SEARCHING FOR SUSTAINABILITY: CHINESE ECOLOGICAL AGRICULTURE IN ZHEJIANG PROVINCE

by

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This paper examines the role of Chinese Ecological Agriculture (CEA) in Zhejiang province as an alternative to conventional agricultural practices. In the past twenty years, the Chinese agricultural sector has begun to use increasing levels of agricultural chemicals and machinery. In spite of limited increases in agricultural productivity, current practices are having a negative impact on the environment and undermining China's natural resource base. CEA has been proposed as an alternative, sustainable agricultural system and has been implemented in several communities in Zhejiang province. In spite of limited success in demonstration communities, CEA has not been widely accepted. The characteristics of CEA that make it sustainable, such as localizing production, utilizing human labor, and applying organic fertilizers, are in direct competition with national economic development efforts. China's current path of rural economic development is not only contributing to environmental degradation, but also creating conditions that exclude more sustainable agricultural systems.

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CHAPTER I

DEVELOPMENT, SUSTAINABILITY AND AGRICULTURE

In the past twenty years, the technologies and practices involved in Chinese agriculture have changed significantly. Economic and agricultural reforms have increased the availability of agricultural inputs such as chemical fertilizers and pesticides. The Household Responsibility System, which redistributed control of land from collectives to households, has increased the ability of individual farmers to make decisions regarding how land is managed. At the same time, new access to the market has increased opportunities for economic profit. Although many of the changes in the agricultural sector have contributed to increasing productivity in certain crops, this has not been without a price. The same economic growth that has facilitated the availability of Green Revolution technologies is also placing increasing pressure on limited agricultural resources. After several decades of increasing reliance on energy intensive agricultural inputs, such as synthetic fertilizers, China is beginning to realize the impact of these technologies on environmental quality. Arable land is being taken over by rural industry and available land is being degraded through unsustainable agricultural practices and pollution. Within the agricultural sector the environmental impacts associated with recent economic growth is beginning to threaten the food source of the entire country.

With 1.2 billion people relying on the continued productivity of China's agricultural sector, the sustainability of Chinese agriculture is of central concern to the entire country and perhaps even the entire world. Furthermore, with declining rates of return on current agricultural technologies and growing problems with declining levels of soil fertility and increasing levels of topsoil erosion, this is not a concern for the future, but rather something that must be addressed today. Is a sustainable agricultural system possible in today's China? The means for creating a truly sustainable agricultural system are currently available in China; however, political and economic trends within the country make the widespread application of an ecologically sustainable system nearly impossible. The dismantling of agricultural communes reduced the availability of social security programs and at the same time increased pressure on the agricultural sector to show short-term economic gains comparable to other sectors. The government has shifted funds from the agriculture to rural industry and farmers are left with little choice, but to utilize practices that meet short term economic needs, even if it is at the expense of ecological sustainability. In short, sustainable agriculture, although increasingly necessary, is unattainable in the political and economic environment of China today. Furthermore, current economic and political trends make it unlikely that a truly sustainable system will be feasible in the near future.

The political and economic forces that are limiting the spread of sustainable agricultural practices are particularly evident in the case of Chinese Ecological Agriculture (CEA). CEA has been proposed by researchers and government officials as an alternative, sustainable agricultural system and has been implemented in around 3,000 communities throughout the country. Research in the are of CEA began over 20 years ago and has received support from a variety of national and local organizations such as the Ministry of Agriculture, the State Environmental Protection Agency, and the Chinese Ecosystem Research Network. In spite of a growing body of literature demonstrating the ecological sustainability of CEA and limited success in demonstration communities, CEA has not been widely accepted. In fact, the agricultural sector in China is moving in a direction quite opposite from that proposed by advocates of CEA. As I demonstrate in this paper, the characteristics of CEA that make it sustainable, such as localizing production, utilizing human labor, and applying organic fertilizers, are in direct competition with national economic development efforts. Consequently, in spite of the potential of CEA to increase the sustainability of China's agricultural sector, it can only do so by impacting China's current efforts to facilitate short-term economic development through increasing market liberalization. On the other hand, China's agricultural sector can only provide sufficient land, labor, and crops to meet China's short-term economic goals through the use of unsustainable agricultural practices.

The techniques implemented in CEA systems are not entirely revolutionary and are very similar to low-input or organic practices in other parts of the world. They involve practices that combine animal husbandry and crop production, utilize multiple cropping and intercropping regimes, and reduce the amount of synthetic chemicals used. The idea is to integrate past practices, such as organic fertilizers, and combine them with more modern technologies such as biogas tanks. The uniqueness of this management paradigm is not in the individual techniques involved; it is in the principles behind these systems. Utilizing the principles of holism, harmony, regeneration, and cycling, CEA is in many ways fundamentally different from the large, simple, production oriented systems characteristic of industrial agriculture.

So, despite the capability of CEA to increase the ecological sustainability of China's agricultural sector, why is it only being implemented on a very limited basis? The problem, I argue in this paper, is that the very practices that make CEA sustainable are in direct competition with the economic development that is being promoted throughout China. The continued emphasis by China on short-term economic development, both nationally and locally, has created economic, political, and environmental conditions that actively exclude CEA as an option available to farmers. Rural labor, a necessity of CEA, is being drawn away by rural industry. Sources of organic manure are limited due to the fragmentation of land holdings and the increasing specialization of rural production units. The dismantling of the social security system and the increasingly vulnerability of rural farmers to market forces has meant short-term production has taken precedence over long-term sustainability. At the same time, new technologies such as hybrid seeds and chemical fertilizers are introduced, which benefit agricultural businesses, but decrease the self-reliance of villages.

The problem, as I will demonstrate, lies not in the failure of individual farmers, practices, or technologies; rather the problem is a fundamental contradiction that exists in China's socialist market economy. As China continues to liberalize its market and promote industrial development in the pursuit of modernization, China promotes a system of positive feedback of consumptive production practices. CEA, as an alternative system of agricultural production, is unable to remain competitive with conventional agricultural practices due to the development pressures inherent in China's current political and economic system. Unfortunately, by excluding sustainable agricultural systems such as CEA, China not only perpetuates environmental degradation in the immediate future, but also undermines the natural resource base necessary for continued agricultural productivity.

There are a number of environmental problems that are related to conventional agricultural practices in China. The dusts storms, which plague northern China and have reached as far as North America, have been caused, in part, by farming practices (US Embassy Beijing, 2001). Water shortages are seriously threatening the agricultural sector, in particular in northern China (Nickum, 1998; World Bank, 1997). Soil salinization, acidification, and erosion have all been related to fertilizer management regimes (He, 1991; Muldavin, 1997). A nationwide decline in the use of organic fertilizers has contributed to a decline in soil organic matter (US Embassy Beijing, 1996b). Many of China's waterways are suffering from eutrophication caused by fertilizer runoff (He, 1991; Johnson, Liu, & Newfarmer, 1997). The ability of China's current agricultural system to meet demands in the long term is in serious question.

