, we can influence it.

The conditions and processes of development during this quarter may be summarized by highlighting certain issues related to the various interactive forces that were at work.

First, most farmers were well educated and well trained by the middle of the century, and able to adopt new methods and techniques relatively easily. By 1950 the living conditions of the agricultural population were much better than they had been at the beginning of the century, but they could still hardly keep pace with the improvements taking place in other groups in society. For example, a 1946 survey revealed that more than half of rural households had no running water and waste water discharge (Lantbruksstyrelsen 1990:127). Some ten years later people in cities even had warm running water and centrally heated apartments. In order to have a higher standard of living, farmers had no choice other than to increase farm surpluses and their productivity, or leave farming.

Second, scientists in general and agronomists in particular at research centers and experimental stations were producing important findings that could substantially increase crop yields, animal production, and labor productivity. Crop breeding selected for varieties that could double or triple acreage yields if mineral fertilizers were used in order to guarantee a high level of nutrients availability, and if synthetic biocides were used in order to assure crop protection.

Third, prolonged high economic performance after the war created three important forces for increasing production and labor rationalization. The first was an increase in real income during a period of high income elasticity for animal based foods and processed foods. This led to a changed structure in food demand. The second was a growing labor shortage. Since agriculture employed about 20% of the country's labor force, it could release labor to other sectors of the economy if various labor saving techniques were utilized. The third was increasing labor costs, which led to a decline in farm employment.

Fourth, the policy of income parity support for farmers that had been implemented in the 1930s continued long into the second half of the century. This commitment was in clear contradiction with the new socioeconomic demand that agriculture restructure production and release workers. The agricultural policy legislated in 1949 instituted a new line of support, rationalization, which conditioned earlier income support. The policy of price and market regulation was thus supported by a policy that encouraged, or rather forced, many farmers who were unable to generate adequate income to leave the sector. In addition, governmental county boards for supporting small farms were replaced by county agricultural boards that had a clear mandate, as well as the appropriate financial, legal, and expert support, to rationalize the sector. Of special importance was their powerful position in respect to the buying and selling of arable lands.

Fifth, services related to agricultural production were generously provided with direct and indirect state support. Official organizations that consolidated important services to agriculture were developed over time, such as schools for agricultural education, research institutes, experimental stations, veterinary organizations, and chemistry laboratories. The semi-governmental county agricultural societies also provided individual and group extension services not only concerning crop and animal production, but also in respect to handicrafts and other activities. These comprehensive services that were available to farmers were directly and indirectly employed to restructure food production.

Sixth, farmers' organizations also contributed both directly and indirectly to the restructuring of agriculture, such as by providing various equipment and services to large and more "rational" farms in order to strengthen their position. Cooperatives were also restructured to promote large farms, reduce farm numbers, and lower costs. Farmers need not worry about product marketing, input purchases, and prices since their cooperatives would buy their products at fixed prices and sell them machinery, fertilizers, seed, and other necessities at low prices and with substantial services.

Seventh, agro-industries expanded their production since farmers were purchasing more inputs to replace labor and increase production. Prices of purchased inputs thereby decreased substantially while their quality rose. This encouraged farmers to use even more such inputs in order to reduce labor.

None of these issues alone caused the rationalization that occurred during this period. All of them developed within the historical context, interacted with each other, and contributed to development. The process of the increased application of mineral fertilizers may help illustrate this point. When food produced by a given agricultural system is largely consumed elsewhere, the depletion of nutrients and a decline in soil fertility should be expected, at least in the long term. This problem was understood in Sweden long before the beginning of the twentieth century, when farm surpluses were often small, and various measures were taken to alleviate it. Legume cultivation, increased animal production, and improved manure management became common practices that consciously and unconsciously brought about better nutrients management. Such biological agents as guano and bone flour were even imported from distant places in other countries to maintain soil fertility, but this practice could hardly be called sustainable. Industrial fertilizers were also used before the beginning of the century, especially on large farms, but this remained limited due to various unfavorable conditions. Finally, increased farm surpluses, less expensive production methods for fertilizers, the development of crop varieties that responded profitably to mineral fertilizers, and changes in both knowledge and values opened the way for the expanded use of mineral fertilizers.

The fourth quarter – the beginning of sustainable agriculture?

Voices against the environmental impact of certain agricultural practices were already heard during the 1960s, particularly regarding the impact of changed land use and pesticide use on birds and biodiversity. Measures began being taken during the 1970s to reduce agro environmental damage, such as the ban on mercury-based pesticides and DDT, which was legislated in connection with the growing environmental awareness symbolized by the creation of National Environmental Protection Agency. During the 1980s many agro-environmental problems associated with post-war agricultural development became widely recognized among politicians, environmental activists, scientist, journalists, and citizens (Chapter 4). At the same time, increasing food production, stagnant food demand, and the consequent ever more costly export of surpluses became embarrassing issues both nationally and internationally on environmental, economic, and political grounds. The question raised then, and which remains valid today, especially in relation to European agricultural policy, was: Why should Sweden follow an overly expensive agricultural policy that causes damage to the environment and supports undesirable practices? This question led to a reshaping of agricultural policy and farm supports that may continue into the foreseeable future.

Between 1976 and 2000 the area of arable land and the number of farms continued to decline, by 8% and 33% respectively (Table 7.2). This indicates continued low economic returns to many farmers. The population of Uppsala increased during this period by 36%, mostly due to a positive net movement of people into the municipality. In 2000 the amount of arable land per person was 0.28 hectares, reflecting a good balance with the population. Even though animal productivity continued to increase during this period, the number of animal units in 2000 indicates a low ratio to arable land and population size. Animal units in Uppsala are currently one-third higher than cattle units (Appendix A), and cereal yields are continuing to increase, albeit at a much lower rate than during the previous quarter. Although the acreage of cereal cultivation decreased by 26%, the production of food and feed cereals per person in 2000 were 334 kg and 367 kg respectively. Despite the weak connection between cereal production, animal husbandry, and food consumption within the Municipality of Uppsala, which does not permit us to draw any conclusions concerning the level of cereal production in relation to consumption, an annual cereal consumption of 700 kg is twice the global average and may be considered unsustainable (Chapter 6).

Table 7.2 also indicates that industrial nitrogen consumption per hectare decreased during the fourth quarter to 90% of the 1976 level, and that the use of phosphorous and biocides decreased to less than half. Factors in this change include larger areas of fallow land, the growth of organic farming, and a decline in cereal cultivation. Agro-environmental improvement can also be noted in the increase in lea cultivation and in the number of farms cultivating lea that has been supported by state policy, which breaks the historical trend that began in the late 1920s. Strengthening this development is important for improving the values of a number of sustainability indicators, including crop rotation, but it is difficult to see how this can happen in light of the falling numbers of cattle and of farms with cattle production. Promoting the cultivation of other legume crops, such as peas and broad beans, can also contribute in improving crop rotation. The numbers of sheep also began to increase after steadily falling throughout the century, particularly on small farms and on residential holdings that previously were farms. It should be noted that cooperation between animal farms and crop farms is important for mitigating the effects of the declining number of farms with cattle.

The clear improvements in certain agro-environmental indicators by the end of the century are associated with what Vail et al. (1994) termed piecemeal and ad-hoc policy measures. These deal with specific problems that are perceived to be important, but without a coherent vision of what the agricultural sector should be in the future. Such a vision both serves to consolidate the various efforts undertaken, and also helps people see how particular measures are in line with a desired path of development. Various policy measures have also been adopted since the middle of the 1980s, meeting with varying degrees of success. This fact reflects the experimental nature of development. In addition, a new general policy objective was introduced in the late 1980s with the aim of reducing agro-environmental practices that were ecologically harmful, especially nitrogen leaching, and promoting those that were positive, particularly landscape amenities. This took its place alongside the three previous policy objectives of production support, income parity, and rationalization.

The new policy objective of promoting environmentally friendly practices has to some degree consolidated into a framework for agricultural sustainability within which two paths of development can be identified. The first is to improve the environmentally sustainable characteristics of mainstream agriculture as it developed in relation to the objective of rationalization introduced in the 1950s. The second is to strengthen the position of ecological (organic) agriculture. This was practiced on some 10% of arable land in 2000, with the goal of being extended to 20% of lands and food production by 2005. This pluralistic stance, which may prove vital for agricultural sustainability (Chapter 3), marks the beginning of an era of post-modernity in agricultural development in the sense that differing views of agricultural development are now accepted as rational. Farmers, consumers, citizens, experts, and politicians are now divided concerning which line to follow. The pluralistic view is questioned by many classical scientists.

As was the case with the first three quarters of the twentieth century, agricultural development in the fourth quarter cannot be attributed to a single driving force and could very well have been different, at least quantitatively. For example, the 1990 agricultural policy reform would have affected farming differently if Sweden had not joined the European Union. A feature in common with earlier developments is that the forces involved operated on higher levels of interaction, further reducing local interconnectedness. This shift was even strengthened by farmers' organizations and by food processing, as the number of dairies and slaughterhouses shrank under the pressure of rationalization, especially in relation to EU membership. European and Swedish agricultural policies in fact now dominate the forces influencing local agriculture.

The over 250 municipalities that were created by the large administrative reform in the mid-1960s have developed into powerful local governments. They have also become increasingly responsible for managing natural resources and supervising the implementation of environmental laws and directives (miljöbalken) for sustainable development (Ministry of Environment 1996). But while this includes supervising animal protection, including farm animals, municipalities have continued to have little influence on local agricultural matters. For example, most of them have environmental offices, but none, to my knowledge, has an agricultural office.

The fourth quarter has witnessed a growing movement to promote the consumption of locally produced food (Naturvårdsverket and SLU 2000), which has generated a number of conferences on the importance of linking rural and urban areas, such as "Stad och Land i Samverkan" (SLU 1992). It is revealing that a study of consumer attitudes in Uppsala and Kristianstad has shown that 43% of those interviewed believe that consuming local food is important or very important Sevebrant (1998a). Nevertheless, the link between farmers and consumers at the local level continues to weaken, and the food on stores shelves is still largely anonymous in respect to local origin and production methods. Although there have been improvements in some national and ecological labeling, none have taken place for food locally produced. There are in fact structural obstacles hindering the selling and consumption of locally produced food (Sevebrant 1998b).

7.4. Examining Agricultural Sustainability in Uppsala during the Twentieth Century

A number of studies have addressed the issue of agricultural sustainability in Sweden during the twentieth century in respect to a variety of different factors. Björklund et al. (1999) have investigated the agricultural generation of various ecosystem services in 1950 and 1990. They conclude that an increase in intensity during this period has led to a decrease in such services. Domeij (1999) has examined the net energy in products as well as the input/output balances of nitrogen and phosphorous on a crop farm for the periods of 1938-42 and 1993-97. If sustainability is measured in terms of the net energy produced by crops and the nitrogen and phosphorous input per produced energy unit, her study reveals that there has been an improvement in sustainability. Jansén (2000) addressed production on the parish level in terms of energy for 1927, 1956, and 1981. In order to facilitate the aggregation of crop and animal products, the study inflated the energy content in animal products by a factor of 10. The study shows that total production increased slightly between 1927 and 1956 while external inputs increased substantially. Total production doubled between 1956 and 1981 while the use of external inputs increased moderately. Hoffmann and Uhlin (1997) also conducted a large energy analysis. However, not only does each of these studies have its shortcomings, none of them can be used in our analysis since they address neither the processes that led to the changes analyzed, nor development early in the century.

Section 6.3 derived various principles of agricultural sustainable in Sweden on the basis of the discussion in Chapter 3. These principles were then translated into ten indicators that would be useful on the local level for measuring and promoting improvement. It was argued that they both reflect reasonably well what we presently perceive to be unsustainable, and are also easy to be measured and understood by the actors involved. The indicators proposed are: 1) net harvested energy per hectare (mCal (million Calories)/ha); 2) percentage of farms with 20-60% percent lea and legume cultivation; 3) percentage of farms with 0.6-1.2 animal units per hectare; 4) use of mineral phosphorous per net harvested energy (kg P/mCal); 5) use of mineral nitrogen per net harvested energy (kg N/mCal); 6) biocide use per hectare (kg/ha); 7) cereal consumption; 8) arable land per person; 9) ratio of farmers' income to that of other groups; and 10) percentage of local food production processed and consumed within the municipality.

Data for many of these indicators are relatively easy to obtain through the official statistics bureau (SCB), especially for current and future values. However, in collecting data for an examination of development during the course of the twentieth century (Appendix A), it became apparent that adequate statistics are not available for indicators 2 and 3. It was possible to modify these two indicators to percentage of farms with lea production and percentage of farms with cattle husbandry, which also serve to illustrate the rotation of crops with lea and the integration of animal production and crop cultivation. In addition, since information on the municipal level for indicators 4, 5 and 6 was difficult to obtain in many years, the country average was used for all periods. This is acceptable since the average for the Municipality of Uppsala is often close to the county and country averages. No reasonable quantitative estimates were possible for indicators 7 and 10, which made it necessary to provide less accurate qualitative estimates. It was also necessary to modify indicator 9 to the percentage of change in the number of farms. Such difficulties demonstrate that the statistics currently available do not provide altogether adequate information for determining the level of agricultural sustainability.

