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METHODS

A coevolutionary model for promoting agricultural sustainability

Basim Saifi^{a,*}, Lars Drake^b

^aDepartment of Urban and Rural Development, Swedish University of Agricultural Sciences, Sweden

^bSwedish Chemicals Agency, Sweden

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ABSTRACT

This article presents a coevolutionary model of agricultural development that is based on observations from the environmental history of agriculture and the need for addressing development processes toward sustainability. It asserts 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 surrounding ecological and socioeconomic systems. Widening the processes to include strong interconnectedness with national and global systems with respect to off-farm resources and farm outputs has led to various agro-ecological problems. Strengthening local interaction and interconnectedness in a rural–urban context is found to be essential for developing a system of sustainable agriculture. Such development requires influencing many subsystems and implementing changes in production methods and land use as short-term responses to the problem, and technological development, resource allocation and changes in values as long-term responses. It also requires some sustainability principles and indicators in order to direct actions and to facilitate communications, which can be derived from the model. Applying the model on Swedish agricultural sustainability during the twentieth century reveals some, probably, important findings for “building” sustainable agriculture and lends support to the usefulness of the model.

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1. Introduction

The concept of sustainability emerged in relation to the contemporary ecological crisis. Since the publication of the Brundtland report (WCED, 1987) various ways of analyzing divergence from sustainable development have been suggested, for example the index of sustainable economic welfare (Daly and Cobb, 1989), ecological foot print (Rees and Wackernagel, 1994), the concept of resilience (Berkes and Folke, 1998), welfare maximization over time (Pearce and Turner, 1990), material intensity per unit of output (Odum, 1987;

Hinterberger et al., 1997), and Emery analysis (Odum, 1988; Brown and Ulgiati, 1997). These methods tend to become mechanical calculation of specific important aspect(s) of sustainability that emphasize measurement and comparison. “Measuring” sustainability through comparative analysis is important, but it is just as important to understand processes of change away from or toward sustainability. 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. As Pretty (1995) argues, sustainability should not be seen as a static model that can be

* Corresponding author.

realized by particular means, but rather as an approach for learning about the ecological problems facing humanity. Agricultural sustainability is not about technical fixes and expertise. It is development processes that need to integrate ecological and societal knowledge through changes in policy, institutions, and behavior.

Norgaard's (1994) "Development Betrayed" meets the argument of environmental determinism (e.g. Meadow et al., 1972) and of social determinism (e.g. Simon and Kahn, 1984) half-way and argues for a coevolutionary paradigm that views social and ecological systems as being in continuous interaction. This paradigm asserts that ecological systems determine the suitability of societies' subsystems of knowledge, value, technology, and organization. At the same time, however, choices in these subsystems determine the suitability of evolving ecological systems. For both systems, development has its roots in the biological principles of mutation (experimentation in social system) and selection. A restrictive meaning of the word coevolution, namely, pair-wise coevolution, which can be based on different relationships, such as competition, parasitic-host, mimic, symposium and prey-predator, implies that a trait in one species evolves in relation to a trait in other species, which itself has evolved in response to the trait in the first (Futuyma and Slatkin, 1983). Like any species, a socioeconomic system has many characters (traits) that have reciprocal relationships with characters in various subsystems of surrounding biophysical or ecological system.

Since Norgaard's "Development Betrayed" a large number of works using the coevolutionary way of thinking have been performed on a wide range of issues within the relationship between socioeconomic and ecological systems (Kallis, 2007). The idea that people develop their economic and social system as adaptation to the surrounding ecological system is now widely recognized (Steiner and Nauser, 1993; Diamond, 1998; Berkes and Folke, 1998; Fernández-Armesto, 2001). For example, Fernández-Armesto (2001) argues that civilization is the relationship that people establish with their ecological 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 development as resulting from interacting processes that involve nature and culture. In an agro-ecological system the character of the subsystems, the system itself, and the relations between them all change over time as they coevolve with each other.

Norgaard (1994) envisions sustainability through discursive communities that coevolve with their surrounding ecological system. Presently, most people and in most countries are living in urban areas and societies become complex systems involving various sectors. Further work is needed for operationalizing the coevolutionary theory and striving toward sustainability based on present prevailing situation. Four postulates may facilitate the operationalization of the theory (Saifi, 2004):

1. A society's perception of what sustainability means and why certain systems are not sustainable is what matters.
2. In order to address what is unsustainable in a given society, it is necessary to examine the issue with 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 these sectors so that they can be used to promote sustainable development.
4. Principles and indicators of sustainability in each sector are important for facilitating communication and interaction.

This article addresses agricultural sustainability with the coevolutionary theory and the above postulates as guide. The objective is to present a coevolutionary model (Section 3) in which agriculture coevolves with surrounding ecological and socioeconomic systems and its sustainability can be promoted by strengthening local coevolutionary processes in rural-urban context and by inducing short and long-term changes. The model is developed in relation to an interpretation of observations from the environmental history of agriculture (Section 2) and to a perception on how an agricultural system presently functions with respect to agro-environmental problems and the role of municipalities in facilitating and building sustainable agriculture. Section 4 provides some results from applying the model on the development of Swedish agriculture. Section 5 summarizes and concludes the article.