Implementation of CEA in demonstration communities has shown that CEA has the potential to solve many of the environmental problems related to conventional agricultural systems. Decreased reliance on synthetic inputs means that runoff is less of a problem. Increased use of organic fertilizer, and recycling of material within individual systems helps to maintain soil fertility and quality and decreases use of nonrenewable resources. At the same time, complex management schemes reduce the amount of water required for crops. Integration of forestry helps to reduce soil erosion while crop diversity decreases the intensity of pest infestations and provides greater biodiversity for the area.

The potential of CEA to fully replace conventional agriculture is by no means a simple thing to evaluate. As China continues to develop, the ability of China's agricultural sector, whether in its current form or another, will be under intense pressure to produce. The World Bank (1997) estimates that grain consumption will increase to 697 million tons by 2020; over 90% of which will be produced domestically. Furthermore, China's economic development is creating a growing demand for material goods and high value foods such as meats and processed foods. Unfortunately, these products are also increasingly resource intensive. In order to increase meat production, for instance, requires that either additional grain be grown or less grain be used for human consumption. Inevitably this leads to a net caloric loss as cattle metabolize the grain. CEA has the potential to increase the ecological sustainability of China's agricultural sector; however, its ability to meet the growing material demands of China's increasingly affluent population remains to be seen. Admittedly, given their relative popularity, conventional agricultural systems appear to be superior to CEA in meeting current demands for agricultural products. However, given the reliance of conventional agriculture on fossil fuels and the increasing environmental problems associated with conventional agriculture, it seems unlikely that this trend will continue very far into the future.

In this paper I address the potential of China's current political and economic environment to support a truly sustainable agricultural system. I explore how CEA is being used today as a sustainable agricultural system and discuss how CEA fits into current development trends. In the first section I will establish the material and energy basis for sustainability. After this I will discuss the system of environmental degradation that is part of conventional Chinese agricultural practices. Based on a literature review of CEA research, visits to CEA communities, and interviews with government officials and researchers, I then describe the theoretical basis of CEA and how CEA systems are constructed, with a particular emphasis on CEA systems in Zhejiang province. I discuss the potential of CEA as an alternative to conventional fossil fuel intensive agricultural practices and examine those characteristics of CEA that contribute to ecological sustainability and compare them to conventional Chinese systems. Then, I examine how the land, labor, and property regimes that are necessary for successful implementation of CEA are at odds with current economic development efforts. I show that while CEA does offer many ecological benefits, it does not contribute to economic development in the same way as conventional systems. Not only has economic liberalization in China created circumstances that are reproducing consumptive, unsustainable agricultural practices; this liberalization would be fundamentally threatened by the widespread application of CEA.

CEA is, of course, only one example of a potentially sustainable agricultural system and my purpose is not to offer it as the only alternative to conventional agriculture. Rather my argument is that the very factors that make CEA (or for that matter any other agricultural system) truly sustainable are not being incorporated into China's market and consequently not a part of China's current path of economic development. Market liberalization is increasing the short-term economic opportunities available to many people, but it is not incorporating the ecological costs of current development. This failure of China's market to account for the environmental consequences of development is reproducing conditions that undermine the ecological productivity of the agricultural sector. As long as the government continues to reproduce these conditions under the rationale of development, the implementation of truly sustainable agricultural systems is unlikely.

CHAPTER II

ENERGY AND AGRICULTURAL SUSTAINABILITY

Energy flow in agricultural systems

Fundamentally, agriculture is the process of applying energy to manipulate natural ecosystems for human needs. This energy may be applied through physical manipulation of the system (through sowing or weeding) or it may take place by altering the chemical environment of the system (through addition of fertilizers). Inevitably, it is the source of this energy that is at the heart of the sustainability of the system. Energy can come either from biological or animate sources such as human labor and animal manure, or mechanical or inanimate sources, such as tractors and manufactured chemicals. If a technology or practice threatens to either exhaust the energy necessary for agriculture or damages the agricultural ecosystem, then the long-term productivity of the system is threatened. Consequently, it is by understanding both how energy is applied into an agricultural system and what sort of energy is being used that I base my evaluation of ecological sustainability.

The use of energy and the laws of thermodynamics as the basis for an evaluation of ecological sustainability are not new. They have been applied in terms of material and energy (Meadows, Goldsmith, & Meadow, 1975) and through ecological economics (Daly, 1996; Daly & Townsend, 1993). They have been used as a means to evaluate productive efficiency

(Pimentel & Pimentel, 1996) and as a planning tool (Clayton & Radcliffe, 1996). Although a great amount can be learned from perspectives such as these, utilizing a material and energy perspective to define ecological limits is not without problems and may fail to address the fundamental causes behind environmental degradation (Davidson, 2000). Admittedly the application of such a basic physical concept as energy to complex issues such as environmental degradation is problematic and it is not my purpose to propose that the laws of thermodynamics can be simply extrapolated from physical to social systems. Nonetheless, energy offers a useful starting point for an evaluation of the sustainability of agricultural systems. Both the quality and quantity of energy used in agricultural systems relates directly to global sustainability in terms of nonrenewable fuel stocks, pollution sinks, and climate change.

Within ecology, energy has for the last few decades offered a useful means for understanding ecosystems (Odum, 1994; Odum & Odum, 1976). Here I use it as a means to compare the sustainability of CEA systems and conventional Chinese agricultural systems. Since CEA and conventional agricultural systems utilize energy from different sources, they also have different impacts on agricultural ecosystems. By understanding both the quality and quantity of energy used by different agricultural systems we gain an insight into how each system relates to surrounding ecosystems.

As living organisms, we human beings must constantly acquire biological material in order to sustain ourselves. Most importantly, we must take animal and plant material, digest that material, and release the chemical energy contained therein. Photosynthesis has, since the beginning of life, been the process by which plants and bacteria take simple elements and bind them together using energy from the sun. Inevitably, it is this solar energy that we release when we consume food. The ability of plants to incorporate solar energy is impacted by a variety of factors such as nutrient availability, pathogens, temperature, day length, and moisture. Through manipulation of factors such as nutrient availability and moisture we have learned to facilitate the growth of certain plants or even certain parts of the plant. However, the process of photosynthesis is still the sole property of plant material and inevitably it is plants that we depend upon as the source of all our food.