Table 7.3 Sustainability indicators in Uppsala's agriculture during the twentieth century

	1901	1927	1951	1976	2000
1. Net harvested energy (mCal/ha)	5.5	9.2	9.0	13.3	15.0
2. No. of farms with lea cultivation (% of total)	>93	>93	>77	63	67
3. No. of farms with cattle husbandry (% of total)	>93	93	77	57	34
4. Mineral phosphorous use (kg/mCal)	0.8	0.6	1.3	1.6	0.5
5. Mineral nitrogen use (kg/mCal)	0.2	0.4	1.8	5.9	4.8
6. Biocide use (kg/ha)	0	0	0.9	1.4	0.6
7. Balanced food diet	Low cereal	Good based	Good	Low animal	Low based
8. Arable land per person (ha)	1.1	0.9	0.7	0.4	0.3
9. Changes in number of farms (%)	-	+60	-32	-54	-25
10. Food prod. consumed locally (% of total)	High	High	High	Med.?	Low?

Sources: Based on Appendix A

Table 7.3 presents what our sustainability indicators reveal for the Municipality of Uppsala in the years selected. It is followed by brief discussions of the values specified. We should keep in mind that approximately one million Calories is a sufficient annual amount of food energy per person. However, this translates into 3-4 mCal of energy in harvested crops per person per year in order to provide a balanced diet (Section 6.3).

1. **Net energy in harvested crops**. Net energy per hectare increased by 150% during the twentieth century, with a 54% increase during the first quarter. Net energy is measured as the energy in harvested crops minus only the energy used in fossil fuels and in industrial nitrogen fertilizers. The energy deducted was approximately 1% of harvested energy early in the first quarter, climbing to roughly 10% in middle and late century. If we consider the energy in other inputs, as well as the energy costs for production and transportation, then this deduction might well double or triple (Hoffman and Uhlin 1997). The value for this indicator would then have roughly doubled during the century, with half of the increase occurring in the first quarter.
2. **Percentage of farms with lea production**. This figure increased during the fourth quarter in spite of the substantial decrease in the percentage of farms with cattle husbandry. This was the result of a policy change that encouraged many farmers during the 1990s to cultivate lea for uses other than to feed their own cows and calves, including selling hay, feeding sheep, feeding recreational horses, and cooperation between crop and milk farmers. But in light of the amount of arable land used for lea (22% in 2000), we may conclude that many of the farms in question cultivate only small areas of lea. If we could apply the indicator to measure farms with 20%-60% of cultivation in lea and legumes, which I was unable to do, then its value would likely be only marginally higher than that for farms with cattle.
3. **Percentage of farms with cattle husbandry**. This indicator reveals the degree of balanced animal intensity in relation to arable land. Since animals other than cattle now constitute about one-third of total animal units, the value of this indicator for 2000 would be improved if all types of animals were considered. There are also many farms with a high number of animal units per hectare since animal production is now concentrated on less than half of the farms. In addition, animal weight and productivity increased during the century by a factor greater than the reduction in the number of animals. It will be difficult for there to be a substantial improvement in the value of this indicator in the short to medium term, but roughly the same effect would result from cooperation between animal farms and crop farms in respect to manure distribution and to the production of lea and legumes.
4. **Mineral phosphorous use**. Some of the phosphorous used in the first quarter was provided by bone and bone flour, which is not a mineral source. The amount of phosphorous used per net energy production was actually lower in 2000 than in 1901, and only one-third of the levels for 1951 and 1976. This is a substantial improvement, even when lower net

harvested energy is considered. However, there is still a large potential for further improvement by means of the circulation of phosphorous-rich local wastes, such as sewage sludge, urine from urine separating toilets, and bone from slaughterhouses and restaurants. This would require the involvement of the municipal authorities as well as the local population.

5. **Mineral nitrogen use**. Some improvement in this value took place in the fourth quarter, but the level is still at least ten times higher than it was at the end of the first quarter. The increase would be even greater if the values for indicator 1 were taken into full consideration. As is the case with mineral phosphorous, there is a great possibility to reduce the use of industrial nitrogen by increasing the circulation of nutrients and by expanding the cultivation of legumes and clover-rich lea. Although the latter requires further study insofar as it may increase nitrogen leaching, such leaching is at least a natural process.
6. **Biocide use**. In spite of the fact that "active substance" is an awkward concept for indicating the undesirability of chemical biocides, there was a clear reduction in biocide use during the fourth quarter. Most of the biocides used in 1951 were fungicides and insecticides, while approximately 80% of those used in 2000 were herbicides. The more important change is actually the qualitative control of hazardous chemicals, such as the ban on mercury-based biocides, which is not reflected by this indicator. Nevertheless, the figures for the fourth quarter indicate a deterioration in sustainability in comparison with the beginning of the century.
7. **Balanced food diet**. Moderate annual cereal consumption per person indicates a balanced diet. However, the import and export of many food products both complicates the calculation of values for this indicator and reduces its usefulness. Only qualitative estimates can thus be provided.
8. **Arable land per person**. This value declined in Uppsala throughout the century at a rate higher than the national average, and at present it is reasonable in comparison with national and global figures. It is thus possible for local residents to meet their basic food requirement from production in the municipality while maintaining long-term soil fertility through nutrients circulation.
9. **Changes in farms number**. The figures for 1901 and 1927 exclude respectively 2,514 and 820 small holdings (crofters, etc.) that the statistics did not consider to be farms. A decline in the number of farms indicates that many farmers faced poor economic conditions in comparison with other sectors. However, it also indicates that conditions for the remaining farmers improved in relation to increasing productivity and to the ability of receiving higher societal support per farm for agricultural services and sustainability.
10. **Food production consumed locally**. It is difficult to estimate the amount of food produced in the Municipality of Uppsala that is consumed locally. It is clear that most was consumed locally early in the century, but regional production was both largely integrated and also mixed with products from other regions by the end. The present large flour mill and slaughterhouse that are located in Uppsala serve many counties, and the

milk produced in Uppsala is transported to a diary plant elsewhere. Consequently, only qualitative estimates are possible.

With the exception of net harvested energy per hectare, there was a deterioration during the twentieth century in the values of virtually all the indicators. The consumption of industrial nitrogen, synthetic biocides, and fossil fuels per mCal net harvested crops increased more than ten-fold, although the consumption of mineral phosphorous per mCal net harvested energy is now roughly the same as its level one hundred years ago. Both crop rotation with lea and the integration of crop and animal production deteriorated substantially. Development in the first and fourth quarters merits attention because of the clear improvement in sustainability. Net energy per hectare increased by some 50% during the first quarter even though the agricultural system in 1927 was basically unchanged in its main features from 1901. The values of almost all indicators remained positive, revealing a high level of sustainability. During the fourth quarter net energy per hectare increased by 13% while phosphorous use per one mCal decreased by more than 100%. The values of certain other sustainability indicators were also substantially improved, such as lea production and the use of mineral fertilizers and biocides. Nevertheless, the values of most indicators indicate a low level of sustainability in 2000.

These indicators were chosen on the basis of two premises. The first is that every agricultural system is in a process of continuous change or development, and that sustainability must consequently be related to place and time (Chapter 3). The second is that these indicators are intended to be useful for identifying what are now considered to be important issues concerning the sustainability of Swedish agriculture, and for strengthening coevolutionary processes on the local level (Sections 3.4 and 6.3). If they represent agricultural sustainability reasonably well, then agricultural development during the first quarter of the twentieth century was more sustainable than in the others, particularly the second and the third. The substantial deterioration in agricultural sustainability indicated for the second quarter is consistent with the results of Jensén’s study (2000).

7.5. Lessons for Promoting Agricultural Sustainability: A Coevolutionary Revision of Future Agriculture in Uppsala

Swedish agricultural development during the twentieth century can be interpreted using the model presented in Chapter 3. The agricultural system, which originally developed in relation to the ecological system, became increasingly dependant on forces in the socioeconomic system, particularly through government policies and direct state involvement. Technology and natural resources shaped agricultural production capacity and food demand. Preferences, prices, regulations, and governmental policies shaped food production and methods. Tremendous technological development also took place during the century and the potential for further development is great, but certain achievements have been, and will continue to be, questioned. Land has moved in and out of the sector in relation to food requirements and production restructuring. Other resources were brought into the agricultural system from distant ecological systems. Food preferences and environmental attitudes have changed and will continue to change. Finally, the traditional agriculture that evolved in relation to primarily local connectedness and interaction has been transformed into modern industrial agriculture, which increasingly integrated interactions and resource flows from higher levels and became an open system that was integrated both nationally and globally.

As noted in Section 7.2, the agricultural system of tilled land for cereal production, meadows for lea harvesting, and village management existed for centuries, thus proving itself to be sustainable and adapted to the environment. But this system could not adapt to the large changes in conditions during the eighteenth and nineteenth centuries. It could have increased food production moderately by increasing the area of cultivated land and improving the productivity of arable lands, meadows, and livestock. Some improvement did in fact take place during the eighteenth and early nineteenth centuries, such as the occasional tilling of meadows with clover used for enrichment. However, the pressures of relatively rapid population growth, technological development, industrialization, and the domination of a belief in modernity drove the rapid development of agriculture. The state accepted the responsibility of leading this development, and it pushed for more radical changes in the form and organization of production. The old system changed qualitatively into a system of crop rotation with lea and individual farm management. State involvement in land reforms, along with other contributions, forced the rapid transformation of agriculture into this new system.

This new system remained in principle locally based in resource use and resource flows, with the new form of production essentially consisting of the integration of meadows with arable land. What had previously been permanent meadows became tilled by rotating cereal and lea cultivation in two to three year cycles on all arable land that could now be used for production. Lea cultivation supplied protein-rich feed for cattle and sheep, provided good weed control, and fertilized arable land with humus and nitrogen. The rapid adoption of the system, which also integrated animal and crop production by using manure in cereal cultivation and supplying animals with feed grown on arable lands, demonstrated that it was socially and ecologically suitable. In social terms, it provided more food and also employed more of the available labor force, which was an urgent task at the time. In ecological terms, it improved the circulation of nutrients and possibly also supplied the system with more and diverse forms of energy. The relatively small farm food surpluses were consumed off-farm, while there was a contribution to good nutrients circulation from water bodies to land by means of the consumption of fish and other food from rivers, lakes, and the sea by humans and other land animals. The use of external resources remained limited, largely consisting of knowledge and implements that could be used for many years. Much of these external resources, which increased the productivity of both the land and farmers, were produced regionally and nationally.

The development of cooperative activities involving farmers has been important for the development of agriculture. There is in fact an interesting history of cooperation between Swedish farmers. Prior to 1850 they organized production on the village level. Between 1850 and 1950 they established various organizations at parish and district levels, such as buyers cooperatives, electricity and machine associations, and dairies and slaughterhouses owned in common. Since the 1950s farmers' organizations have primarily operating on county, regional, and national levels, and have mainly been concerned with financial matters, such as price negotiations, product processing and marketing, and farming inputs purchases. An agricultural system that interacts with the socioeconomic and ecological systems primarily at the municipal level could make beneficial use of this heritage. Cooperation could indeed prove vital to future agriculture in reducing production costs, such as by sharing equipment, and in better natural resource management, such as by the partial integration of animal and crop farms.

In each of the four quarters of the twentieth century agricultural development, which lifted the agricultural system to a higher level of complexity in relation to the socioeconomic system, was the result of short and long-term processes that were affected by state involvement, technological development, and natural resource use. Short-term processes in fact dominated development by the end of the century as policy measures came to have an immediate impact on farmers' decisions, including their choices of agricultural mix and production methods. Environmental events and the awareness of ecological problems also became powerful forces influencing short and long-term changes not only in respect to policy measures, but also regarding consumers' preferences, citizen involvement, and technological development. For example, unacceptable animal treatment in production and mad cow disease have, to varying degrees, contributed both to the formation and implementation of agro-environmental policy, and to temporary as well as permanent change in food preferences and environmental attitudes, including animal welfare. The improvement in sustainability towards the end of the century (Table 7.3) may very well be related to these events and changes.

The development of the agricultural system during the first quarter was essentially an improvement of the agricultural system that evolved around the middle of the nineteenth century, and it demonstrated itself to be suitable to the conditions of local production and consumption on the basis of local resources. Labor, land, and animal productivity were improved substantially on the basis of technical development and yet sustainability indicators maintained good values (Table 7.3). Some ecological deterioration might have occurred in relation to the drying of wetlands, but this was not perceived to be a problem. In addition, it might well have been compensated for by the increase in biomass energy and by the reduction of arable land use per person.