2. An interpretation from agricultural development and environmental history

Life on Earth has been evolving for some 3 billion years. Climatic, biotopic, and geological changes, including 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. As hunter-gatherers, our numbers were under the constraints imposed by the ecological system. By protecting certain wild plants and animals and encouraging them to grow at the expense of others, humans not only increased the quantity of food that could be taken from the environment, but also placed it at their disposal in a more regular fashion. Such activities encouraged settlement, which in turn encouraged more knowledge, and increased production further. 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 (Norgaard, 1994).

People ceased to be wandering hunter-gatherers in various parts of the Near East around 7000 BC, and through technological and institutional changes that proceeded at various degree of scale, pace and continuity they became builder of the Sumerian-Akkadian cultures around such city-states as Uruk and Ur during the third millennium BC (Reilly, 1980; Roux, 1992; Diamond, 1998). The development of early villages and towns was connected with the use of specialized implements and institutional arrangements that supported agricultural production and development. The scope of building and maintaining complex irrigation systems, which permitted large food surpluses from agriculture and allowed for building relatively large cities, required assembling large labor forces from the countryside and the city. This interdependence was strengthened by the eventual production of items that

required raw materials supplied by agriculture, such as textiles, leather goods, sweets, beer and even furniture and building, and by increasing need for rules and regulations in agriculture. During the third millennium BC agriculture thus became increasingly dependent on the associated city state and adopted many techniques suitable to the ecological and socioeconomic systems. Date palm cultivation spread extensively. A rotation system involving fallow and crops was adopted to maintain soil fertility and reduce salt accumulation, and it also supported grazing which in turn improved soil fertility. Barley was also increasingly used because of its tolerance to salt concentrations. Such adaptations lasted for more than 4000 years, and they are still important. The survival of the city of Babylon for more than 2000 years indicates that its agriculture followed a sustainable path.

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; Myrdal, 1999; Gadd, 2000). 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 5000 years ago. The rise of a strong state and an effective central administration under the reign of Gustav Vasa in the sixteenth century promoted 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. Most of the Swedish towns and cities emerged and expanded in relation to agricultural capacity to support more people and to produce food surpluses. As has been the case in most agricultural regions of the world the connection between land cultivation and animal husbandry on the basis of nutrients and feed was realized in Swedish agriculture, and it was used to increase and improve food production, and to maintain soil fertility. This connection was strengthened by technical and institutional changes, especially around the end of the 19th century when a rotation system with lea cultivation was adopted and when the influences between agriculture and city/town intensified. Like in ancient Iraq, an important feature of agricultural development in Sweden is the change from coevolution involving simple farming community and the ecological system to a more complex evolution involving an expanding socioeconomic system within the rural–urban sphere.

The impact of agriculture on the ecological system has been most substantial, occasionally destructive. Negative effects were reduced and food production gradually increased through trial and error practices that have driven agricultural development by observing improvements in the quantity and quality of food, effects on the resource base and the ecological system, efforts undertaken on the levels of farm and society, along with constraints and incentives arising from the systems of value, knowledge, and organization. An initial adoption of a new method, technique or crop 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 that even involved towns and cities. While the coevolutionary

perspective developed by Norgaard (1994) stresses interaction between people and the ecological systems, the above discussions suggest viewing agricultural sustainability also in light of coevolutionary processes involving agriculture and the surrounding ecological and socioeconomic systems in rural–urban context.

In the era of traditional agriculture the expansion of humankind was characterized by a growing efficiency in its interactions with the ecological system. The presence of ecological constraints made it possible for the socioeconomic system and its agriculture to undergo long-term development through changes in knowledge, values, social organization, and technology that were suitable in relation to the ecological system. This suitability made agricultural development sustainable in providing adequate food to people, and laid the foundation for towns and cities to emerge by virtue of farm surpluses, which encouraged further development in traditional agriculture. Low population growth, due to high infant mortality, some forms of birth control and occasional famine, war, pest outbreak and emigration, implied low growth in food requirement and thus allowed agriculture to undergo long-term interaction with the ecological system in relation to increasing its capacity to meet societal needs. Traditional agriculture managed to provide food to more than a billion people and create many diverse cultural and agro-ecological systems without causing substantial ecological damage, and without using technologies associated with fossil fuel utilization.

The industrialization of agriculture has rendered food production increasingly less dependent on surrounding (local) socioeconomic and ecological systems and more dependent on non-renewable resources, particularly fossil fuels and mineral phosphate. However, it did substantially increase land productivity in terms of yields, thereby satisfying the sharp increase in food demand associated with rapid population growth and rising material standard. Industrial agriculture succeeded in reducing constraints arising from within the ecological system by drawing on the physical and intellectual resources provided by other systems, and it did so without sufficient experimentation and consideration of its ecological impact. Insofar as modern agriculture is greatly dependent on non-renewable resources and contributes in degrading ecological systems at local, regional and global levels, it can hardly be considered as sustainable in providing human needs in the long run.