Agricultural practices, at their most basic, are an effort by human beings to alter a given ecosystem in order to increase the amount of food (i.e. energy) that is produced by that system in a form available to humans. For the most part this involves the management of an ecosystem so that it produces plant material easily digested by humans and containing nutrients necessary for human health. However, the production of fiber for clothing, materials for housing, plants for medicine, and other needs are also important goals of agriculture. Most of the time agricultural systems involve a simplification of natural ecosystems and a decrease in the net primary productivity of the system (Tivy, 1990). In other words, the total amount of solar energy converted into plant matter decreases; however, the amount of energy converted to plant matter useful to human beings increases. This is evident when one considers the large amount of biomass in an unmanaged forest compared to a field of corn.

Energy, of course, must be consumed in order to manipulate an ecosystem so that it produces plant matter that meets human needs. Energy must be used to maintain the system in a specialized state. For the most part, the maintenance of an agricultural ecosystem involves the conversion of chemical energy (i.e. food or fossil fuels) into mechanical energy (i.e. weeding or plowing). This can take place through a biological system, such as a human or water buffalo, or through a mechanical system, such as a tractor. How energy is applied toward agriculture is central to the issue of sustainability. Simply, if an agricultural system cannot be maintained in such a manner as to continue to produce plant material that can be conveniently utilized by human beings, it cannot be considered sustainable. Consequently, if the energy that is used for this management of the system cannot be sustained, than the system in its current state is clearly unsustainable. Furthermore, if the waste produced by the process of energy conversion undermines the biological processes that are necessary for agriculture, than the system is also not sustainable. Thus in order for an agricultural system to be considered sustainable, it must be able to 1) maintain sufficient quantities of energy for ecosystem manipulation and 2) provide energy from a source that does not significantly undermine the biological processes necessary for agriculture. In agricultural systems, these two factors are intimately related.

How energy is applied toward agricultural systems has changed greatly in China over the past twenty years. Although prior to the 1980s, Chinese agriculture was already using increasing amounts of manufactured inputs, this movement accelerated rapidly as a result of China's political and economic reforms of the early 1980s. The reasons for this shift are complex and involve various political and economic factors. China's open door policy made imported fertilizers and pesticides more readily available while government subsidies on agricultural inputs made them more affordable. At the same time new employment opportunities outside of agriculture began to draw labor away from the agricultural sector. As in many more developed countries, agricultural systems, which traditionally relied on human and animal labor, and organic inputs, began to be replaced by systems that were based on small tractors and synthetic chemicals. Although, this change in agricultural practices did contribute to rapid increases in agricultural productivity, these increases have not been without a cost. Not only has the quality of the environment decreased as result of this shift, but also the sustainability of these new agricultural inputs is in serious question.

The sustainability of mechanical and biological systems

In *The Unsettling of America*, Wendell Berry notes that energy for agriculture comes from either biological sources, primarily humans and animals, or mechanical sources, primarily combustion engines (Berry, 1996). Energy in one state must be converted to another state in order for any work to be accomplished. Once that energy is converted its utility, in the previous sense, is inevitably destroyed (that is its entropy increases). This takes place whether the energy is food consumed by a farmer or petroleum consumed by a tractor. Once the fuel from which that energy is derived is metabolized, it cannot be recovered and rather new fuel must be acquired. While a new technology may decrease the amount of energy wasted when fuel is metabolized, there is really only a net increase in efficiency if the production of the technology utilizes less energy than the technology currently being used. In a sense, biological and mechanical systems are extremely similar and many would argue that they could easily be substituted. This is also where we begin to see the qualitative differences in these two systems. These differences are fundamental to our understanding of sustainability.

One difference is in the 'fuel' that drives biological and mechanical systems. Mechanical systems are primarily driven by fossil fuels. Since fossil fuels were only created after several thousands of years of chemical and physical processes and will not be reproduced in a reasonable time frame, they are generally considered nonrenewable resources. Although the amount of chemical energy contained in fossil fuels makes them a rich source for mechanical energy, they will inevitably be exhausted. Furthermore, mechanical systems are largely throughput systems. That is, once fossil fuels are utilized within the system they come out as a resource that cannot easily be incorporated either back into the system or into other systems. In other words, fossil fuels produce waste. Although the specific impacts of global warming will likely be debated well into the future, it is well agreed on that our consumption of fossil fuels has affect climate change on a global scale.

The concept of a 'mechanical system' implies only the use of tractors, water pumps, or other machines in agriculture, and certainly these are the most convenient examples of mechanical systems. However, the most defining aspect of a mechanical system is the driving energy source and not simply how that energy manifests itself. In particular, a mechanical system can be defined as one that is driven, not by human or animal energy, but rather by fossil fuels. In this sense, I would include synthetic fertilizers and pesticides in the category of mechanical systems. The complex processes that are necessary for the production, transport and application of these chemicals rely strongly on fossil fuels. Nitrogen fertilizers, in particular, are created from natural gas and even phosphorus and potassium must be transported from mining sites to agricultural sites.

On the other hand, biological systems, with the exclusion of photosynthetic plants, utilize fuel from other biological systems. That is, except for biota that use energy from the sun, all biota must metabolize chemical energy contained in other plants or animals as energy sources. Consequently, the 'fuel' for biotic systems can be recreated in a reasonably short time frame. Needless to say, plants grow faster than fossil fuels are made. Furthermore, the waste produced by biological systems generally exists in forms that are usable by other biological systems. In this sense both the 'fuel' and 'wastes' of biological systems are multifunctional and do not simply accumulate in the atmosphere or geosphere as in the case of fossil fuel wastes. Thus rather than metabolizing fuel as a throughput, as in mechanical systems, biological systems metabolize fuel in cyclic manner. Plants can easily reincorporate waste materials into their biomass and, using energy from the sun, recreate 'fuel' for the system. In other words, waste from one system is incorporated into another system to create a complex set of linkages that maintain balance within the system. This is what is commonly referred to as the food web.

Increasing reliance on fossil fuels is itself an obvious problem. Not only are they nonrenewable resources, but also the burning of them is creating pollution at rates much faster than can be absorbed by the earth. Even if humanity does successfully identify alternative energy sources that are as portable and potent as fossil fuels, this will be of little consequence unless we are also able to identify ways in which to process the waste produced by these fuels. Increasing reliance on manufactured solutions is also problematic because of the unifuncitonal nature of manufactured technologies, which makes reuse and disposal a significant problem (Clayton & Radcliffe, 1996). For the most part, current technologies that claim to decrease waste do little to contribute to sustainability since even air scrubbers and wastewater treatment plants still require a large amount of energy to construct and maintain.