Five issues are worth noting in this respect since they may be useful today for promoting a sustainable path of development in agriculture.

- Processes of development that are largely based on local interconnectedness and local interaction may lead to less environmental and social damages since such development incorporates constraints arising within the local ecological and socioeconomic systems.

- When the agricultural system is perceived to be an important part of society, government intervention can mobilize various forces for rapid development while also maintaining local interconnectedness.
- Development that is based on short and long-term trial and error, accompanied by public debate and evaluation, reduces the possible negative effects on other systems. The importance of public participation in policy making is now widely emphasized.
- Changes were the results of interaction between many forces, some of which restrained the rapid application of external inputs.
- Farmers inherited a cooperative tradition involving themselves, other sectors, and the state. They thus are capable of meeting challenges imposed by the socioeconomic system.

Development during the second and third quarters, which can be termed the period of industrialization, expanded the interconnectedness and interaction involving the agricultural, socioeconomic, and ecological systems to the national and global levels. The impact on the ecological system was clearly negative, particularly during the second quarter, when all indicators showed negative results, including net harvested energy per hectare. The impact on the social system could be characterized as positive since more food could be produced by about one-fourth of the previous agricultural working force, and since the living standards of the remaining farmers improved substantially. The following lessons may be useful for future development.

- The new emphasis on decreasing the number of farms reflected changing socioeconomic conditions and the consequent need for rationalization.
- The falling prices of machines and chemical inputs and the increase in labor costs were important forces underlying the changes.
- The ability of farmers to apply new methods and adapt to policies, along with increased biological knowledge, were the main reasons for the growth in land and animal productivity.
- The increased productivity of farm labor was largely related to the mechanization of farming, which today can be powered by biomass instead of fossil fuels.
- While many interactive forces contributed to the industrialization of agriculture, most of them stimulated a rapid acceleration in the use of external resources. Almost none encouraged concern with the possible impact on the environment.

Although there is clear improvement in most indicators during the fourth quarter, there was an obvious deterioration concerning the integration of crop and animal production and the integration of production and consumption within the municipality. The high percentage of farms with lea production may partially offset the negative impact of the low number of farms with cattle husbandry since this may imply a degree of cooperation between animal and crop farmers that needs to be encouraged. Nevertheless, the weakening of local interaction has had serious consequences since even those indicators that have improved still reveal a low degree of sustainability. The number of farms decreased by one-fourth during this period, roughly indicating a lower economic return among farmers than in other sectors. However, the low number of farmers may indicate a significant opportunity to improve sustainability since society's ability to support individual farmers economically has increased. By the end of the century farming supported some 2% of the population at a standard of living comparable with that in other sectors, and it also provided basic food for most of the population. However, the increased local interconnectedness and nutrients circulation that characterize a path of sustainable development will require a larger farm labor source. The following conclusions can thus be drawn.

- Ad-hoc agro-environmental policies may well lead to both improvement and deterioration. There is a need for a more comprehensive picture of how agriculture should operate.
- Agricultural sustainability may demand a mobilization of efforts similar to those that succeeded in increasing food production in the first quarter and enhancing rationalization at the middle of the century.
- Such mobilization will need to influence many related sub-systems and processes, and it will have to be based on a strengthening of local interaction.
- Since farming is now totally dependant on agricultural policy and on the socioeconomic system, it can react rapidly to changing demands concerning production methods and mixes.
- Regardless of the common emphasis on local contributions in dealing with many environmental and social issues, agricultural interaction with the socioeconomic system at the local level is still deteriorating.
- There are currently still no institutions to promote a strengthening of local interaction between agriculture in the Municipality of Uppsala and the socioeconomic system.

The market logic of survival of the cheapest, which drives the development and adoption of technology, leads to distortions when ecological and social costs are not taken into consideration. Agriculture involves many such costs that demand the intervention and control of the socioeconomic system at the local, regional, national, continental, and global levels. Even when products prices are fixed, the drive to lower costs can lead to undesirable agricultural development and practices. Regulation and policy intervention at the local and national levels are thus needed in order to reduce and prevent agro-ecological problems and to protect societal interests. There was hardly any broad discussion before the 1960s concerning the environmental and resource issues related to agricultural production. The agricultural census of 1951 even published a photo of a plane spraying insecticide, symbolizing modernity in agricultural practices.

The weakening of local interaction involving the agricultural, socioeconomic and ecological systems

Although agricultural sustainability has been emphasized at all levels since the early 1990s and measures have been taken throughout the fourth quarter to reduce various agro-environmental problems, the principles and indicators of agricultural sustainability reveal a continuing low level of sustainability. This is grounded in the weakening of coevolutionary interactions involving farming and the surrounding socioeconomic and ecological systems. As Section 7.2 argued, the system of traditional agriculture that survived for centuries was both socially and ecologically sustainable since both social and ecological systems could benefit from as well as adjust to agricultural development. Agricultural development advanced through interaction with the ecological system on the basis of short and long-term processes of on-farm trial and error in which only suitable changes survived. This led to the creation of today's agro-ecological systems, which have steadily degraded from the middle of the twentieth century even though they are still highly appreciated by Swedish society. In addition, the basic interactions and flows of materials remained at the local level in traditional agriculture level even though the state and the nearby town introduced various changes into production and appropriated some portion of the products through taxes and purchases.

The agricultural system as a whole had to change qualitatively in order to cope with the new conditions that emerged during the nineteenth century. The new system of crop rotation and the practice of individual management were promoted by the increasing involvement of the socioeconomic system in general and the state in particular. The main aim of state involvement was to increase food production by implementing new technology and new methods on the basis of modern science. However, not only were these changes experimental to some degree, having to prove their usefulness, they also preserved local interconnectedness insofar as resources and consumption remained largely local in character. The system improved during the first quarter of the twentieth century and continued to be sustainable since it benefited both the socioeconomic and ecological systems even as it steadily incorporated forces and resources form higher levels than local.

The interactive forces that brought about the emergence of the crop rotation system and improved animal and crop integration led to a steady increase in farm food surpluses and the release of ever more agricultural workers for the growing industrial and service sectors. The gradual replacement of muscle power by machines clearly widened the scope of interaction to include resource flows, particularly fossil fuels, from other systems. Horse and human work, which were powered by feed from the agro-ecological system, substituted by external resources. In addition, as food surpluses increased to one-third and then one-half of farm production, nutrients losses had to be replaced if land productivity was not to decline to an economically unsupportable level. Industrial fertilizers were increasingly used to meet this need even though it would have been possible to transport organic waste from the city to nearby arable land. The conditions for the latter were not mature since ecological awareness was weak and relative prices increasingly favored mineral fertilizers, particularly in light of falling transport costs.

Revising agricultural development in order to strengthen local interaction and integrate urban and rural areas involves more than merely managing nutrients circulation. Such issues as agro-ecological heritage, the protection of water bodies, influencing production methods, food security, and food safety have the power to engage the local population in changing the agricultural system. State involvement need not constitute an obstacle to maintaining basic interaction involving the agricultural, ecological, and socioeconomic systems on the local level. A given local community at municipal level must become more involved in supervising and shaping the agricultural production that takes place within its borders, particularly in respect to promoting sustainable development. National and other higher levels of interaction must support this strengthening of local interaction by means of financial support, constraints, knowledge, services, regulations, and other forms of assistance. Indeed, this type of development was to a large extent the main feature of agricultural growth during the first quarter of the twentieth century.

Chapter 2 and Chapter 3 demonstrate that there are solid grounds for adopting the coevolutionary model of development I have proposed, and that serve to promote interaction between agriculture, the local community, and the local ecological system. This chapter has demonstrated that agricultural development during the twentieth century was sustainable only in the first quarter. Deliberate intervention is now necessary to strengthen local interaction in order to resolve the various ecological and resource problems that have arisen from integrating farming with the national and global economies.

The potential for sustainable agricultural development in Uppsala Municipality

Agricultural development that benefits not only farming but also the socioeconomic and ecological systems is considered to be sustainable. Evaluating the character of development is a difficult task because we cannot obtain exhaustive knowledge concerning the impact of change on all the systems and elements involved. Nor have we agreed upon methods for weighing the results when the values of indicators move in different directions. Nevertheless, I have selected principles and indicators that appear to be useful for this purpose.

It is currently not feasible to undertake a comprehensive project for the whole of Sweden with the aim of steering agriculture onto a sustainable path of development. However, it does seem useful to implement such as project in an experimental fashion in a limited number of municipalities in order to prepare ourselves for when ecological and socioeconomic conditions might demand that we seriously undertake such a task. We cannot, at least in the foreseeable future, recreate the agricultural system of the early twentieth century. But it is possible to develop within a decade or two an agricultural system that in its fundamental features is similar to that of early century, at least in the Municipality of Uppsala. This would involve the integration of animal and crop production, rotating crops with lea and legumes, restricting the use of mineral fertilizers and synthetic biocides, and linking production and consumption. These four features may well form a vision of a realistic system of sustainable agriculture.

Realizing this vision requires a strong political and administrative organization at the municipal level, which may be called the "Agricultural Office," with a clear mandate to lead agricultural development in accordance with the sustainability indicators depicted above. Financial and technical support for this type of experimental project will have to come from various organizations at county, national and EU levels, while many local forces and organizations, representing politicians, farmers, consumers, concerned citizens, distributors, and scientists, will have to be mobilized. The following is a brief discussion of the possibility to do so in Uppsala.

First, at least one-third of the farms in Uppsala now integrate crop and animal production. While the potential to substantially increase this number is small, at least in the short-run, there is a large potential for some degree of integration by means of cooperation between animal and crop farms concerning manure distribution, crop rotation, and machinery utilization. Moreover, this is supported by the particular historical tradition of cooperation among farmers. New regulations concerning animal intensity and policies that provide incentives for rotating crops and lea would also encourage this type of development.

Second, the cultivation of lea and legumes now occupies some one-fourth of arable land, and approximately two-third of farms are now engaged in such cultivation. Continued policy support for such crops coupled with a general policy of conditional support (Section 4.2) should make it relatively easy to induce substantial cooperation between crop and animal farms as well as increase the share of lea and legume cultivation to one-third of arable land on most farms.

Third, crop rotation and integrated animal and crop production would lead to less use of mineral fertilizers and synthetic biocides since they are practices that improve nutrient circulation and biological crop protection. In addition, closer interaction between agriculture and various other forces inside the municipality would likely increase the re-circulation of organic wastes from the city and impose restrictions on certain production methods, particularly in sensitive areas.

Fourth, linking food production and consumption at the municipal level involves changing consumption preferences as well as additional processing and distribution costs. This would make it more difficult to realize than the above three features, but Uppsala still has certain advantages in this respect. For example, the project in question may well stimulate rapid, favorable changes in attitudes and preferences since Uppsala is a "student" city with two universities and a large interest in environmental issues. And since the municipality is a large buyer of food, to some extent it could favor local production by means of purchase conditions. Present EU rules do not allow official organizations to condition their purchases of goods and services on the place of production, whether it be local, regional, or national. Even so, such indirect conditions as freshness and delivery time can be used and rules can be changed. There are already a flour mill and a slaughterhouse in Uppsala that could provide a local labeling at some extra cost. Since there is no dairy plant, a choice would have to be made between requiring the dairy plant receiving Uppsala's milk to label the processed milk with its point of origin, or building a new dairy plant in coordination with the farm organization. Building such a plant is feasible in light of the improved efficiency of modern small-scale equipment, reduced transport costs, and possible support for reducing processing costs.

Such an experimental project could draw on expertise at the two local universities, as well as rely on experience garnered from other locally based projects within the municipality, in other municipalities, and abroad. It would also provide important opportunities for research and experimentation. I estimate that this project would require a year of detailed study and network building and ten years to implement.

8. Conclusions and Policy Implications

8.1. Weaving Together the Threads of the Thesis

This thesis has addressed a number of issues that are relevant to agricultural sustainability. In order to bring these issues into a more coherent whole, a summary of the main points and arguments from each chapter is now presented.

Chapter 1

- The concept of sustainability emerged in relation to the awareness of steadily increasing ecological problems affecting the welfare of people throughout the world. While a number of methods have been developed for analyzing sustainability, they tend to be mechanical calculations of important aspects of sustainability insofar as they treat the concept as a property or a fixed model that can be designed and implemented.
- Agricultural sustainability can be generally understood as maintaining an agricultural system over a long period of time without irreversible degradation of the environment and depletion of the resource base.
- We need to analyze processes of development both away from and towards sustainability in order to promote agricultural sustainability.
- The main objective of the thesis is to develop and apply a method for understanding, analyzing, and promoting agricultural sustainability in Sweden using the paradigm of coevolution.
- The theory of coevolution, which asserts that culture and nature affect and are shaped by each other, is process and history oriented. Since it is grounded in processes of agricultural change and development in history, it may provide important understanding of agricultural sustainability.