The view presented in this section differs, at various degrees, from many development studies which endeavor to identify the factors and forces that trigger development in various regions and periods, such as population growth, technological development, urbanization, resource scarcity and climatic fluctuations (see for example Boserup, 1981; Worster, 1988). Wilkinson (1973) and Grigg (1974) view agricultural development in terms of interactive forces involving surrounding ecological systems, but they too overlook the urban–rural interaction. The diverse history of agricultural development can provide materials and evidences for diverse interpretations that can not be universally verified. Our above interpretation is no exception but we believe that it could be useful for promoting sustainability since most people in most countries are now living in towns and cities that are largely

surrounded by agriculture and presently the role of towns and cities can be crucial in building sustainable agriculture, not least through safe nutrient circulation.

Five 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 during the agricultural era 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 also larger socioeconomic system associated with the emergence of towns and cities. Third, this 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, 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.

3. A conceptual model of coevolution in agriculture

In the previous section an explanation is put forward for how coevolution involving agricultural communities and the very local ecological system has largely transformed into coevolution involving agricultural, socioeconomic and ecological systems in relation to the emergence of towns and cities that was largely affected by and affected agricultural development in the surrounding. The processes, it is argued,

maintained sustainable agriculture because the suitability of a given change emerges not merely in respect of the costs and benefits incurred to farmers, but rather in respect of the reactions of various related systems and subsystems, including the environment, values, knowledge, and organizations. Further widening of the coevolutionary processes to include integration with higher national and global level decreases the feedbacks from local ecological and socioeconomic systems. Returning the nutrients in organic waste of urban population to the agro-ecological system is fundamentally important in building sustainable agriculture due to resource depletion and environmental degradation. Furthermore, production method and its impact on the environment and agro-ecological services concern local population more than others.

Fig. 1 describes these processes and relations that pertain between the agricultural subsystem and the ecological and socioeconomic systems at municipality level in rural–urban context. Municipalities in many countries, especially in Nordic countries, often cover urban and rural sphere and function as local government responsible for many services that could be important for agricultural sustainability, such as waste management and education, and can thus be treated as socio-ecological system. As argued by [Musters et al. \(1998\)](#) sustainability requires demarcation of socio-ecological system. The system/framework, which consists of agriculture coevolving with ecological and socioeconomic systems at municipality level, is linked with lower parish and farm systems (far left-side arrows) and with higher national and global ecological and socioeconomic systems (far right-side arrows). The process of industrialization weakens the internal interaction and interconnectedness within the system and strengthens external interaction and interconnectedness with higher socioeconomic and ecological systems. Presently the national socioeconomic system largely dominates agriculture at municipality level by bringing in off-farm resources from other ecological systems and by common national socioeconomic system.

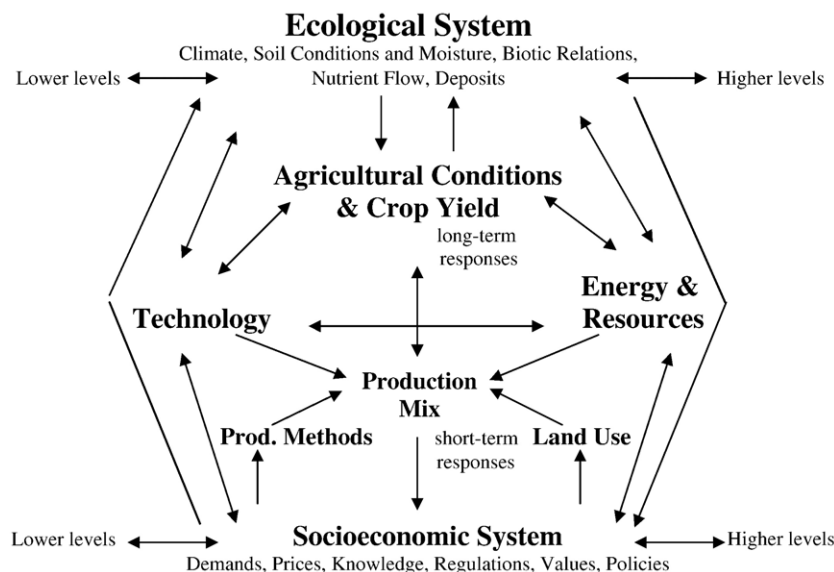


Fig. 1– The coevolution of the agricultural subsystem with the socioeconomic and ecological systems within a rural–urban context and with changing influences in form and strength over time (see text).