Even if we assume that technological developments will increase agricultural sustainability by increasing the efficiency of energy consumption, unless there is a decrease in reliance on nonrenewable resources, stocks will inevitably depleted. In fact, worldwide there is evidence that agriculture is not becoming more efficient and actually increasingly relying on nonrenewable resources. Worldwide agriculture dependence on fossil fuels is only continuing to increase. Between 1950 and 1985, the amount of energy used to produce one ton of grain has increased from 0.44 barrels of oil to 1.14 barrels of oil (Brown, 1988). Unfortunately, China is adopting the very same agricultural practices that were behind this rise in energy consumption. Since globally estimated ultimately recoverable oil production will peak sometime between 2007 and 2013 (MacKenzie, 1996), the increasing dependence of agriculture on oil should be of central concern to any discussion of sustainability. Fundamentally, a sustainable agricultural system must not simply decrease reliance on fossil fuels—it must decrease the need for energy inputs of any sort. The idea that pouring more and more energy into a system can facilitate sustainability is simply naïve. Rather a sustainable agricultural system should seek to create an internal balance that facilities both human and environmental needs.

Unfortunately, agriculture in China is changing in a manner that makes decreasing energy inputs increasingly problematic. China's population of 1.2 billion is relying on agricultural practices that are not only energy intensive, but also alter agricultural ecosystems in such a manner that require increasing dependence on fossil fuels. That is, conventional agriculture in China is not only relying on nonrenewable resources, but also it is recreating conditions that necessitate the increasing use of these resources. Consequently, even when more sustainable agricultural practices are available, their application is difficult or impossible due to the conditions created by conventional energy intensive practices. In other words, the agricultural sector is becoming increasingly 'addicted' to fossil fuel intensive agricultural practices. Thus when China began what appeared to be a beneficial movement towards 'modern' agricultural practices involving synthetic fertilizers and pesticides and agricultural machinery, the country in fact entered onto an increasingly destructive and invariably unsustainable cycle of production.

From mechanical systems to consumptive agriculture

Some argue that as energy shortages or environmental degradation is encountered, we will simply shift from unsustainable technologies and practices to those that are more sustainable. The problem is that our increasing reliance on mechanical systems for agricultural production is not taking place in isolation. The forces that are replacing labor with innovations like tractors, potent agrochemicals, and hybrid seeds are not simply changing agricultural practices—*they are fundamentally altering the structure of the entire agricultural sector.* These changes are creating conditions that necessitate the continued use of energy intensive inputs while actively excluding more environmentally benign agricultural activities. That is, agricultural development based on fossil fuels is one of increasing dependence. The longer that these technologies and practices are used, the more difficult it is to pursue alternative forms of production, even as environmental problems are encountered.

The problem with mechanical technologies and practices (i.e. fossil fuel based systems) is not simply that they rely primarily on a nonrenewable, polluting energy source (although certainly this is an important consideration). The problem is that they ecologically, socially, and economically recreate conditions of increasing consumption. Biological based ecosystems are generally regulated by systems of negative feedback. A negative feedback system operates like a thermostat. Once the temperature in the room gets too high, the air conditioner might turn on until the temperature returns to normal. In a natural system, once an insect population gets so high, predator populations may also increase and reduce the insect population.

Positive feedback systems, on the other hand, create conditions that reinforce the previous conditions. An excellent example of a positive feedback system in agricultural ecosystems is that of pests and pesticides. An application of pesticides to crops leads to the initial decline in pest populations. Then, as pests develop resistance to the pesticide, their populations return to original levels. The cycle continues and more and more pesticides are applied simply to keep pest populations at original levels. In other words, the application of pesticides recreates conditions that require the increasing use of pesticides. The trend has been noted both in developing countries such as India (Shiva, 1991) and in developed countries such as the United States (Norgaard, 1994). Already, there is evidence that pests in China are developing resistance to pesticides (US Embassy Beijing, 1996a).

Systems, such as pesticide based pest management regimes, are part of what I shall refer to as consumptive agriculture. Namely, consumptive agriculture is an agricultural system that, because of the logic inherent in the system, requires increasing levels of energy in order to maintain the system. As I will demonstrate in the next section, in the past 20 years the Chinese agricultural sector has begun to move rapidly in the direction of consumptive agriculture. Conventional agricultural systems in China are recreating conditions, ecologically, socially, and economically that require increasing amounts of energy in order to meet the demands made on the system. Smil (1990) has noted the rising energy costs of agriculture and there is little evidence that the energy demands of agriculture are decreasing. It is the perpetuation of such a system that both threatens the sustainability of Chinese agriculture and actively excludes the incorporation of more sustainable production systems.

Admittedly, the increased consumption of energy is not per se a threat to agricultural sustainability. In individual cases, increasing use of renewable, nonpolluting energy sources may compensate for increases in energy consumption. However, alternatives to fossil fuels are extremely costly to produce and in the case of biofuels, an equal amount of petroleum equivalent to the amount of biofuel produced is consumed in the production process (Barker & Chapman, 1990). Within China, less than 7% of power consumed comes from sources other than fossil fuels (National Bureau of Statistics, 1999). Consequently, it is safe to assume that the energy sources for agriculture will continue to come from fossil fuels well into the future.

CHAPTER III

SYSTEMS OF CONSUMPTION: TRENDS IN AGRICULTURAL PRACTICE IN CHINA

Agricultural practices in consumptive agriculture

China is an extremely diverse country in terms of agricultural practices, climate, geography, and society and it is difficult to make generalizations regarding trends in China's agricultural sector. Nonetheless, there is evidence that much of China's agricultural sector is developing in such a way that is reproducing conditions of increasing energy consumption. Green Revolution technologies such as fertilizers and pesticides are not only having significant impacts on the environment, but also altering agricultural ecosystems in such a way that increases dependence on synthetic inputs. Many scholars have noted environmental degradation related to over application of fertilizers and pesticides in the form of water eutrophication, decreases in soil pH, and soil salinization (He, 1991; Johnson et al., 1997; Muldavin, 1997; Smil, 1984, 1993). Few, however, have considered how over reliance on synthetic chemicals has created a cascading effect that requires increasingly energy intensive agricultural practices.