Chapter 2

- Science is an evolutionary enterprise that requires pluralism. It cannot be restricted to the claim of objective reality and to the atomistic-mechanistic worldview. Moreover, it is difficult to conduct value-free research and not influence the object of study, particularly in the social sciences.
- Since various disciplines and schools of thought perceive sustainability differently, they may overlook important issues that lie beyond their scope. Consequently, interdisciplinarity may enable us to attain important knowledge concerning sustainability.
- The scientific tradition that grows out of modernist philosophy becomes destructive if it is not complemented by a synthetic study of linkages. That is to say that cultural and ecological systems should direct modernity, not the reverse.
- Modernism maintains that development should be governed by science, the role of which is to determine the technologies and social organization

that are to be utilized in order to raise economic standards and improve production. It views culture and nature as exogenous in respect to development.

- Constructing and shaping property rights upon the basis of reasoning is important for promoting sustainability through taxation, regulation, and/or compensation. Reasoning may lead to public policy that compensate farmers for taking measures that improve sustainability, not as a duty or obligation in respect to private property rights, but because of other socially important reasons.
- Cost-benefit analysis is important for facilitating sustainability, especially in the short term. At least as important, however, are the processes and conditions that shape such analysis, such as preferences and technological development.
- The coevolutionary paradigm asserts that social and ecological systems consist of elements and relations that change over time. It views economic development as an adaptive response to ecological change that is a source of ecological change itself. In such processes culture is endogenous and nature is more than merely a provider of resources. This paradigm asserts that nature, technology, values, knowledge, and organization continuously interact with each other.
- Four postulates may facilitate developmental processes that promote sustainability. These are: 1) Sustainability must be addressed in a societal context. 2) Sustainability must be broken down to the sectors that form a society. 3) Processes in these sectors that lead to what we perceive as unsustainable development must be understood. 4) The meaning and indicators of sustainability in each sector must be adequate to the processes in question, and they must be understandable to the actors involved as well as to the general public.
- Industrialization based on fossil fuels has weakened the interaction involving societies and the surrounding ecological systems. In promoting sustainability it may be necessary to bring ecological constraints to bear upon our economic activities. This will involve the creation of discursive communities and the reduction of connectedness over distances.

Chapter 3

- Unlike the conventional approach of explaining changes in an agricultural system by stressing a number of causes, a coevolutionary approach views changes as resulting from interactions between subsystems in a complex and evolutionary way. In the pre-industrial period such changes involved a long-term inter-generational accumulation of knowledge that was based on interactions involving the environment and the resource base. This made it possible to adopt appropriate techniques, methods, and crop and animal varieties.
- Modern agriculture emerged in relation to the domination of atomistic-mechanistic science, rapid population growth, fossil fuel-based industrialization, colonization, globalization, and the commercialization of agriculture. It comprises a great deal of accumulated changes that have been adopted during a relatively short period of time with little

consideration given to long-term effects on the ecological system, the resource base, and society.

- Agricultural development may be viewed as consisting of coevolutionary processes involving the agricultural, ecological, and socioeconomic systems after the rise of towns. These coevolutionary processes are based on cultural adaptation in order to satisfy food requirements and improve food quality under the conditions presented by the surrounding ecological system. They utilize trial and error within both short and long-term time frames.
- Certain developments in traditional agriculture not only increased food production for human beings, but also expanded the ecological system and increased its complexity by producing more biomass energy through the application of knowledge.
- Coevolutionary processes involved in the industrialization of agriculture have gradually expanded to include higher ecological and socioeconomic systems. Feedback from the surrounding ecological and socioeconomic systems has been steadily weakened.
- The model presented in Figure 3.1 illustrates how an agricultural system continuously changes due to forces within and outside the system as well as the changing nature of it many subsystems. Agricultural sustainability must thus be understood dynamically and in relation to those elements that influence its development.
- In promoting agricultural sustainability we need to influence short-term processes affecting production methods and land use as well as long-term processes affecting technological development, value systems, and energy and resource utilization.
- The historical integration of the local community with the agricultural and ecological systems, which has drastically decreased during the last century, particularly in industrial countries, indicates an important path for promoting agricultural sustainability. The strengthening of local coevolutionary processes is a likely pre-condition for developing a sustainable system of agriculture.
- The goal of agricultural sustainability requires principles that facilitate communication and feedback. The agricultural history of a given region, the problems encountered in the past, and the anticipated future problems should provide the basis for such principles.
- The model in Figure 3.1 indicates the dimensions in which principles of sustainability are located. These include the value system, traditional agriculture, food demand, technological development, energy and biomass production, on-farm natural resources, off-farm natural resources, environmental degradation, health aspects, food security and regional distribution, and farm economy.

Chapter 4

- Historical development in Sweden since the 1930s is inconsistent with a strengthening of local interconnectedness and interaction insofar as it has been characterized by a steady weakening of linkages between towns/cities and agriculture. However, various important features of the ecologically sustainable traditional form of agriculture that coevolved with the socioeconomic and ecological systems, such as animal and crop integration and rotating crops with lea, are still practiced on a large percentage of arable lands. Furthermore, agricultural lands are still "well" distributed throughout Sweden in relation to population.

- Both costs and benefits in a general sense of environmental improvement now tend to support the promotion of a sustainable system of agriculture. Technological development decreases costs, education and resource scarcity increase benefits, and reducing production decreases the costs of exporting surpluses.
- A policy of conditional support to farmers is important in implementing feasible agricultural practices that promote sustainability. The basic premise of such a policy would be to pay farmers for their social services while demanding certain measures from them that increase agricultural sustainability.
- Both short and long-term strategic choices may rely upon the view that changes in environmental policies are products of interactions between agriculture, citizens, mediating institutions, and the political system.
- The food system in modern industrial countries emerged through and has been reinforced by policy interventions beginning in the 1930s. These have encouraged the industrial sector to act as a driving force for an ongoing restructuring of agriculture around the industrial production of food for mass consumption.
- Awareness of the impact on the environment of modern industrial farming systems has increased substantially since the 1980s. An analysis of conditions and trends within the agricultural, socioeconomic, and ecological systems indicates that there is a large and growing potential in Sweden for the development of a sustainable system of agriculture.
- With some 20% of disposable income spent on food and 2% of the workforce engaged in farming, Sweden's ability to pay farmers for improved agro-environmental management, including food safety and the humane treatment of farm animals, is substantial. In addition, political institutions function reasonably well in translating public demands into policy interventions.

Chapter 5

- Today's ongoing global environmental degradation, including land degradation, climate warming, and air and water pollution, may substantially decrease agricultural production capacity and lead to increasing food prices. In addition, the growing scarcity of fossil fuels, especially oil, may further reduce agricultural production. Efforts to double food production by the middle of the twenty-first century will not only face great difficulties, they may even threaten global food security.
- Various measures to mitigate environmental degradation and resource depletion are necessary, but their strength and effectiveness will depend on political will and on a commitment to allocate adequate resources, particularly in industrialized countries.

- These efforts will affect future food supply in respect to technological development, the reduction of off-farm inputs, and the allocation of a percentage of agricultural capacity to energy production. They will affect food demand in respect to population growth and per capita cereal consumption. The latter will not only reduce future prices, but also enhance the opportunity to reduce environmental degradation instead of increase production.
- The coevolutionary interpretation of the effects of environmental degradation and resource depletion on future global agriculture indicates that no reliable prediction of future supply and demand is possible because of the number of complex and interacting factors. Moreover, most of the latter can be influenced by social choice, such as ending the dependence on fossil fuels and enhancing local interaction and ecological constraints.
- The problems discussed should motivate industrial countries, including the EU in general and Sweden in particular, to follow a sustainable path of agricultural development. Such a strategy is not only capable of serving both short and long-term interests, it can also involve moral commitments concerning the environment, poverty, and the nature of agriculture.

Chapter 6

- Agricultural sustainability can be promoted in Sweden by strengthening the local coevolutionary processes, which have been weakened during the development of modern industrial agriculture, supported by some sustainability indicators to facilitate communication.
- The model presented in Chapter 3 provides a basis in terms of sustainability dimensions for identifying the principles and indicators needed for this purpose under present conditions.
- Analyzing agricultural sustainability at the local-regional level requires addressing national and global issues as well. The principles involved in such analysis include the high production of biomass; the rotation of crops and lea; combining crop and animal production; the minimal use of mineral phosphorous, mineral nitrogen, and biocides; balanced food consumption; adequate income for farmers; the balanced regional distribution of farms; and a high degree of integration between the farming and non-farm populations at the municipal level.
- These principles must be translated into indicators that are easily measured and understood in order to promote interaction between farmers, consumers, politicians, environmentalists, scientists, distributors, and citizens. Ten indicators that correspond to the above ten principles are: net harvested energy per hectare; percentage of farms with 20-60% lea and legumes; percentage of farms with 0.6-1.2 animal units per hectare; phosphorous use per million calories harvested energy; mineral nitrogen use per million calories harvested energy; biocide use per hectare; per capita cereal consumption; farmers' income in comparison with that of other groups; per capita arable land; and the percentage of food production processed and consumed within a given municipality.

- These principles and indicators should be seen as suggestions derived from a way of understanding agricultural sustainability that emphasizes process, history, and the involvement of farmers and the non-farm population. The principles are subject to change in relation to changes in economic, social, and ecological conditions. The indicators are subject to change in relation to available data.

Chapter 7

- Swedish agriculture, which originally developed in relation to the ecological system, became increasingly dependent on forces in the socioeconomic system. Changes in such socioeconomic conditions as food demand, industrialization, technology, values, relative prices, and state involvement brought about two radical transformations in agriculture during the nineteenth and twentieth centuries.
- The traditional system of tilled land combined with meadow harvesting and village management, which had existed for centuries and was ecologically sustainable, changed qualitatively around the middle of the nineteenth century to a system of crop rotation with lea, greater crop and animal integration, and individual farm management. This new system, which remained within the traditional framework of local resource flow and product consumption, was rapidly adopted because of its social and ecological suitability.
- This new system was further improved during the first quarter of the twentieth century such that it became capable of producing much greater quantities of food. Although this development was led largely by the state in conjunction with agricultural experts, it nevertheless maintained interaction and interconnectedness between farms and local ecological and socioeconomic systems. The limited external resources used, primarily knowledge and implements with long terms of utilization, increased land and farm productivity. Much of these external resources were produced regionally and nationally.
- The second transformation led to modern industrial farming characterized by a low degree of local interaction and interconnectedness. The resource flow became uncoupled from the surrounding ecological and socioeconomic systems, and food consumption became uncoupled from local food production. Developments during the second and third quarters of the twentieth century, which could be termed the period of industrialization, transformed farming into an open system integrated with both national and global systems that was directly and indirectly dependant on fossil fuels. The fourth quarter saw the introduction of various policy measures in order to address environmental concerns, but interconnectedness at the local level continued to weaken.
- Applying the sustainability indicators presented in Chapter 6 to agricultural development in Uppsala (table 7.3) reveals that agricultural sustainability was high and generally improving in the first quarter of the twentieth century, low and deteriorating in the second and third quarters, and low but improving in the fourth.

- The new traditional system of agriculture that still existed in the late 1920s had a lower net harvested energy per hectare than modern agriculture, but it could have been substantially improved if development of that system had continued.
- The state successfully mobilized various forces at the local, regional and national levels at the beginning of the twentieth century in order to boost food production and improve the living conditions of landless people. Another mobilization was successfully launched in the middle of the century to restructure farming in order to improve the living standards of farmers and create a workforce for the growing industrial sector. The state later introduced various agro-environmental policies in order to promote an environmental friendly and sustainable system of agriculture, but with little success.
- There is great potential for a substantial improvement in agricultural sustainability in Uppsala that can be utilized in the near future, at least experimentally, through a strengthening of local coevolutionary processes. The policy instrument of conditional support along with the history of cooperation among Swedish farmers and between farmers and the society at large can be useful elements in this effort. However, there is no organization at the municipal level responsible for agriculture.

8.2. Conclusions

Like the important social concepts of freedom, democracy, and development, the concept of sustainability is complex and needs to be addressed contextually. It is relatively easy to say that this or that system is unsustainable, but it is very difficult to confirm the sustainability of a given system, and not least of all agriculture, because the surrounding social and ecological conditions are continuously changing. Any definition of sustainable agriculture must thus be broad, and each society and ultimately each community may well form their own meanings and principles for such a system in accordance with their perceptions of what is unsustainable. The model of coevolution presented in Chapter 3 illustrates that agricultural sustainability must be understood in relation to the elements or subsystems that shape agricultural systems as well as the processes of change in agricultural development. And not only is no agricultural system ever a finished work, we need to realize that we will never be able to predict fully all the consequences of any given change. We must thus abandon the idea of designing in advance a completed system of sustainable agriculture.