The agricultural subsystem is represented by production capacity, or agricultural conditions and crop yields, which is influenced by long-term processes involving technology and energy and resources, and by production mix, which is influenced by short-term processes involving land use and production method. Technology is part of the socioeconomic system but is placed in Fig. 1 within the agricultural system due to its special role in agricultural development. Similarly energy and resources are part of the ecological system but are placed with agriculture. The agricultural system is influenced by environmental problems directly and through the socioeconomic system. Production methods represent the techniques and knowledge available to agriculture at a given point in time. The production mix and the level of inputs are determined by the farmer in response to output and input prices, policies and regulations and farmers' values and attitudes. Since the Second World War short-term changes become increasingly important and rapid.

Unlike the subsystems of knowledge, value and technology, the organizational subsystem is disaggregated in Fig. 1 and presented in terms of demand, prices, regulations and policies. The arrows represent influences that could be in diverse forms, such as information, physical–chemical fluxes, demand, and physical flows in terms of energy, goods, materials, services, money and labor. Most of the arrows imply various forms of influences that are not always identical in reciprocal relations and can change over time.

3.1. Processes and operational levels

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. Instead of focusing increasing crop and animal production, a common feature in the industrialization of agriculture, public knowledge and concern could make the socioeconomic system respond consciously to actual and perceived agro-ecological problems. The socioeconomic system may 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, a significant environmental tax on mineral fertilizer may lead to a decline in demand and encourage nutrient circulation at farm and municipality level. Within the long-term responses, changes in technology, values and resources can have a substantial impact on agriculture. An important aspect of this process is to drive technological development towards both resolving and avoiding ecological problems, such as searching for crop/variety that give a reasonable yield but has good genetic properties in respect of the environment and requires less protection and nutrient nursing, and to build values that comply with ecological limitation, such as balanced diet that includes small share of animal products.

Contemporary ecological degradation and resource depletion have negative impacts on agricultural production capacity and thus on the health and well-being of present and future generations. If no consideration to ecological problems is made, which was/is a common feature during the indus-

trialization of agriculture, it can be said that the agricultural system has coevolved in response to rapid increase in food demand and the availability of cheap fossil fuel, through an increased use of resources and the adoption of new technology. But when the issue of ecology, including the perception of natural resource scarcity, is introduced into this picture of agricultural development, a new path of development may be necessary because of three factors. The first consists of the direct environmental impact upon agricultural production capacity, such as land degradation. The second consists of indirect socioeconomic effects by means of public concerns and governmental policies, such as the reduction of nutrient leaching, the decrease use of non-renewable resources and the preservation of valuable agro-ecological landscape. The third consists of increased opportunity costs of resources, such as land for forestry, conservation and energy production.

The coevolutionary processes at work in agricultural development can be perceived at local, national, and global levels. Agricultural development began with coevolutionary processes at the very local level that gradually widened to include higher-level influences. As suggested in Section 2 when the very local interaction and interconnectedness widened to include emerging towns and cities and larger ecological system, agriculture generally was able to maintain its sustainability. That is, when agriculture coevolves within a demarked socio-ecological system in an urban–rural context, sustainability could be achieved since any change would result in feedbacks that arise from the relatively closed system. During the industrialization of agriculture further widening led to a weakening of interaction and interconnectedness involving the local community, agriculture production and nature. Perhaps the most important negative impact of this particular development is the sharp reduction in feedbacks from socio-ecological constraints. It was this feedback mechanism that rendered traditional agriculture sustainable in relation to the ecological system and thus able to survive for millennia. Insofar as this widening comprises the source of most of the ecological problems associated with industrial agriculture, strengthening coevolutionary processes on the local level should be the long-term focus with respect to sustainability.

At the national level, where presently most of the interaction between agriculture and the socioeconomic system occurs, agro-environmental policy can be viewed as an institutional arrangement for carrying out societal objectives, even though certain forces may work for policy changes that favor environmental improvement while other forces may resist such changes. The awareness of agro-environmental problems has increased significantly during recent decades in most countries. Policy change in the socioeconomic system arises from complex processes that reflect material interests, knowledge, moral convictions, and macroeconomic efficiency (Vail et al., 1994). Furthermore, the perception of global ecological constraints and the various works that are taking place at the international arena in that respect are putting further pressure on national governments to strengthen their agro-environmental policies. Policy measures operating on national level, such as taxes, regulations and supports are important for promoting sustainable agriculture. It is equally important to supplement national measures with national

policy support for strengthening the coevolutionary processes at municipality 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 change no longer affect people on merely local and national levels. The perception of global ecological constraints (WCED, 1987; Odum, 1987; Daly and Cobb, 1989; Rees and Wackernagel, 1994) and the increasing evidences of their existence are putting pressure on the industrial countries and the international community to mitigate and solve global ecological problems. The four major assessment reports from the Intergovernmental Panel on Climate Change between 1990 and 2007 demonstrate how the perception of, and demand for actions to reduce, global warming is increasing. Although global environmental problems require substantial allocation of resources and technology and global regulation and governance (Harris, 1992) it is not possible to achieve adequate progress without the participation of local communities throughout the world on bases of both moral commitment and long-term interest. Agricultural environmental issues are also interrelated with each other and with the structure of international trade and investments and with population growth (Redclift, 1987). Increasing global trade with beef produced on grazing land that was rain forest represents a perverse case of uncontrolled market mechanism. Conflict on land use for food production, conservation, forestry and the production of bio-fuel and other products are evident on global, national and local level.