While synthetic fertilizers are an efficient means of applying high levels of macronutrients, farmers must incorporate a whole series of changes in cropping in order to take advantage of new fertilizers. Generally, crops that are adapted to a certain ecosystem have only a limited responsiveness to additional levels of fertilizer. They may simply be unable to uptake additional nutrients. High levels of fertilizer may simply contribute to accumulation of nutrients in useless parts of the plants, like the stem or leaves, when it is the grain that the farmer seeks to use. In some grains, additional fertilizer may even cause the overgrowth of grains that the plant's stalk is unable to support and lead to the collapse of the plant. This was one of the reasons that short stalk varieties of grain were such an essential part of the Green Revolution. Consequently, in order to take advantage of high levels of fertilizer input, many farmers are required to simplify their cropping patterns and utilize only those varieties of crops that respond to fertilizer. Although the importation of high yield varieties of cereal crops began in the 1960s and 1970s, it was not until the 1980s that they began to be used on a widespread basis. The area sown under semi-dwarf varieties of wheat increased from 2.956 million hectares in 1980 to 5.126 million hectares in 1984 (Stone, 1989). This spread of hybrid crops combined with increasing availability of synthetic fertilizers has contributed to the rapid increases in synthetic fertilizer that have taken place in the past two decades.

In addition to requiring high levels of fertilizer, hybrid crops also tend to require higher levels of water and therefore irrigation is an essential part of modern agriculture. Within many parts of China, water is already in extremely short supply (Nickum, 1998). One World Bank Report (1997) states that the limited availability of irrigation water is one major factor limiting agricultural productivity. Water that is currently available for irrigation is often polluted. In fact, agricultural irrigation is the largest consumer of polluted water and it is estimated that in 1993 use of polluted water for irrigation resulted in a loss of 1 million tons of grain production (Johnson et al., 1997). As conventional agricultural systems seek to continue to increase productivity, they will inevitably become a larger burden on China's limited water supply.

By decreasing the diversity of the agricultural ecosystem the crops become even more susceptible to pest complexes (Matson, 1997). Without different habitats for natural predators and a range of available food sources, it is relatively easy for pests to exist in high densities. In other words, simple, fertilizer intensive systems provide a high concentration of highly palatable food for pests. High nutrient inputs often have a significant, positive effect on pathogen and insect pest populations. Furthermore, many crops are selected for high productivity instead of pest resistance (Altieri, 1998). They consequently require increased application of pesticides in order to minimize the losses available. As pests develop resistance to pesticides, it is necessary to apply increasing amounts of pesticides merely to keep crop losses the same from year to year. Pesticides are already one of the major sources of water pollution in China (Johnson et al., 1997) and, clearly, any system that requires increasing use of these chemicals cannot be considered sustainable.

The increased application of synthetic fertilizers and the farming practices associated with it have a fundamental impact on the quality of the soil. In particular, this may lead to a decrease in the diversity of soil biota, which may profoundly alter the biological regulation of decomposition and nutrient availability (Matson, 1997). The changes in soil biota may be effectively masked in the short-run since high inputs allow the farmers to obtain high yields, even when soil quality is in decline (Luna & House, 1990). The decreasing diversity of soil biota may aggravate the need for synthetic fertilizers as the soil is stripped of its ability to provide nutrients through natural processes. A report by the US Embassy Beijing states that currently soil fertility is decreasing in China (US Embassy Beijing, 1996b). They attribute part of this decline to the shift from organic fertilizers to synthetic fertilizers.

The problems associated with the application of synthetic fertilizers do not end there. The fact that they are replacing organic fertilizers is itself an issue. Organic fertilizers not only provide nutrients to the soil, but also modify the soil structure. They may increase the water holding capacity of the soil and improve the soil structure. The application of organic fertilizers may also help to prevent erosion.

The use of synthetic fertilizers is just one of a series of closely related technologies which mutually reinforce each other. Hybrid seeds are only successful when planted in association with synthetic fertilizers and pesticides (Shiva, 1991). The use of pesticides leads to increased resistance in pests, which require additional applications of pesticides. Already there is evidence that pests in China are developing resistance to pesticides (US Embassy Beijing, 1996a). Declining soil quality due to decreased use of organic fertilizers leads to decreased water retention and increased nitrogen leaching, which requires additional applications of fertilizers and irrigation. Fertilizers must either be mined, as in the case of potassium and phosphorus fertilizers, or manufactured from natural gas, as in the case of nitrogen fertilizers. Pesticides are typically manufactured in fossil fuel intensive processes.

My point is simply that the practices and technologies related to synthetic fertilizers, agricultural machinery, and hybrid crops are not only energy intensive in themselves, but they also interdependent and in many cases reinforce the use of energy intensive practices. In other words, they create a system of positive feedback that reinforces their use. Some may argue that these are minor problems that can be overcome with technological advances. It is likely that new advances in biotechnology will help alleviate some of the problems related to pest complexes. At the same time, better fertilizers such as time-release fertilizers may be combined with better management practices to create more reasonable application schedules. It is true that new technological advances will help to mitigate or even solve some of the problems addressed above; however, in terms of sustainability, these technologies can only be considered more sustainable if they reduce energy consumption. Unfortunately, this is rarely the case and, I would argue, waiting optimistically for technological advances that may or may hold the answers to environmental problems is dangerous in a country where food production is barely able to keep up with demand. The biological limits to agricultural technologies are already being realized in many countries, and over reliance on undiscovered technologies are risky to say the least (Brown, 1997).

Trends in agricultural practices and technologies in China

The question I wish to address is to what extent China has entered onto this path of ecological change and increasing energy intensity. Aggregate data regarding agricultural technologies and practices may not reveal the specific nature of agricultural development in China. However, certain trends are evident in national statistics and there are some very clear indicators that China is moving in a direction of increasingly unsustainable agricultural production very similar to that described above. Other authors have noted the increasing energy intensity of Chinese agriculture (Smil, 1990). This increasing energy intensity is contributing to nonrenewable resource depletion and environmental degradation such as water and air pollution, and declining soil fertility levels. Certainly China has had its share of environmental problems even prior to economic reform (Elvin, 1998). However, the scope and type of environmental change is much different today. Climate change is taking place on a global scale and entire species are being driven to extinction due to human alterations of the environment. The demands that China's growing population is placing on a decreasingly viable agricultural base are largely unprecedented. Two trends are evident in rural China today. First of all, sustainable agricultural practices such as organic fertilizer are gradually being replaced by fossil fuel driven agricultural technologies. Secondly, these agricultural practices are contributing directly and indirectly to environmental degradation of a sort that threatens the continued productivity of the agricultural sector.

Even prior to the economic and agricultural reforms of the early 1980s China was already beginning to utilize Green Revolution technologies such as synthetic fertilizers and pesticides; however, it was the economic and agricultural reforms of the early 1980s that provided the stimulus for their rapid expansion. In 1984 the Household Responsibility System (HRS) effectively dismantled China's agricultural communes and leased plots of land to individual households. Although quotas for products such as grain and cotton remained in place, farmers were allowed to sell excess crops on the open market and thus had new economic incentives to increase production. At the same time, government subsidies allowed for the cheap purchase of agricultural inputs such as chemical fertilizers and pesticides. The new freedoms created by the decentralization of decision making regarding crops allowed farmers to plant crops suited to local conditions rather than simply striving to meet provincial grain quotas. The way agriculture was practiced in China began to change rapidly.