The main contribution of this thesis is the extension of Norgaard's notion (1985; 1994) of development as coevolution involving social and ecological systems into a model of agricultural development as coevolution involving the agricultural, socioeconomic, and ecological systems (Chapter 3). It is supported by reflection upon the history of how agriculture has changed throughout the world through interaction with emerging towns and cities. In contrast to the idea of building a system of sustainable agriculture through modern atomistic-mechanical science, the model put forward here affirms the importance of traditional agriculture, coevolutionary processes, and the involvement of people in following a path of sustainable development in agriculture.

The application of this model to an analysis of agriculture in the Municipality of Uppsala (Chapter 7) reveals that the weakening of local coevolutionary processes is at the heart of today's unsustainable agricultural system. While the strengthening of interconnectedness at the local level is essential to a system of important sustainable agriculture, today's system of agriculture is, on the contrary, strongly interconnected at the national and international levels. Moreover, it has also reduced or removed constraints arising within the ecological system and on the part of consumers and citizens. Changing the character of such a system depends on a new type of communication between the actors involved, appropriate stimuli at the national level, and supportive policies. In addition, it may be necessary to distinguish between short-term influences affecting land use and production methods and long-term influences affecting technological development, values, and the utilization of natural resources and energy.

There is an already large and still growing potential to increase the sustainability of Swedish agriculture by a strengthening of local coevolutionary processes. This conclusion is based on a number of issues discussed in Chapters 4, 5, and 7. First, an awareness of problems associated with modern industrial agriculture, including animal welfare, has increased in recent decades. If the effect of such awareness upon the socioeconomic system is to include ecological factors in agricultural production, a different type of agricultural development will result. And there has been some recent improvement in the agro-environmental record, even though it has steadily deteriorated sine World War Two. In addition, agricultural lands are still relatively well distributed throughout Sweden, while certain important features of the ecologically sustainable traditional system of agriculture, such as animal and crop integration and rotating crops with lea, are still widely practiced.

Second, there has been a growing interest in recent decades in non-marketed agricultural goods and services, especially the agro-ecological landscape. If people are willing to pay for such services, a source of revenue will be created for improve the agro-ecological system at the local level. This provides a strong case for compensating the weakening of local linkages in terms of the food base with a strengthening of local linkages in terms of the landscape base. However, local linkages in respect to food and the resource base will also have to be strengthened in light of the anticipated world shortage of fossil fuels. The perception of rising environmental degradation in relation to the use of fossil fuels may also serve to strengthen local interconnectedness in respect to food production and nutrients circulation.

Third, costs and benefits are seen to be merely elements that relate to the value system in a particular time and setting when agricultural sustainability is addressed in a more holistic way. Not only are the value system and technological development probably the most important elements of agricultural systems that cannot be taken as givens, they are also key issues in long-term development towards sustainability. And both are influenced by resource abundance and scarcity. For example, if we anticipate a growing energy scarcity, then there are grounds to expect that values and technological systems will change in a way quite different than they did during industrialization. That is to say that a more prudent use of energy sources will be both stimulated and enforced. Similar arguments can be put forward concerning other natural resources and environmental degradation. Therefore, it can be argued that the costs of improving sustainability will decrease over time while the benefits will increase.

Fourth, Sweden has an important tradition of cooperation between stakeholders in order to meet challenges. In addition, public policies have largely reflected public interests. In addition, negotiation between farmers, landowners, workers, and industrialists, with or without the mediation of the state, was the main approach in conflict resolution throughout the twentieth century. Such facts add further weight to the potential to increase agricultural sustainability.

Fifth, although global food production has doubled since the 1950s accompanied by falling prices, further significant growth will likely be accompanied by a substantial rise in food prices due to environmental degradation, such as erosion and climate warming, and the depletion of many important natural resources, such as fossil fuels, land, and water. However, it is possible that climate warming will benefit Swedish farming by reducing thermal constraints and thus improve its competitiveness. Also worthy of note is the large potential of lea, an important crop in sustainable agriculture, to utilize the projected reduction in thermal constraints and thus promote higher yields.

Adopting a comprehensive path of sustainable development in Swedish agriculture would certainly be in the national interest by ensuring safe food and other important agricultural services for present and future generations. It would also reflect a sense of moral responsibility concerning assistance to developing countries as well as the mitigation of global problems in respect to the environment and natural resources. Both industrialized and developing countries can benefit from a reduction in pressure on natural resources and the biosphere and from the development of viable technologies for sustainable agriculture. Unfortunately, it will not be possible to transform the present system of industrial agriculture into a sustainable one in the near future because of the many complex issues involved, including various economic and social factors. In addition, it is of significant importance that a system of sustainable agriculture is interconnected with a sustainable society. But we can direct agriculture toward sustainability by following a path of development that enhances local coevolutionary processes and complies with certain appropriate principles of sustainability in agriculture. This type of development needs to be integrated not only with national and regional stimulus policies, but also with formal and informal regulation of production methods.

The development of an agricultural system in a given Swedish municipality that coevolves with the surrounding socioeconomic and ecological systems necessarily involves a decrease in interconnectedness with national and global levels. While this type of development might take place by virtue of a collapse in the present global food system brought about by global food, economic, and/or ecological crises, it could also arise through conscious measures taken to promote a sustainable agricultural system that ensures the adequate production of safe food and maintains agro-ecological services. But such choices, involving changes in technology and value systems, demand the support of proper national policy, which in turn has to be formulated in cooperation with other nations, especially within the domain of European agricultural policy. The strengthening of local interaction and connectedness thus requires a chain of cooperative relationships, and such development is inevitably experimental in character.

When global agriculture is viewed as coevolving with global socioeconomic and ecological systems, it becomes clear that global ecological constraints have an important impact on agriculture. Modern industrialized agriculture has attempted to deal with such constraints by shifting them to other systems and to higher levels, but the truth is that they cannot be removed from the overall picture. Of particular importance are three constraints imposed by the biosphere on food production. These are 1) the limitation of on-farm resources, especially land and water; 2) the depletion of such important off-farm natural resources as fossil fuels and rock phosphate; and 3) the degradation of the biosphere through climate warming, atmospheric ozone depletion, etc. Following a sustainable path of agricultural development in Sweden requires that these factors be given the highest priority, on the basis of both moral commitment and long-term interests, in order to protect agricultural land, reduce the use of off-farm natural resources, and stop the degradation of the biosphere.

The new traditional system of agriculture that emerged in the late nineteenth and early twentieth centuries integrated meadows with arable land, thereby producing a closer integration between the production of livestock and crops. What had been permanent meadows became tilled in two to three year cycles involving lea and cereal cultivation on all the arable land of a farm. These developments, which utilized the support of the socioeconomic system in general and of the state in particular, were in effect a response to changes in the conditions surrounding the previous village system of arable land and meadows. They also relied upon experimentation in that they had to demonstrate their usefulness while preserving important connections with the old system. Local interaction and interconnectedness were in fact maintained since resources and consumption remained primarily locally based.

The development of cooperation between farmers is crucial to the future development of agriculture, especially in respect to the need to coordinate crop and animal production, increase crop rotation with lea, and improve manure management. There is an historical basis for this in Sweden. For example, farmers "collectively" organized production on the village level prior to 1850. Between 1850 and 1950 they established various common organizations at the parish and district levels and collectively owned dairies and slaughterhouses. Farmers' organizations have been responsible since the 1950s for various financial and commercial matters, such as price negotiations, the processing and marketing of products, and purchases of farming inputs. Also important are the historically good relations between farmers and the non-farming population as represented by various political parties, civil organizations, and the state, which have resulted in public support for farming and farmers. Such a heritage can promote beneficial changes in the agricultural, socioeconomic, and ecological systems at the municipal level, particularly when there is a significant potential for reducing agro-ecological problems.

Interactive forces behind agricultural development during the nineteenth century continued to produce change during the twentieth century, but of a different degree and with a changing character. The changes were driven by various short and long-term processes that affected both technological development and natural resource use and raised the complexity of the agricultural system as a whole. For example, food demand related to population growth was a powerful force in the early part of the century that caused substantial change. Food demand became related to increasing income in the middle of the century, later being affected by food surpluses and agricultural policy as well. Today it has the effect of decreasing food production, clearly stimulating diversity and environmental considerations. The character of agricultural development has thus changed substantially during the twentieth century as the socioeconomic conditions and forces influencing agriculture have changed. Short-term processes have dominated change in the sector in recent decades as policy measures have come to have an immediate effect on farmers' decisions. This raises the possibility that economic incentives can lead to a substantial improvement in sustainability in the short to medium term.

Agricultural development during the first quarter of the twentieth century, in which the newer form of traditional sustainable agriculture was appropriated, had a positive impact on both the socioeconomic and ecological systems. The sustainability indicators presented in this study make this clear. For instance, the food standard was significantly improved and many landless agricultural workers became farm owners. Net energy production per hectare increased substantially without a deterioration in the ecological system in terms of an increase in off-farm resource utilization. And even though such improvements were largely associated with state-led modernization, they were nevertheless sustainable because they maintained, perhaps unintentionally, basic interaction and resource flow on the local level. Indeed, common objectives throughout state intervention were food self-sufficiency at the county level and better utilization of such local resources as manure and animal power.

Development during the second and third quarters of the century, which was the period of industrialization and restructuring, changed the interactions between the agricultural, socioeconomic, and ecological systems from being locally based to nationally and globally based. The rise of fossil fuel-related technologies was the key element in bringing any further development of the new traditional system to a halt. All sustainability indicators, including net harvested energy per hectare, demonstrate that the impact of agriculture upon the ecological system was clearly negative, especially during the second quarter. Agriculture's impact on the social system was positive in the sense that many fewer workers could produce much more food. In addition, the standard of living of the remaining farmers increased substantially.

Environmental events and agro-ecological problems became a powerful force during the fourth quarter driving both short and long-term change not only in respect to policy measures, but also concerning consumer preferences, citizen involvement, and technological development. But in spite of the introduction of various measures to address agro-environmental concerns, which have had some success (see Table 7.3), all indicators show a seriously low level of sustainability, even in areas where there has been some improvement. Two indicators especially reveal an obvious deterioration, namely, on-farm crop and animal integration and production/consumption integration within the municipality. There are a few positive signs. One is the high number of farms with lea production, which may imply a certain cooperation between animal and crop production that needs to be encouraged in spite of the fact that few farms are involved with animal production. The fact that the number of farms decreased by one-fourth during this period roughly indicates a lower economic return among farmers than in other sectors. However, it is ironic that this may indicate improved possibilities in respect to promoting sustainability since there is a consequent increase in society's economic ability to support individual farmers.

The interactive forces that led to the emergence of the system of crop rotation and improved animal and crop integration increased farm food surpluses and released labor from farms for the industrial and service sectors. The gradual replacement of muscle power by tractors and other machinery widened local interactions to include flows of resources from other systems, especially fossil fuels. This was also the case with nutrient circulation. As food surpluses increased to one-third and even one-half of food production, nutrients losses had to be replaced by low-cost industrial fertilizers produced outside the local system. Such developments increased the direct and indirect dependence of farming on the market. However, the market's concentration on the reduction of production costs can give no proper consideration to the agricultural costs that require the intervention and control of the socioeconomic system at local, regional, national, continental, and global levels. For example, prior to the 1960s there was little discussion of environmental and resource issues connected with agricultural production, but agricultural sustainability has become emphasized at all levels since the early 1990s by forces not subservient to market logic.

The promotion of agricultural sustainability may require a mobilization of efforts similar to that of early twentieth century in order to change the many sub-systems and processes involved and strengthen local interaction. For example, the integration of farm and non-farm populations at the municipal could very well involve the circulation of nutrients through the transportation of urban organic wastes to nearby arable land. Similarly, the utilization of fossil fuels could be replaced, at least in part, by energy generated through local biomass production. If our contemporary ecological crisis is grounded in industrialization based on fossil fuels, then our future development must be based on local resources as long as no secure and abundant alternative energy source is available. Such changes are no small task.

The 10,000 year history of traditional agriculture, based on coevolutionary processes involving agricultural and ecological systems and later also the socioeconomic system, was associated with the development of marvelous cultural and agro-ecological diversity throughout the world. It succeeded in supporting a world population that eventually doubled eight-fold. Fossil fuel-based industrialized agriculture doubled food production twice during the twentieth century through the application of modern scientific methods and the reduction of ecological and socioeconomic constraints. However, this was accompanied by substantial social and ecological destruction. And the doubling of food production that may be necessary during the present century will have unforeseeable consequences on many social and agro-ecological systems.

Chapter 7 discusses how Sweden doubled food production twice between the 1850s and the late 1920s by building a new type of traditional agriculture that was largely based on improving the old system of land cultivation while maintaining local interconnectedness. I have argued that this system could have supported another doubling of food production while remaining ecologically sustainable if the nutrients removed from arable land in the form of food for the urban population had been restored, and if agricultural motorization had been fueled by agricultural products. The point is that it is no utopian dream to claim that traditional systems can serve as the basis of sustainable systems of agriculture capable of producing sufficient quantities of food, particularly if diets are changed to include fewer animal products and animal production is not based on cereal feeds.