Since the Second World War environmental degradation and resource depletion have been increasingly shifting from being local to national and global problems. At the global level further outside shifting is not possible, and sooner or later many perceived problems would become real. This is presently more or less valid for such ecological problem as climate change and such resource depletion problem as fossil oil. At this stage the challenge to humankind and nations' leaders is either to work together and mitigate or solve such problems or accept the unprecedented consequences. In either case feedbacks arise and the problem shifts to national and local level for resolution. Furthermore, global and national level interactions are increasingly stimulating local contribution on such issues as development and resource management. Thus, the processes of changes at local, national and global level speak for shifting feedbacks to local level, and this implies that reducing the interconnectedness with global and national systems with respect to such important issues as food and energy may be plausible.

3.2. *Important subsystems in agricultural development toward sustainability*

Fig. 1 and the above discussions indicate that a number of subsystems are involved in the interaction between agriculture and the surrounding socioeconomic and ecological systems, each of which may affect others within the system as well as the system as a whole. When the system is stable, "closed" agricultural community with stable population, the subsystems are locked to each other and little development takes place. But when the system is not stable, each

subsystem can become an active force capable of changing other subsystems by virtue of their mutual interdependence. The European scientific revolution and the Enlightenment movement set in motion tremendous changes that eventually affected the whole world. Presently it is difficult to find many examples of a stable agricultural system with subsystems that are locked to each other. However, many of the interactive subsystems discussed below can be effectively influenced at municipality level in coordination with national level. Such focus implies increasing interaction and interconnectedness within municipalities.

Technological development and the utilization of natural resources comprise the basis of agriculture. Technology, as techniques and methods associated with knowledge application, 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, biotechnology can be directed to partially replace 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, integrated pest management, and agro-forestry are examples of technologies that can increase production while reducing ecological degradation. Research institutes in many countries are now working on the development of so-called ecological (low input, organic, traditional) agriculture. Parallel processes of technological development may, however, be active side by side even within a country or municipality.

Concerning natural resources, agriculture in general now depends on on-farm resources, which are more or less related to the ecological system immediately involving the farm, as well as off-farm resources, which are brought to farmers from other areas. Traditional agriculture developed in relation to on-farm and local resources. Land and water are the main on-farm resources that limit the expansion of agriculture. However, technological development and the increased use of off-farm resources may increase the production from a given quantity of land and water. It is important to note that fossil fuels and mineral phosphorus, vital off-farm resources in modern agriculture, are non-renewable resources. The use of such off-farm resources as fossil fuels, mineral fertilizers, and synthetic biocides has strongly contributed to the creation of environmental problems affecting air, water, soil, the biotic system, and human health. 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 demands particular attention in future agricultural development since energy flow constitutes a fundamental link between agricultural activities and the ecological and socioeconomic systems. Modern industrial agriculture is largely dependent on chemical and mechanical inputs that require substantial amount of fossil fuel to produce and to use. Since fossil oil empowers the increasing

use of off-farm resources and the widening of the coevolutionary processes, its scarcity and environmental degradation may strengthen local processes. Furthermore, the ecological systems that agriculture modify/change part of them differ widely in terms of their annual primary production of energy and the stock of biomass energy (Whittaker and Likens, 1975). This implies that in protecting life-support ecosystems it is important to address the impact of an agricultural system on surrounding ecosystems.

Food demand is another important interactive subsystem. In industrial countries, with low or negative population growth, relatively stable or decreasing demand for food, and a small percentage of disposable income spent on food, it is relatively easy, compared with developing countries, to follow a sustainable path of agricultural development. Rapid population growth leads to unstable agricultural system and influences other subsystems by increasing food demand. Food demand also increase in relation to changing diet structure towards more animal content. The ecological costs often increase when diet is based on animal products and animal production is based on feed grain (Goodland, 1997).

Value, 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 with respect to food preferences, the attitude towards the natural environment, animal welfare, and even the choice of technological development. Ethics expresses the commitment of a society to protect and foster its well-being. Issues related to value system 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 policy they prefer. Nevertheless their consumer role is important and could bring changes that comply with ecological constraints.

Knowledge is another important element of the socioeconomic system that coevolves with values, technologies, food demand, resource use, and the ecological system. Knowledge about ecological constraints clearly influences, and is influenced by, these systems. Agriculture contains a body of formal and informal knowledge that shapes it. The formal knowledge intensified with the advance of the atomistic-mechanical mode of inquiry. 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.