Chinese agricultural policy has also changed greatly. In addition to the institution of the HRS, there has been a tendency to shift control of the agricultural sector away from the central government and onto the market. Most agricultural products operate on essentially a free market with grains being the only major exception. The government still heavily controls cereal crops. Part of this control was motivated by rising grain prices in the early 1990s which led to reassertion of central government control in 1994. Subsequent reforms in the control of cereal crops have been relatively modest and focused on decentralization of controls. The World Bank states that the major objectives of China's grain policy are: to maintain 95% grain self-sufficiency, to increase control of production, pricing, and marketing, and to continue control of stocks and international trade (1997, p. 22). In 1995, the central government enacted the Governor Responsibility System, which delegated responsibility of balancing provincial grain supply and demand to individual provinces. Although this replaced national policy with a multitude of provincial policies, the content of the policy changed little (World Bank, 1997).

China's goal of grain self-sufficiency has been problematic since grain quotas often fail to account for difference in soil and climate among regions. Furthermore, allocation of such vast quantities of grain in a country as diverse as China cannot easily be planned and coordinated. Reducing government control of grain would likely contribute to more efficient allocation of resources (World Bank, 1997). Allowing the market to allocate agricultural products has contributed to overall increases in agricultural production in the past (Kalirajan, Obwona, & Zhao, 1996). It would, consequently, seem reasonable to have similar expectations of grain crops. On the other hand, agricultural productivity is not an indicator of ecological sustainability and some scholars have questioned the environmental price that was paid for these increases in productivity (Muldavin, 1996; Rozelle, Veeck, & Huang, 1997).

China's self-sufficiency policy will have to be addressed in the future; however, it is important to keep in mind that the issue of agricultural sustainability is not so much one of increasing productivity as it is creating a system of production that can be maintained.

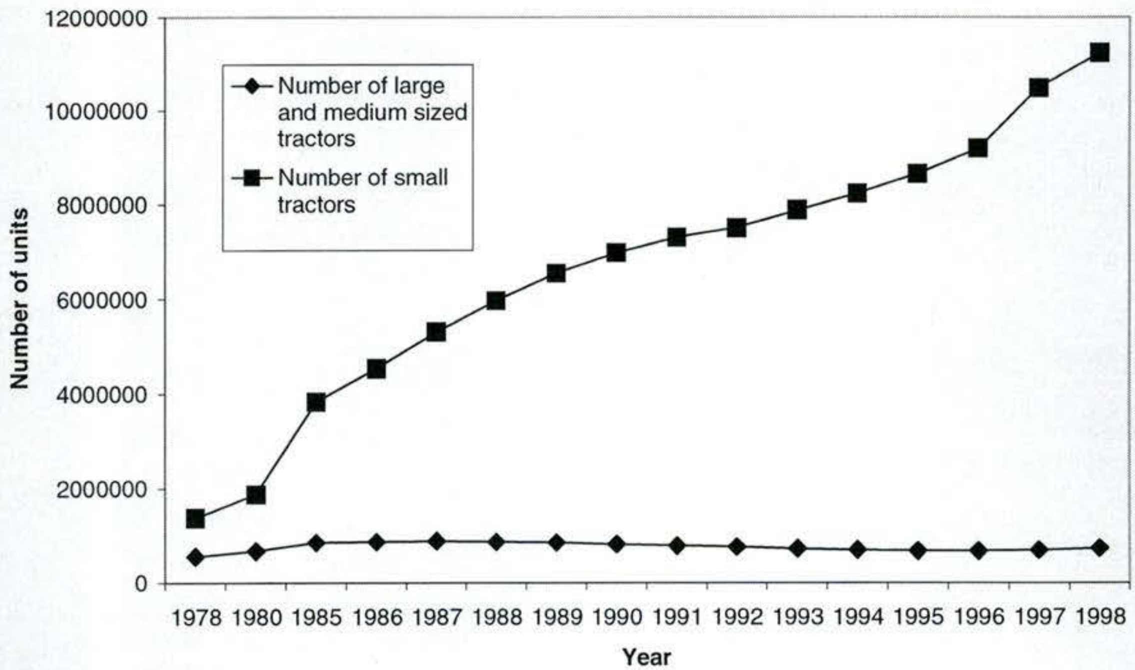

Figure 1. Number of tractors in China from 1978-1998
Note. The data are from National Bureau of Statistics, 1999

Since reforms the use of machine and chemicals in agriculture has increased rapidly. While the dismantling of the communes meant that the use of large and medium sized agricultural machines was largely impractical, small scale tractors were still of use to individual households. Consequently, while the use of large and medium sized tractors changed relatively little in the past two decades, there has been a very definite increase in the use of small tractors (see Figure 1). In fact, the number of small tractors increased by over 800% from 1978 and 1998. Most of these tractors are small, hand-held tractors, driven by one-cylinder diesel engines. They have a flexible belt-driven mechanical power train, which also allows the engine to be used for a variety of purposes such as to power farm machinery, pumps, and electrical generators (US Embassy Beijing, 1996b).