The long-term sustainability of traditional agriculture was based on the adoption of crop varieties and production methods that were proven through trial and error to be suitable in respect to the socioeconomic and ecological systems. Creating a system of sustainable agriculture in the future will require extensive experimentation, especially on the farm and local levels, involving a wide range of possibilities, including horse-based mechanization as well as high technology farming. Since we are living in a changing world in which the future is unknown, the suitability of any experimental system, including the project suggested for the Municipality of Uppsala (Sections 7.4 above and 8.3 below), will depend on conditions that arise in respect to changes in the socioeconomic and ecological systems.

Today's economic realities do not support a comprehensive program involving all Swedish municipalities in order to strengthen the local interaction necessary for managing nutrients circulation, maintaining agro-ecological heritage, protecting water sources, and influencing production methods in new ways in order to promote agricultural sustainability. But it may well be justified to begin such programs on an experimental basis in selected municipalities in order to establish a body of knowledge that will allow for further development when economic and social conditions both permit and demand it.

It is obviously impossible to resurrect the traditional system of agriculture typical of the early twentieth century. But as I have argued in Section 7.4, it is quite feasible to develop a successful agricultural system in Uppsala within only one or two decades that shares the fundamental features of that system. These features, which were not designed in advance by scientific experts but rather arose from coevolutionary processes on the local level, include the integration of animal and crop production, the rotation of crops with lea and legumes, the minimal use of mineral fertilizers and synthetic biocides, and the linking of production and consumption. Realizing such a vision of agriculture requires a strong political and administrative agricultural organization at the municipal level that has a clear mandate to lead agricultural development in accordance with the principles and indicators of sustainability stated above.

Of crucial importance to the success of such a project for resolving the various ecological and resource problems that have arisen from the integration of farming with the national and global economies is heightened cooperation and interconnectedness between animal producers, crop producers, farmers as a whole, and the non-farm local population. State involvement will clearly be needed in order to make available the necessary knowledge, services, regulations, and support, but the basic coevolution of agriculture with the ecological and socioeconomic systems must occur at the local level.

8.3. Policy Implications and a Future Research Agenda

The large and increasing potential in Sweden to pursue a sustainable path of development in agriculture should motivate increased state involvement in diverse issues related to this issue, not least of all because building a sustainable system of agriculture is now a stated goal. Such state involvement should be understood as directing and promoting change towards what a such system is understood to be, not as the implementation of a completed design that has been prepared in advance. This can take the form of encouraging and supporting various appropriate forces and organizations within the socioeconomic system and of strengthening the interconnectedness between agricultural, socioeconomic, and ecological systems on the local level.

In promoting agricultural sustainability it is important to influence both short-term processes affecting production methods and land use and long-term processes affecting technological development, natural resources and value systems. It must be noted in respect to both short and long-term processes that environmental policy changes are the consequences of interactions between agriculture, citizens, mediating institutions, and the political system. Although such changes appear to result from a combination of local interaction, national stimulus policy, and regulations at various levels, the strengthening of local coevolution is a precondition for building a sustainable system of agriculture. The historical integration of the local community, agriculture, and the ecological system in the creation of traditional systems of agriculture, which has dramatically been weakened during the last century, needs to be viewed as an important path for facilitating agricultural sustainability.

Agriculture can be directed toward sustainability by influencing many related subsystems and processes and by following a path of development that utilizes knowledge from traditional agriculture, enhances the coevolutionary processes on local level, and complies with principles of sustainable agriculture useful for facilitate such interactions. The corresponding changes can only be experimental in nature. However, they may well become necessary in respect to fossil fuel shortages, serious environmental degradation, or economic disruptions that give rise to food security problems.

Today it is possible to judge the notion of agricultural sustainability only in relation to the prevailing socioeconomic and ecological conditions for the system of agriculture. Of particular importance is the fact that humanity currently has no safe long-term source of energy except the sun, a point which underlies the argumentation of the present thesis as a whole. During the 1970s we thought that nuclear energy was the solution for the future, but this dream was crushed only a decade later. Given the unpredictability of the future, the only sensible alternative is to reduce what society perceives to be unsustainable. This is particularly important in respect to agriculture, which produces a most basic human need.

The goal or the vision of building a system of sustainable agriculture in Sweden is put forward without specifying the details of such a system. Two competing paths may be adopted, namely, organic farming and a transformation of the present system so that it uses fewer off-farm resources and generates fewer agro-environmental problems. These two approaches both have to be coupled with an emphasis on interaction and interconnectedness on the municipal level. The main conclusion of this thesis is that the weakening of local coevolutionary processes and the reduction of local ecological and socioeconomic constraints has led to an unsustainable path of agricultural development. A sustainable path of agricultural development must thus reduce national and global connectedness, particularly concerning major inputs and outputs. Nevertheless, agricultural interaction with the socioeconomic system at the local level continues to weaken. This may be related to a lack of awareness concerning the importance of local interconnectedness, structural rigidity, momentum driving further national, European, and global interconnection, and the failure to mobilize and coordinate local forces.

Strengthening local interaction should not be seen as reversing development, but rather as providing a better linkage between food production and the public interest concerning the agro-ecological system. For example, it is important to realize that the agro-ecological landscape and biological diversity are byproducts of centuries-long efforts to produce food through traditional systems of agriculture. Present and future efforts to develop a system of sustainable agriculture may well have no alternative but to make use of certain fundamental features of the traditional system that made it sustainable. These include the rotation of crops and lea, the integration of animal and crop production, cooperation between crop and animal farms, integrating food production and consumption at the local level, and severely restricting the use of mineral fertilizers and synthetic biocides. With suitably experimental modification, all of these can be feasibly used today if provided with the proper incentives and support.

The contribution of this thesis in providing a model of coevolution that is useful for understanding agricultural sustainability and implementing changes that promote sustainability on the municipal level, calls for further research in order to improve the findings and widen the application. A future research agenda may consist of the following projects and programs:

1. **A comprehensive project to strengthen local coevolutionary processes in Uppsala in order to promote the development of a system of sustainable agriculture.** As Section 7.4 demonstrated, there is a significant potential in the Municipality of Uppsala for this type of development. Such an experimental project requires the mobilization of many forces within the municipality, including farmers, politicians, consumers, environmentalists, distributors, reporters, and scientists, along with substantial support from higher levels, especially the national level. It is also necessary to establish an agricultural office at the municipality level with a clear mandate to supervising the project in order to attain a high degree of agricultural sustainability according to the principles presented in this study. In addition, financial resources adequate for a local policy of conditional support need to be available. Since farming is now totally dependant on agricultural policy and on the socioeconomic system, it is capable of reacting rapidly to changed influences on production mix and methods. The project as a whole must be coordinated with national and European agricultural authorities, not least of all in respect to the policy of conditional support, which comprises a promising alternative to the present widely criticized system.

The project should also be associated with an interdisciplinary study in the form of action and/or participatory research in which the research team contributes to negotiating cooperation involving the stakeholders in the municipality. Such a study will also provide important knowledge and the documentation of experiences necessary for enhancing local interaction and interconnectedness in other municipalities and in other countries.

2. **Improving the coevolutionary model of agricultural development**. The coevolutionary model of agricultural development that is developed and presented in this thesis will benefit from further research concerning relationships pertaining between the agricultural, socioeconomic, and ecological systems. Investigating the historical development of agriculture in various parts of the world will strengthen and improve this model.

3. **Testing the relevance and usefulness of the model and of the principles of sustainability in other municipalities**. The results of the discussion in Chapter 7

concerning agricultural development in Uppsala during the twentieth century can be applied to an investigation of agricultural sustainability in other municipalities, both in Sweden and elsewhere. This would further refine the model presented in Section 3.2, testing both its strengths and weaknesses.

4. **Applying the model to the study of a developing country**. The coevolutionary model of agricultural development could be applied to an examination of a developing country now facing challenges similar to those facing Sweden in the early twentieth century to determine whether there is a feasible path of development other than that undertaken by Sweden beginning in the 1930s.

5. **Understanding the development of organic farming and testing its sustainability**. It would be important to study the development of various agricultural sub-systems, production forms, and problems from a coevolutionary perspective. It would be particularly valuable to study the development of organic farming in Sweden and to evaluate its sustainability in respect to the principles and indicators presented in Chapter 6.

6. **Understanding the coevolutionary process away from sustainability in the energy and forestry sectors**. If the idea of addressing agricultural sustainability upon the basis of a study of the historical processes of development in the sector has proven to be useful, then it may be fruitful to apply the same method in a study of sustainability in such other sectors as forestry and energy.

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Appendix A: Basic Data Collection and Calculations for Agriculture in Uppsala Municipality for the Years 1901, 1927, 1951, 1976, and 2000

General Explanation

Statistics and data describing agricultural development in Uppsala during the twentieth century can be selected and presented in different ways. My focus is on information that could be useful for understanding agricultural sustainability over time in relation to the coevolutionary model presented in Chapter 3 and to the principles and indicators presented in Section 6.4. The choice of years was developed while working with the data as I discovered that important changes relevant to agricultural sustainability were related to the individual four quarters of the century. The findings (Table A1) shaped the structure, and partially the content, of Chapter 7. I refer to the four periods in question as: 1) the continuation or appropriation of traditional agriculture, 2) the period of motorization, 3) the chemical and rationalization period, and 4) the beginning of environmental and sustainability period. These characterizations are incomplete, but I believe they help in understanding coevolutionary processes and in examining the principles and indicators of sustainability in a more meaningful way.

The data is relevant to the area of the Municipality of Uppsala in 2003, i.e., without Knivsta. During the twentieth century there have been a number of changes in this regard. For example, the present municipality-based division of Sweden was established and developed during the 1960s. The 1976 agricultural census provides statistics for parishes, municipalities, and counties (församlingar, kommuner, län), while the 1927 census provides data for municipalities, districts and counties (kommuner, härad, län). Agricultural statistics for the parish level are no longer published in the official agricultural statistics beginning in the 1980s. Moreover, the names of certain parishes and districts have changed during the century. Changes in classification, boundaries, and names thus demand special attention in order to produce meaningful historical data for the years chosen.

In addition to the above complexity, there are other problems that affect the accuracy of the collected data. For example, data required are often not available for the municipal level, making it necessary to use information from the county or even country levels. At other times the data are not directly available, making it necessary to collect relevant information that can indirectly indicate what we are searching for. Reasoning and judgment thus play important roles in establishing various values that could otherwise not be presented. One example is that agricultural statistics in 1927 and 1951 are based on farms with more than 0.25 hectares of arable land, while in 1976 and 2000 they are based on farms with more than 2 hectares of arable land. Fortunately, this only marginally reduces the value of statistical comparison involving these years since the share of small farms with less than 2 hectares is very low later in the century.

I have used the following procedures and guidelines in order to collect and evaluate data:

1. I compare the 1976 census of agriculture with that of 1951 and determine the area of the Municipality of Uppsala for these two years by matching various localities, parishes, and districts. From what was defined as Uppsala County in 1951, the following parishes and districts are considered as belonging to the Municipality of Uppsala: Södra Hagunda, Norra Hagunda, Bälinge, Vaksala, Rasbo, Stavby, Tuna, Vattholma, Björklinge, and Uppsala. And from what was defined as Stockholm County in 1951, the following parishes and localities are considered as belonging to the Municipality of Uppsala: Knutby, Bladåker, Faringe, and Almunge. Knivsta and the surrounding areas of Lagga, Alsike, Vassunde, Östuna and Husby-Långhundra, which were part of the Municipality of Uppsala between the 1960s and 1990s and part of Stockholm County prior to 1951, are not counted as part of Uppsala in our statistics because these areas now belong to the Municipality of Knivsta. These districts, parishes, and localities were checked against the Atlas of Regional Divisions in Counties, Municipalities, Parishes and Localities 1992 as well as against records in the Office of City Planning for the Municipality of Uppsala to determine whether or not they should be included in Uppsala.

2. I use the same principles to determine the area of the Municipality of Uppsala in respect to the data for 1901 and 1927. In comparison with the 1951 census, the following districts and parishes are considered as belonging to the Municipality of Uppsala: Hagunda (except Gryta), Ulleråker, Bälinge, Vaksala, Rasbo, Norunda, Savby, Tuna, and Uppsala city. The parishes of Bladåker, Faringe, Almunge, and Knutby are also added to the Municipality of Uppsala from Stockholm County.

3. Since no statistics are available beginning in 2000 for the districts and parishes that transferred out of the Municipality of Uppsala (Knivsta area), I proportionally reduce the statistics available on the municipal level for 2000 by the ratios valid in 1976.

4. I primarily seek information on the municipal level. When this is not available, it is reasonable to use information from the county or country levels since the average data for the Municipality of Uppsala are often near the county and country averages. In such case data for county or country is used for all years In addition, marginal errors are not important in my analysis since only major and clear differences are used for drawing conclusions.