Food security is an important issue in the coevolution of agriculture. Food security is now defined as access by all people now and in the future 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 recent literature, concerns the ability of all people to acquire food. However, the ability of a society to produce own food is deeply rooted in most societies and it could be important for future development especially regarding possible crises and nutrient circulation.

Farm economy is a crucial issue in moving away from or toward sustainability. Economic conditions can more or less force farmers to follow a path of development that implies resource and environmental degradation. Costs and benefits, or efforts and gains, have always played an important role in decision-making on the farm. Economic feasibility, which is often influenced by macroeconomic factors, is thus crucial in promoting agricultural sustainability. Yet, farmers' attitude towards the environment is an important factor in such development (Drake et al., 1999). 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.

Other issues of importance in the evolution of agriculture are related to various types of environmental degradation that affect the ecological system as a whole and, consequently, the welfare of the society. Land degradation, climate change, air and water pollution and biodiversity depletion affect, and are affected by, agricultural systems in various ways, for example while climate change may impact agriculture through changing climatic regime, enhancing crop yield because of carbon dioxide enrichment and rising sea level, mitigating it would also have substantial impact on agriculture through reducing the emission of greenhouse gases and producing bio-fuel (Parry, 1990). 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 preservation, biological toxicity, and diseases that affect the animals we eat. Problems such as salmonella, feed contamination, and mad cow disease have generated concern at both national and international levels. Evidence obtained through a large number of studies has demonstrated that some widely used biocides suppress immune reactions in fish, birds, and mammals, including humans (Repetto and Baliga, 1996).

3.3. Dimensions for depicting sustainability principles

The presented coevolutionary model illustrates that agricultural sustainability involves various processes and subsystems. Evaluating the character of development in sustainability term is a difficult task because humans cannot obtain exhaustive knowledge concerning the impact of change. Nor is there agreed upon method for weighing the results when the values of indicators move in different directions. Further problem arise from the level of analysis. However, promoting agricultural sustainability may demand strengthened coevolutionary processes on the local level so that ecological constraints and social requirements interact directly with the farming system in the area. This requires some principles that could be translated into measurable indicators in order to facilitate interaction and direct actions. Such 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.

The above discussions in this section indicate that there are many important subsystems and special aspects or issues in agricultural development that interact both with each other, and with the larger agricultural, societal and ecological systems. The discussion also indicates that traditional agriculture contains practices which proved ecologically sustainable and thus can be useful for depicting sustainability principles. As Goma et al. (2001) and Holling et al. (1998) observe traditional agriculture involves knowledge that is important with respect to agricultural sustainability. Insofar as these issues constitute the characteristics of a given agricultural system they can indicate its sustainability level, and should thereby be considered as dimensions or aspects of sustainability. Appropriate principles and indicators of sustainable agriculture in a country or region can thus be found in the following dimensions.

1. Value system and ethics
2. Traditional agriculture
3. Food demand
4. Technological development
5. Energy and biomass
6. On-farm natural resources
7. Off-farm natural resources
8. Ecological system and environmental degradation
9. Food safety and other health aspects
10. Food security and regional distribution
11. Farm economy

By studying important sustainability issues in each of the above dimensions for a particular country or region and by discussing the relations pertaining between these issues, we may be able to depict a limited number of reasonable principles of sustainable agriculture. Although the above eleven dimensions are relevant to sustainability with 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. 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 integrating crop and animal production. However, promoting sustainable agricultural development cannot be resided in one or a few of them, and there will be both conflict and reinforcement between such principles even within a given country or a region. 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, which reduces sustainability. There is also obvious conflict in most industrial countries between reducing the use of off-farm resources and accepting higher food prices and/or budget cost. Each society, and ultimately each community, may arrive at its own internally and externally consistent principles and definition of sustainable agriculture.

4. Applying the coevolutionary model on agricultural development in Sweden

The coevolutionary model presented and discussed in the previous section suggests that in addressing the sustainability of an agricultural system it is important to consider the framework of agriculture coevolving with the ecological and socioeconomic system (Fig. 1) and to study the development processes away from and towards sustainability in that system, the subsystems/forces involved in these processes and the issues and principles that are important for promoting agricultural sustainability. The model asserts that in building sustainable agriculture it is essential to strengthen local interactions and interconnectedness at municipality level. The application of the model according to these propositions on the Swedish agricultural development during the 20th century, with Uppsala municipality as case study, reveals information important for promoting agricultural sustainability in Sweden and lends support to the usefulness of the model (Saifi, 2004).