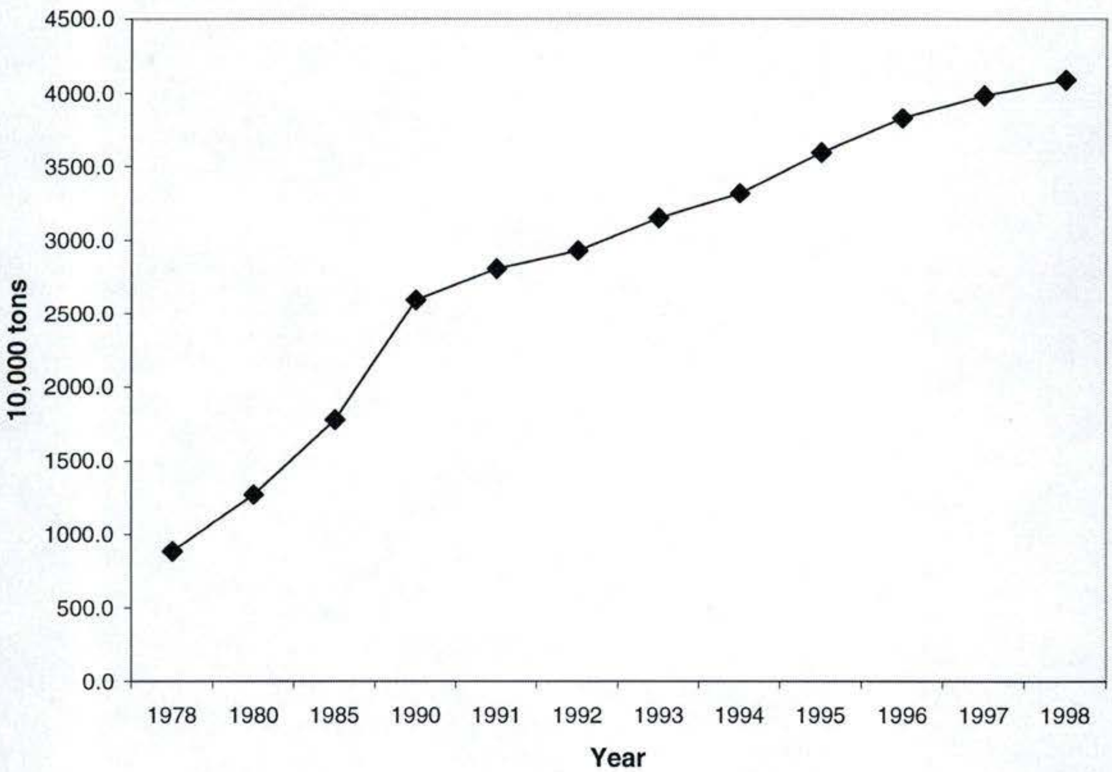

Figure 2. Consumption of chemical fertilizers in China from 1978-1998
Note. The data are from National Bureau of Statistics, 1999

Although a variety of factors influence the relative energy efficiency of agricultural systems utilizing mechanical systems, there is evidence that due to the energy required for animal based systems actually produce more food per energy input than machine based systems (Pimentel, 1984). Consequently, while tractors may allow farmers to increase their output per hour of human labor, the efficiency of the agricultural system is actually lessened. In other studies relating to China, large farms were found to be generally less productive than small farms and not suited to China's situation of high labor and low land availability (Prosterman, Hanstead, & Ping, 1998). Furthermore, the increased use of machinery in China requires increasing consumption of fossil fuels, which are negatively impacting air quality nationally and globally.

The use of chemical fertilizers has also increased rapidly during this same period. The amount of chemical fertilizers used in China increased almost fivefold from 8,840,000 tons to 40,856,000 (see Figure 2). Nitrogen fertilizer is manufactured by combining dinitrogen gas from the atmosphere with hydrogen, usually from methane in natural gas, at high temperate and pressure to produce ammonia. As yet, there is no shortage of atmospheric dinitrogen; however, it is estimated that the energy consumed in production of fertilizer nitrogen is 18,000 kilocalories per kilogram of nitrogen (King, 1990). This means that in 1998 the energy used to produce the 22,344,000 tons of nitrogen fertilizer consumed in China was approximately twice that of the energy used for electricity in all of rural China during the same year (National Bureau of Statistics, 1999). This is the amount of energy used only for production and does not include the energy necessary for the packaging, transport, and application of these fertilizers. Nor does it include the energy required for phosphorus, potassium, or compound fertilizers. Already some of China's fertilizer plants have encountered problems with declining reserves of natural gas and oil (Wong, 1986).

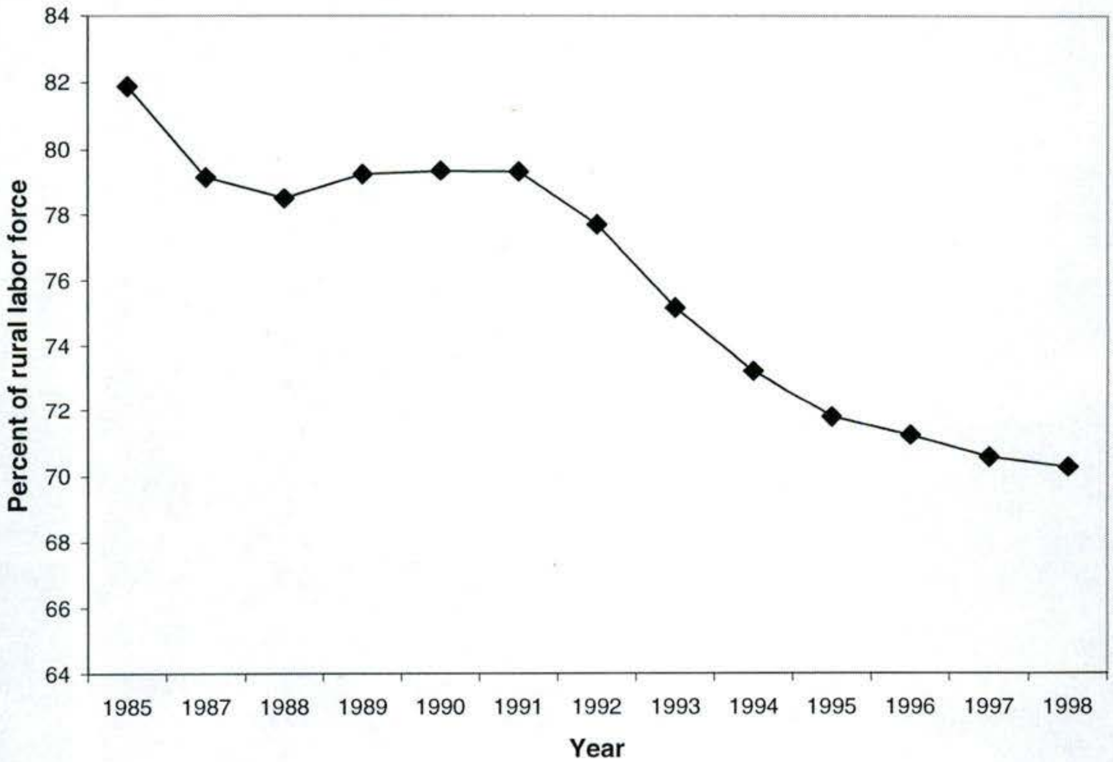

Figure 3. Percentage of rural labor force in agricultural sectors from 1985-1998
Note. The data are from National Bureau of Statistics, 1999

There is some evidence that the increased use of small tractors and agricultural chemicals is facilitating a decline in the proportion of the labor force working in the agricultural sector. Within rural areas, the percentage of people engaged in agriculture has declined from over 80% in 1978 to 70% in 1998 (see Figure 3). At the same time, a general decline in total rural populations is also evident (see Figure 4). Some researchers have identified the relative profitability of sideline activities outside of agriculture as one of the major factors contributing to declines in labor involved in agriculture (Carter, Zhong, & Ts*ai, 1996; Putterman, 1993). With new opportunities in sideline industries, many farmers are dedicating part of their household labor outside of agriculture without changing their primary occupation.