5. Indirect information and reasoning are extensively used for several estimates. It should be noted that certain historical statistics may be less accurate than information available today, which renders reasoning and judgment more important. For each post I explain as clearly as possible how the estimates have been made.

Further explanations are given under the heading Posts Explanations and Sources, which are numbered as in Table A1.

Table A1 Basic data for agriculture in Uppsala Municipality during the twentieth century

Posts	1901	1927	1951	1976	2000
1. Land area (ha)	215 580	213 434	213 418	218 000	218 000
2. Arable land (ha)	62 220	64 303	62 090	54 279	50 279
3. Graz. land and meadows (ha)	9 271	7 108	5 584	6 943	6 919
4. Population	54 440	68 348	88 750	131 592	178 782
5. Population outside the city	31 585	38 035	24 997	29 742	41 081
6. Number of farms	2 047	3 292	2 787	1 286	968
6a. No. of crofters/small hold.	2 514	820	-	-	-
7. Number of tractors	-	101	1 722	2 606	2 400
8. No. of work horses and oxen	9 457	8 958	4 029	-	-
9. Food cereal area (ha)	9 656	8 186	10 940	17 525	12 259
10. Food cereal yield (kg/ha)	1 351	1 804	2 307	4 486	4 870
11. Feed cereal area (ha)	17 422	19 799	17 718	22 442	17 511
12. Feed cereal yield (kg/ha)	1 350	1 841	2 033	3 666	3 751
13. Lea and green fodder (ha)	18 882	24 410	22 329	8 787	11 197
14. Lea yield (kg/ha)	2 200	3 703	3 610	5 362	6 704
15. Fallow area (ha)	13 019	7 903	5 853	2 650	6 134
16. Total animal units	41 735	46 490	34 402	20 305	18 704
16a. Cattle units	26 789	30 130	25 903	14 555	12 186
17. Ener. harv. from cer. (mCal)	140 717	197 645	234 731	611 396	473 648
18. Ener. harv. from lea (mCal)	153 010	332 943	296 910	173 547	276 493
19. Energy harvested from other crops and fallow (mCal)	48 170	66 967	74 880	60 368	93 354
20. Energy harvested per hectare (tCal/ha)	5 495	9 293	9 768	15 573	16 811
21. Fuel consumption (liter/ha)	0	2	63	105	109
22. Nitrogen consumpt. (kg/ha)	1.0	3.7	16	78	71
23. Phosphorus consum. (kg/ha)	4.2	5.0	11	21	7
24. Biocide consumpt (kg/ha)	0	0	0.9	1.4	0.6
25. Farms with cattle husb. (%)	>93	93	77	57	34
26. Far. with lea for hay/gr. (%)	>93	>93	>77	63	67
27. Ener. in fuel/nitro. (tCal/ha)	22	103	817	2 245	1 853
28. Net harvested energy (tCal/ha)	5 472	9 190	8 951	13 328	14 958

Sources: Sweden official statistics published by the Statistics Sweden (SCB) are the main sources of this table. Detail sources are given below for each post.

Posts Explanations and Sources

1. Land area. Total land area without water cover has changed because of the drying of wetlands, improved measuring methods, and data collection errors. Some change can be noted between 1901 and 1927, with a greater degree of change between 1951 and 1976. The former is likely due to improvements in measuring and need not be discussed further. The latter was problematic since the calculations according to the agricultural census gave a land area of 199,000 hectares for 1976. Examining the changes for various parishes and localities according to the agricultural census and comparing them with land statistics according to the census of population and holdings provides the grounds for concluding that the discrepancy is mainly due to data collection in the agricultural census, which is based on the register of firms. Both censuses provide similar findings concerning land area in the 1950-1951 statistics. The figures for 1976 and 2000 are thus calculated upon the basis of the census of population and holdings. It should be noted that more than half of the total land area in Uppsala is forest. The sources for the 1901, 1927, and 1951 estimates are given in Post 2. The sources for the 1976 and 2000 estimates are given in Post 4.

2. Arable land. Arable land is defined as land under plough. Agricultural lands that are not ploughed, and which are often used to feed animals by providing cut grass or grazing, particularly hagmark (semi-wooded pasture land), are not considered to be arable land. In the early part of the twentieth century a substantial portion of agricultural land (meadows) was harvested by farmers and yet not considered to be arable land. Beginning in the late twentieth century certain agricultural lands were planted as forest for energy production that would not be ploughed for a decade or two, but it was still statistically considered to be arable land. The recorded changes concerning the area of arable land are primarily due to changes in land use, although certain meadow areas were converted to arable land early in the century and certain arable land was removed from cultivation later in the century. Certain changes during the second half of the century may also have been based on administrative considerations as some farms were transferred to other parishes and districts and certain districts and parishes were transferred to other municipalities and counties. In 1901 small farming units that were part of larger farms were not counted statistically as farms, but the land thus cultivated is included in the statistics. The figures used are based on data taken from the following sources: County Agricultural Societies Reports for 1901 (Hushållningssälskapens Berättelser för år 1901 (SCB 1903)); Census of Agriculture 1927 (Jordbruksräkningen år 1927); Census of Agriculture 1951 (Jordbruksräkningen 1951); Census of Agriculture 1976 (Lantbruksräkningen 1976); and the SCB (Statistiska centralbyrån) statistics on arable land use in 2000 (SCB, JO 10 SM 01 02). The figures in this and other posts for all but the last year are aggregation of statistics for parishes and districts that presently belong to the Municipality of Uppsala. The figures for 2000 are estimated proportionally in order to exclude the Knivsta area.

3. Grazing land and meadows. There is a significant problem concerning accuracy involving the figures for grazing lands and meadows insofar as the classification and its contents have changed over time. In the statistics for 1901 and 1927 the category in question was termed meadows, whether for hay harvesting or grazing. Hagmark was not included. This latter type of land, which was estimated at 7,912 hectares in 1927, was instead classified as forest land. In 1951 this category was referred to as cultivated grazing land and natural meadows. After 1976 it was termed cultivated grazing land and other grass growing land, including hagmark. The sources of these figures, except for 2000, are the same as for Post 2. The figure for 2000 is based on proportional calculations involving 1992 data (SCB, J 13 SM 93 02) in respect to the ratios in 1976 statistics for Uppsala County. In recent years it is reported that grazing land has increased substantially due to financial support. For the whole of Sweden, natural meadows decreased from 1.24 million hectares (mha) in 1927 (Census of Agriculture 1927) to 0.54 mha in 1951 (Census of Agriculture 1951). During the same period grazing land increased from 0.03 mha to 0.2 mha. In 1976 the entire category of cultivated grazing land and other grass growing land was about 0.7 mha (Agricultural Census 1976), which was further reduced to about 0.3 mha in 1988 (SCB, J 10 SM 89 01).

4. Population. The population size of what is now considered to be the Municipality of Uppsala is calculated by aggregating the populations of districts and parishes. Unlike land use, the figure for 2000 is actual and not proportionately calculated. The figures are based on the following sources: Population Report for Uppsala County 1850-1945 (Befolkningstatistik 1850-1945, Uppsala länsutredning (1946)); Census of Population 1930 (Folkräkningen 1930); Census of Population 1950 (Folkräkningen 1950); Census of Population and Holdings 1975 (Folk och bostadsräkningen 1975); Population Statistics 2001 (Befolkningsstatistik 2001, http//www.scb.se/statistic/be0101).

5. Population outside the city. I use this term to indicate the portion of the population that has a larger contact with agriculture and agricultural land by virtue of the location of their residence. The official statistics on urban and rural population (tätort and glesbygd), which define urban areas as groups of houses with at least 200 inhabitants, often with less than 200 meters separating houses, was not judged to be sufficiently adequate for indicating people who have contact with agricultural land. The statistics for 1950 show that only a few parishes and districts had this concentration of houses, the sole exception being Uppsala City, while such is now the case with more than twenty areas in the municipality. Some of these areas (Bälinge, Börklinge, and Storvreta) have a few thousand inhabitants. Unlike in the early part of the century, where most people living outside the city were engaged in agricultural activities, most people now living in rural areas receive their income from non-agricultural sources. While this development is largely related to construction policies, particularly in respect to the protection of arable land, it also indicates the interest that many people have in living in the countryside. The sources used are the same as for Post 4

6. Number of farms. The 1976 and 2000 statistics concern farms with more than 2 hectares arable land, while the 1927 and 1951 statistics figures are for farms with more than 0.25 hectares. As noted above, this does not substantially decrease the accuracy of the figures. In 1927 there were also 820 holding units with less than 0.26 hectares, the members of which were engaged in various seasonal activities related to agriculture and forestry. The number of farms in 1901 is not specified in relation to the size of arable land under cultivation, but the census does provide information concerning various small holdings. We can thus calculate that there were 2,514 units of small holdings involved in diverse rural activities (crofter holdings). In respect to the time spent on farming activities, it is reasonable to view holdings with a small area of arable land as farming units during the earlier part of the century since most of the means for living came from agricultural-related activities, of which a large portion were wages. Most farms during the later part of the century have been managed on a part-time basis. However the figures for early century do not include crofter holdings, which are indicated in Post 6a. Sources for the figures in this post are the same as for Post 2.

7. Number of tractors. The form, function, and power source of tractors have changed significantly during the century. 1901 statistics indicate that no tractors were used in production, while Jansén (2000) reports that 4 tractors were used in Viksta parish in 1927. Morell (2001) states that there were some 5,000 tractors in all of Sweden in 1930. Proportional adjustments involving arable land in Viksta and Sweden as a whole provide an estimate of 87-115 tractors in Uppsala, with an average of 101. The 1951 figures are based on the number of tractors in Uppsala County (Census of Agriculture 1951) proportionally adjusted in relation to the area of arable land, as is also the case with the 1976 estimates (Census of Agriculture 1976). The figure for 2000 is based on the number of tractors in Uppsala County in 1999 (SCB, JO 30 SM 00 01) calculated in proportion to the area of arable land.

8. Number of work horses and oxen. The number of horses used for field and other agricultural work has declined during the course of the century to almost zero. The figures in the table are for oxen and for horses that are at least 3 years of age. In 1901 there were 957 oxen in the area, which declined to 36 in 1927. The number of horses declined substantially in 1976 and increased towards 2000, but horses have been used primarily for sport beginning in the 1960s. Consequently, no estimates of the number of horses and oxen are given for 1976 and 2000. The figures are based on the sources used in Post 2.

9. Food cereal area. Food cereal (or bread grain) acreage includes winter wheat, spring wheat, and rye. Rye dominated this group in the early part of the century, but it now accounts for less than one-tenth of cultivation. The figures are based on the sources used in Post 2. The figure for 1901 is calculated from the County Agricultural Societies Reports for 1901 (SCB 1903), which indicates the area of grain cultivation as winter grain (höstsäd) and spring grain (vårsäd). However, since the harvest reports indicated only a small amount of spring wheat (1%), we consider winter grain as food cereal and spring grain as feed cereal. But we need to keep in mind that even feed cereals are fit for human consumption, although oats were mainly used for animal feed, particularly for horses, even during the nineteenth century.

10. Food cereal yield. This figure is based on the three-year average harvest per hectare in Uppsala County. It is calculated proportionally in respect to cultivated land for the major food grains of winter wheat, spring wheat, and rye. The figures are based on the following sources: County Agricultural Societies Reports for 1900, 1901, and 1902; Agriculture and Livestock for 1926, 1927, and 1928; Agriculture and Livestock for 1950, 1951, and 1952; the Yearbook of Agricultural Statistics for 1976, 1977, and 1978; and the Yearbook of Agricultural Statistics for 2000, 2001, and 2002. The cereal yield statistics for 1900-1902 were presented in terms of volume (hectoliters). I assume that 1 hectoliter of food cereal is equivalent to 70 kg. insofar as 1 hectoliter of rye in Uppsala County weighed 72.2 kg in 1900, 69.2 kg in 1901, and 64 kg in 1902 (County Agricultural Societies Reports for 1900, 1901, and 1902)

11. Feed cereal area. Feed cereal acreage includes barley, oats, and mixed cereal. In the early part of the century about 70% of this group was mixed cereal, but this figure declined to about 5% by the end of the century. In Uppsala County mixed cereal often consists of 2 units of barley, 1 unit of vetch, and 2 units of oats. The figures are based on the sources used in Post 2. The information available for 1901 is for winter grain and spring grain (Post 9). I assume that all areas of spring grain comprise feed cereal.

12. Feed cereal yield. Yield figures for feed cereal are based on three-year average harvests per hectare in Uppsala County for barley, oats, and mixed cereal. They are based on the sources used in Post 10 for each respective year. The 1901 figure was estimated by assuming that 1 hectoliter of feed cereal is equal to 60 kg. In Uppsala County 1 hectoliter of oats weighed 49.4 kg in 1900 and 51.2 kg in 1901. The weight of 1 hectoliter of barley was 67.6 kg and 67 kg respectively.