The Swedish agricultural system, which originally developed in relation to the surrounding ecological systems, became increasingly dependent also on forces in the socioeconomic system, particularly through state involvement and emerging towns and cities. Changes in technology, values, knowledge and organization brought about two radical transformations of agriculture since early 19th century. The first transformation, which ended around 1930, was basically changing the traditional system of tilled land combined with meadow harvesting and village management to a system of cereal rotation with clover-enriched lea, stronger crop and animal integration, and individual farm management. Towards 1930 the new system, which remains within the traditional framework of local resource flow and product consumption, was capable of producing much more food and ending the periodic hunger and emigration. The interaction and interconnectedness with associated city/town intensified through food production, processing and consumption. The use of external resources from other systems remained limited, largely consisting of knowledge and implements that could be used for many years. This development complies with close coevolutionary processes depicted in Fig. 1, i.e. weak interconnectedness with higher national and global level. Yet, some trade with other systems occurred and socioeconomic forces that change the sector were interacting with national level. Furthermore, short-term responses to such organizational forces as expanding non-agricultural sectors, changing relative prices and increasing state intervention were not distinct as in Fig. 1.

The second transformation, which started around 1930, led to modern industrial farming characterized by a low degree of local interaction and interconnectedness. As in Fig. 1 the sector responded positively to changes in such socioeconomic forces as prices, demands, values, technology and policies through short and long-term processes. The flow of resources became decoupled from the local ecological and socioeconomic systems, and ecological problems could be shifted to higher systems. During the second and third quarters of the 20th century the use of machine powered by fossil oil,

chemical fertilizers and biocides, and biological technology increased continuously in Uppsala. Like in other regions throughout the industrial countries not much attention was given to the impact of these practices. Furthermore, food production and land use became independent from food demand within the urban–rural sphere. The fourth quarter saw the introduction of various policy measures addressing agro-ecological problems that were created by agricultural industrialization.

Changes in the interactive subsystems of demand, prices, technology, value, knowledge and policy within the socio-economic system have led to different development in Swedish agriculture throughout the century. For example, in early century it was increasing labor employment and land productivity through better utilization of local resources. After the Second World War it was agricultural industrialization and increasing labor productivity through employing mechanical, chemical and biological inputs. The point is that influencing the above subsystems was important in bringing desired changes in agriculture. Similarly, in building a sustainable agriculture a number of changes in these subsystems may prove to be necessary in the course of development.

When the 11 dimensions of agricultural sustainability depicted in Section 3 above are discussed in Swedish context, a very large number of issues relevant to sustainability could be found. But when the relationships between these issues were investigated it was possible to choose 11 principles that reflect most of the important issues. These principles are; high production of energy in terms of biomass, combining animal and crop production, crop rotation with lea or legumes, limited use of mineral phosphorous fertilizer, limited use of mineral nitrogen fertilizer, limited use of fossil fuel, limited use of biocides, balanced food consumption, balanced regional distribution of agriculture, adequate income to farmers and high degree of integration between farming and both rural and urban population. The value of derived indicators from these principles for the municipality of Uppsala reveals that agricultural sustainability during the 20th century was generally improving and high during the first quarter, deteriorating during the second and third quarters and low but improving during the fourth quarter of the century.

The development of the agricultural system during the first quarter was essentially appropriation of the agricultural system that evolved during the nineteenth century in coevolution with Uppsala's ecological and socioeconomic systems. Food production and availability, labor employment, and productivity of labor, land, and animal were improved substantially and yet sustainability indicators maintained good value. Net energy in harvested crops per hectare increased by almost 70% and no significant deterioration occurred in any of the other 10 indicators. Some ecological deterioration might have occurred in relation to drying 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, the reduction of arable land use per person, and maintaining rich agro-ecological system in terms of variation and number of species that are dependant on it. This new traditional system had the potential for further improvement, especially regarding the productivity of arable land, but it could not continue because of the

changing socioeconomic conditions in support of agricultural industrialization.

Development during the second and third quarters led to an open agricultural system integrated with national and global systems. Lifting local ecological and socioeconomic constraints opened the road for the emergence of various agro-ecological problems. Despite the large increase in the use of off-farm resources during these two quarters of the century net harvested energy per hectare increased by less than 45%. The value of all the other indicators has substantially deteriorated. The development during the fourth quarter achieved some agro-environmental improvements and shifted policy attention from production and productivity to agro-ecology and its services. Net harvested energy per hectare increased during this period by 13% and the value of indicators reflecting the use of off-farm input improved. Yet, the value of other indicators continued to deteriorate and the overall sustainability record remains low.

Agricultural development in Sweden during the 20th century supports the argument of this paper that when the coevolutionary processes could be maintained within municipality, agricultural sustainability would be achieved. The movement from sustainable development during the first quarter into the unsustainable development during the second and third quarters may be explained in term of weakening local interaction and interconnectedness in rural–urban context. The conditions that made both developments possible were grounded in the socioeconomic system. The sustainable development during the first quarter of the 20th century emerged in relation to prevailing conditions that were largely influenced by state mobilization of various social forces to boost production and improve living condition of the people engaged in farming. State involvement need not constitute an obstacle to maintaining basic integration involving agricultural, ecological, and socioeconomic systems on municipal level. A given local community at municipal level can become more involved in supervising and shaping the agricultural production that takes place within its borders. National and other higher levels of interaction can support this strengthening of local interaction by means of financial support, constraints, researches, services and regulations.

The potential for a sustainable path of agricultural development by strengthening local interaction and interconnectedness at municipality level is large and increasing. Swedish agriculture still exists in most municipalities and it still combines grain and animal production to some extent. Furthermore, the awareness of ecological degradation, resource depletion and living in an uncertain world is increasing. In addition, such issues as managing nutrients circulation, agro-ecological heritage, the protection of water bodies and influencing land use and production methods according to community's values and demands can be better addressed by engaging local population, politicians and actors at the municipal level. Although the perception of the important role of local community in sustainable development is increasing, it is currently not feasible to undertake a comprehensive project for such development in the whole of Sweden. However, it does seem useful to implement such project in an experimental fashion in a limited number of municipalities, e.g. Uppsala.

5. Conclusion

The coevolutionary approach views change as resulting from complex interactions between subsystems. The nature of the system and the subsystems, as well as the relations pertaining between them, all change over time as they coevolve with each other. Agriculture has historically developed in coevolution with the surrounding ecological system and later also with a larger socioeconomic system as the emerging towns and cities increasingly influenced, and was influenced by, agriculture. Traditional agriculture, which emerged in relation to local ecological and socioeconomic systems, has managed to provide food to some 8 doublings of world population, up to early 20th century, and created diverse and sophisticated agro-ecological and cultural systems throughout the world. This was possible, it is argued, because in the pre-industrial period agricultural development was based on long-term interaction with the environment and the resource base so that adapted techniques, methods, crop varieties, could be characterized by long-term suitability. In contrast, modern industrial agriculture comprises a large number of accumulative changes that have been adopted over a relatively short period of time, with no or little consideration has been given to their long-term impact on the ecological system, the resource base, and society. It basically lifted local ecological constraints and broke the rural–urban links. This system managed to double food production twice, but with significant environmental degradation and resource depletion.

In promoting agricultural sustainability it is important to understand how and why a course of non-sustainable development comes to be pursued. The model of coevolution presented in Section 3, attempts to address that by reflecting upon the history of agriculture when it could achieve sustainability through coevolutionary processes with the ecological system and the associated city. The processes are depicted in Fig. 1 on basis of present municipalities and include the agricultural subsystem as part of the ecological and socioeconomic systems. Environmental events and the awareness of agro-ecological problems at local, national and global level have become powerful forces influencing short and long-term changes not only with respect to policy measures supporting resolutions, but also regarding consumers' preferences, citizen involvement, and technological development. This may set in motion changes that strengthen local coevolutionary processes.

The application of the coevolutionary model presented in this paper on Swedish agricultural development during the 20th century provides important support to the usefulness of the model. In early century an interesting sustainable development in agriculture could be achieved. Food production and the productivity of the arable land could be increased substantially and yet sustainability indicators maintained good value. This was possible, it is argued, because the interaction and interconnectedness between agriculture and the surrounding ecological and socioeconomic systems remain largely within rural–urban domain. In contrast, during the second and third quarters of the century the agricultural system was transformed into an open system integrated with national and global systems, and the result was low degree of

sustainability. It is neither possible nor warranted to revive the traditional system of agriculture of the early 20th century. But, it is possible to reconstruct the framework and conditions that shaped that system by strengthening coevolutionary processes at municipality level in order to facilitate the development of sustainable agriculture.

The main conclusion of this article is that the weakening of local coevolutionary processes and the reduction of local ecological and socioeconomic constraints have led to an unsustainable path of agricultural development. Fossil oil largely powered this process, which was enhanced by transferring environmental problems to larger ecological system and to the biosphere and by importing various off-farm inputs from other systems. Presently not only the perception of ecological degradation and resource depletion is increasing, but also such problems as oil shortage and climate change are becoming real. Addressing these problems is an urgent task that would have profound implication on agricultural production and food consumption. A sustainable path of agricultural development may thus assign municipalities as socio-ecological systems and reduce national and global interconnectedness, particularly concerning major off-farm inputs and farm outputs.

Agriculture can be directed toward sustainability by following a path of development that enhances the coevolutionary processes on municipality level, influences many related subsystems and short and long-term processes, utilizes knowledge from traditional agriculture and prevailing condition, and complies with principles of sustainable agriculture useful for directing actions and facilitating such interaction. The corresponding changes can presently only be moderate and experimental in nature. However, they may well become necessarily strong with respect to fossil oil shortage, ecological disturbances, or economic disruptions that give rise to food security problems. Furthermore, based on moral conviction, long run interest and relatively small cost involvement, industrial countries can/should direct seriously their agriculture towards substantial reduction in ecological degradation and in the use of non-renewable resources. Such development may help many developing countries to follow a path of agricultural development that differ from that followed by industrial countries with respect to ecological degradation, extensive use of off-farm resources and food consumption pattern.

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