13. Area of lea and green fodder. Lea for hay dominated this group throughout the century. The figures for 1901 and 1927 are for lea harvested or used for grazing. They also include cereal not harvested for grain (about 5%). The 1951 figure also includes non-lea crops used for green feeding (about 3%). Lea for hay was about 70% of this group in 1951 and about 80% in 1976. The sources of these figures are those used in Post 2.

14. Lea yield. Lea yield is calculated as the yield of lea harvested for hay (three years average). The sources of these figures are those used in Post 10 except for 2000. The latter is rather problematic because the information for lea production and yield deteriorated substantially in late 1990s. The figure for 2000 is calculated as 85% of the average standard yield in 1996 and 1997 for Uppsala County (Yearbook of Agricultural Statistics for 1997 and 1998). The statistics for 1994 (Yearbook of Agricultural Statistics 1995) show that the standard yield of the first harvest was 5,200 kg. even though the actual yield was 4,320 kg. During the first half of the century the common practice was to collect one harvest per year. During the second half of the century, particularly during the fourth quarter, mechanization and improvements in variety made it both possible and profitable to collect two harvests per year.

15. Fallow area. Estimates of the area of fallow land are based on the sources used in Post 2. Fallow land became less important for land cultivation with the adoption of a system of crop rotation with lea containing clover and, at a later date, the use of chemical herbicides. Prior to the beginning of the twentieth century, leaving a portion of arable land fallow was important for restoring land productivity, improving soil nutrients, and controlling weeds. Fallow land was also often used for grazing and for the limited cultivation of legumes. The increasing amount of fallow land during the last decade is related to policy measures designed to reduce production.

16. Total animal units. The importance of balanced animal intensity in relation to arable land was realized early in the century. The agriculture census of 1927 estimated animal intensity in Uppsala County at 0.72 animal units per hectare arable land and meadows. An animal unit was defined as 1 mature cow, which was considered equal to 2 calves, 2/3 mature horse, 4/3 young horse, 4 pigs, 10 sheep, and 12 goats. Except for horses, these ratios are still considered to be reasonable, with Mattson (1985) and The Natural Environment in Figures (2000), the official annual report on the Swedish environment, using similar figures. The animal units I utilize are similar to the above except for horses, which are considered to have a value of 1.2 animal units for 1901, 1927, and 1951, but only 0.8 animal units for 1976 and 2000. Although livestock weight and productivity have more than doubled during the century, no weighing adjustment has been made. If such an adjustment was made, then the number of animal units during the century would probably not change substantially. The figures are based on the agricultural census used in Post 2 except for 2000, which is based on SCB, JO 20 SM 00 01, and presents livestock numbers in 1999 per municipality. A proportional adjustment for the exclusion of the Knivsta area is made on the basis of 1976 statistics concerning the number of animals in parishes and districts. Animal units for cows and calves are given in Post 16a.

17. Energy harvested from cereal. I estimate the energy harvested from cereal in respect to the harvested biomass production when dried per cultivated area and yield (Posts 9-12), assuming a moisture content of 15%. Dry mass is converted to millions of Calories (mCal), assuming that 1 kg wheat = 4,410 Cal (kcal), 1 kg rye = 4,330 Cal, 1 kg barley = 4,380 Cal, 1 kg oats = 4,790 Cal, and 1 kg hay = 4,385 Cal (Hoffmann and Uhlin 1997). Energy per kg food and feed cereals is estimated on the following basis: For 1901, I consider food cereal as consisting of 75% rye and 25% wheat, with feed cereal consisting of 60% oats and 40% barley. For 1927, I consider food cereal as consisting of 40% rye and 60% wheat, with feed cereal consisting of 55% oats and 45% barley. For 1951, I consider food cereal as consisting of 15% rye and 85% wheat, with feed cereal consisting of 50% oats and 50% barley. For 1976, I consider food cereal as consisting of 20% rye and 80% wheat, with feed cereal consisting of 40% oats and 60% barley. For 2000, I consider food cereal as consisting of 10% rye and 90% wheat, with feed cereal consisting of 25% oats and 75% barley.

18. Energy harvested from lea. In estimating the energy harvested from lea cultivation, I assume that the entire lea harvest is used for hay, with 16% moisture content when dried. The figure is based on cultivated area and yield (Posts 13 and 14). I also assume that 1 kg dry hay is equal to 4,385 Cal on the basis of the source used in Post 17.

19. Energy harvested from other crops and fallow. In estimating this figure, I assume that the energy harvested per hectare from other crops is equal to the average energy harvested per hectare from cereal and lea, and that the energy harvested per hectare from fallow is equal to 0.33 of this average. It is very difficult to estimate the contribution of fallow land in providing biomass.

20. Energy harvested per hectare. Energy harvested per hectare cultivated arable land is calculated for the total area of arable land (total energy production as per Posts 17, 18, and 19 divided by the total area of arable land). tCal indicates 1,000 Calories.

21. Fuel consumption. Since it is difficult to find reasonable statistics concerning the quantity of fossil fuels consumed in agricultural production in Uppsala, I base my calculations on the average consumption per hectare arable land in Sweden. I estimate fuel consumption for 1927 in relation to the number of tractors. Since tractors and threshing machines were rare in 1901, I estimate fuel consumption per hectare as zero. There were a growing number of tractors and threshing machines in Uppsala in 1927. If we assume an annual consumption of 1,000 liters of fuel per tractor, we establish a figure of 1.7 liters of fuel per hectare arable land. Jansén (2000) estimates an annual consumption of 500 liters per tractor, but I believe we must make a provision for fuel consumed by threshing machines and in various other activities, particularly when the 1954 consumption of fuel per tractor was approximately 2,500 liters. The figure for 1951 is based on the 1954 fuel consumption (Agriculture and Livestock 1954) reduced by 20% (between 1951 and 1954 the number of tractors increased by about 20%). The figure for 1976 is based on fuel consumption in 1977 (Yearbook of Agricultural Statistics 1979). The figure for 2000 is based on fuel consumption in 1994 (SCB, J 63 SM 95 01). The figures for 1951, 1976, and 2000 are based on total fuel consumption and on the total area of arable land in the country.

22. Nitrogen consumption. This figure concerns the use of industrial/mineral-/synthetic nitrogen. It is estimated that there were additional deliveries in 1999 of nitrogen per hectare of arable land of 24 kg from barn manure, 9 kg from air deposits, 10 kg. from nitrogen fixing crops, and 15 kg from grazing animals (SCB, MI 40 SM 01 01). The figures for 1901, 1927, and 1951 are drawn from Persson (1997) and Jansson (1963), and they reflect the average Swedish use of commercial nitrogen per hectare. 1901 figure is for 1901-1905, the 1927 figure is for 1926-1930, and the 1951 figure is for 1946-1955. Figures from early in the century include guano imported from South America. Since this nitrogen source required a substantial amount of energy for transport, it is treated here as a mineral source. The figure for 1976 consists of average sales in the country for 1975/1976 and 1976/1977, which are taken from the Yearbook of Agricultural Statistics for 1977 and 1978. The figure for 2000 consists of average sales in the country for 1999/2000 and 2000/2001, which are taken from SCB, MI 30 SM 02 01. The use of mineral nitrogen per hectare arable land in the Municipality of Uppsala is often near the average for Sweden.

23. Phosphorous consumption. This figure concerns the use of industrial /mineral/synthetic phosphorous. It is estimated that there were additional deliveries in 1999 of phosphorus per hectare arable land of 7 kg from barn manure, 1 kg from sewage sludge, and 2 kg from grazing animals (SCB, MI 40 SM 01 01). The figures are based on the sources indicated in Post 22, which reflect average commercial fertilizer sales in Sweden per hectare. The 1901 figure is for 1901-1905, the 1927 figure is for 1926-1930, and the 1951 figure is for 1946-1955. Substantial quantities of bone and bone flour were imported early in the century for use as fertilizer after treatment with sulphuric acid. For example, Sweden imported 14,852 tones of bone and bone flour in 1901/1902. Although this source of phosphorous is biological in origin, it is here considered as a mineral source. The use of mineral phosphorous per hectare arable land in the Municipality of Uppsala is often near the average for Sweden.

24. Biocide consumption. It is difficult to find statistics for the use of biocides in agriculture during the first half of the last century. For example, Morell (2001) covers many issues in Swedish agricultural development between 1870 and 1945, but he does not address biocides. We may thus conclude that the use of biocides for crop protection was close to zero early in the century. This increased substantially after World War II. Between 1948 and 1951 the sale of biocides more than doubled for all categories, including insecticides, fungicides, and herbicides. The figures are estimated in terms of active substance per hectare arable land. Statistics concerning the total sales of biocides in Sweden and the total area of arable land are used to estimate the figures. The data for 1951 is stated in terms of total weight, not active substance (Yearbook of Agricultural Statistics 1970). In this case, active substance is calculated using the same ratios of active substance in 1976, namely, 31% for insecticides, 25% for fungicides, and 65% for herbicides. The 1976 figure is based on the Yearbook of Agricultural Statistics 1978. The figure for 2000 is based on SCB, MI 31 SM 02 01.

25. Farms with cattle husbandry. Since information concerning the number of farms with animal production is difficult to obtain for all years, I choose to use the number of farms with cattle production. In Post 16 cattle comprise about two-thirds of animal units. In 1976 less than 50% of farms with cattle in Uppsala County did not have such animals as pigs and sheep. No information for the number of farms without livestock or cattle was found for 1901. However, we may conclude that the percentage of farms with cattle was higher then than in 1927 insofar as most farms without cattle at that time were small farms with 0.26-2 hectares arable land, which were then 23% of farms but only 8% in 1901. The 1927 census of agriculture reports that 3.8% of farms were without livestock in the plain regions of Sweden, which includes Uppsala, and that most of them had less than 2 hectares of arable land. In Sweden as a whole, the number of farms without livestock was 4.4% of the total number, while those without cattle were 7.4% of the total. We may thus estimate that 7% of farms in Uppsala were without cattle at that time. The 1951 census of agriculture reports that in Uppsala County there were 6,590 holdings with livestock, of which 5,413 were with cattle. Since holdings with less than 0.26 hectare arable land had only 88 cows (Table 10) and only 0.4% of such holdings in the plain regions had cattle (Table 14), we may estimate that out of the 6,988 farms in Uppsala County with more than 0.25 hectares of arable land there were 5,392 farms with cattle (Census of Agriculture 1951). The 1976 figure is estimated on the basis of the number of farms with cattle in the Municipality of Uppsala (including Knivsta), i.e., 774, in relation to the total farm number of 1,495 (Census of Agriculture 1976). The figure for 2000 is estimated from the number of farms with cattle in the Municipality of Uppsala (including Knivsta) in 1999, i.e., 374, in relation to total farm number of 1,119 (SCB, JO 20 SM 01 01).

26. Farms with lea for hay and grazing. Information for the number of farms with lea production is difficult to obtain prior to 1951. Consequently, I use the figures for farms with cattle in 1901, 1927, and 1951 as the lowest estimate for farms with lea in those years. I reason that lea is basically used as cattle feed, and that farms with cattle are expected to produce lea for hay and/or grazing. The 1976 figure is based on adjusting the number of farms in the Municipality of Uppsala with lea cultivation for hay, 946, out of the total farm number, 1,495 (Census of Agriculture 1976), to include farms with lea for grazing. The number of farms with lea for hay and grazing is considered to be 1.11 of the number of farms with lea for hay. This was estimated in relation to the number of farms with lea for hay in 1999 (SCB, JO 10 SM 00 01) in comparison with the number of farms with lea for hay and grazing in 2000 adjusted for the reduction in the total number of farms. The figure for 2000 is based on the number of farms in the Municipality of Uppsala that cultivated lea for hay and grazing, 737, in relation to total farm number of 1,099 (SCB, JO 10 SM 01 03). In 1976 and 1999 less than 2% of the area cultivated with lea was for green fodder and seeds.

27. Energy in fuel and nitrogen. Energy in fuel and nitrogen is based on consumption per hectare (Post 21 and Post 22 respectively). It is calculated as the energy content in fuel for machinery and in the fuel used for producing nitrogen. To determine the energy in fuel for machinery, I assume that the energy content of 1 liter of fuel is 10 KWh, or 8,600 Cal, which is valid for all years. To determine the energy in fuel used to produce nitrogen, I assume that 1 kg nitrogen was produced with 2.5 liters of oil (or the equivalent) in 1901 and 1927, 2 liters of oil in 1951 and 1976, and 1.5 liters of oil in 2000 (see Persson 1997; Hoffmann and Uhlin 1997).

28. Net harvested energy. Net harvested energy per hectare is calculated as the net energy harvested per hectare (Post 20) reduced by energy in fuel and nitrogen per hectare (Post 27).