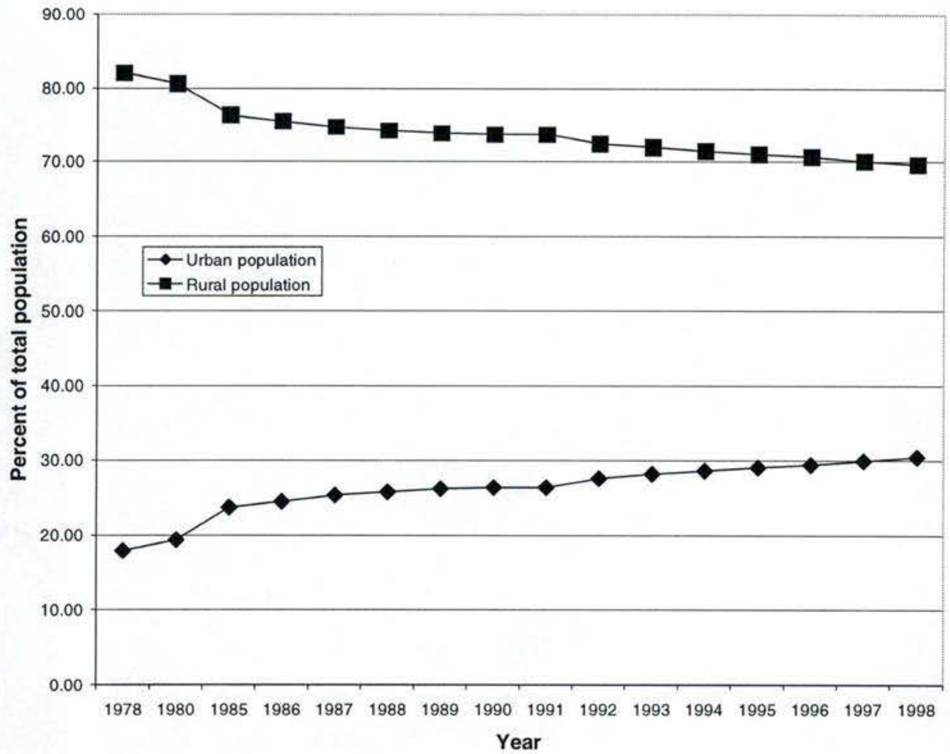

Figure 4. Proportion of rural and urban populations from 1978-1998
Note. The data are from National Bureau of Statistics, 1999

The decline in agricultural labor has affected agricultural practice and particularly contributed to the use of chemical fertilizers. It is often women or elderly individuals who are responsible for agriculture when men allocate their labor towards sideline activities. This may impact the ability of some households to effectively utilize organic fertilizer (Kung & Cai, 2000). In some cases, researchers have noted that farmers avoid the use of organic fertilizers, such as animal manure, simply because synthetic fertilizers are more convenient and easy to use while the application of organic fertilizers is relatively unpleasant (Chen, 1997). Nationally, there has been a decline in the use of organic fertilizers (Wang, Halbrendt, & Johnson, 1996).

Admittedly, the movement of labor to sideline activities has facilitated economic prosperity in many parts of China. Furthermore, the use of new agricultural technologies has contributed to increases in productivity in the past two decades (Kalirajan et al., 1996). However, the environmental degradation that has also taken place during this period is beginning to overcome these initial benefits. The ecological changes that are associated with synthetic fertilizers and agricultural machinery are beginning to threaten the natural resource base on which agriculture relies. Thus we find, that the technologies that are replacing biological energy sources are creating conditions of environmental degradation and increasing dependence on energy intensive practices.

The positive impact of productive inputs during the second half of the 1970s and throughout the 1980s was offset by the effects environmental degradation (Rozelle et al., 1997). In fact, as much as 5.7 million metric tons of grain has been lost to environmental degradation—this was nearly a third of China's yearly grain imports in the early 1990s. It is important to note that the impacts of environmental degradation are usually seen in yield reductions and not simply losses of arable land.

Many of these environmental issues are interrelated and self-replicating, which only worsens the scope of the problem. Topsoil is being lost to erosion at the rate of 5 billion tons per year (He, 1991). Some of this soil erosion is due to unsustainable agricultural practices encouraged by economic reforms (Muldavin, 1997). Since the 1980s increased grazing pressure and deforestation have reduced natural windbreaks and erosion controls. Not only does this impact the fertility of agricultural land, but also it has led to additional problems with water resources. Siltation is a major problem in many areas and has contributed to increased flooding along the Yellow River (He, 1991). Although periodic flooding is a necessary and sometimes useful natural process, the intensity of floods is a direct consequence of anthropomorphic influences.

The overuse of fertilizers has led to eutrophication of waterways in many areas (He, 1991; Smil, 1993). Pesticides and chemical fertilizers are one of the major sources of water pollution in China (Johnson et al., 1997). In some areas, the over application of fertilizers is contributing to the acidification of agricultural soils (Muldavin, 1996). The US Embassy reports that the contamination of waterways by fertilizer is continuing to increase (US Embassy Beijing, 1996b). It is easy to blame the farmers for these farming practices. However, it is not simply a matter of lack of education or unwillingness to use organic fertilizers. In many cases farmers are more than willing to use organic fertilizers and it is only a lack of sources for organic fertilizers that forces the use of synthetics (Kung & Cai, 2000). Farmers are, for the most part, simply making the most out of the opportunities provided in the current political and economic system. As long as labor can more profitably dedicated elsewhere and resources for sustainable agricultural practices are limited, it is inevitable that land managers will utilize agricultural practices that coincide with these conditions.

There is evidence that pests, such as the bollworm, are developing resistance to pesticides (US Embassy Beijing, 1996a). At the same time, the Ministry of Agriculture estimates that pesticides and fertilizers poisoned more than 100,000 people during 1992 and

1993. 14,000 of these people died (Smith, 1997). It is convenient to blame the farmers for their mismanagement of agricultural chemicals, and certainly increasing education regarding the management of agricultural chemicals would reduce some of the problems associated with them. However, even efforts to change the management of chemicals will not entirely eliminate problems associated with their production and use.

Water quality and quantity are also a growing problem as a result of current agricultural practices. The use of chemical fertilizers and hybrid crops requires additional water and consequently irrigation facilities must be expanded. The overuse of groundwater from aquifers in northern China has led to seawater intrusion and a decline in water quality (Nickum, 1998). Urban areas and industry are also competing for use of China's shrinking aquifers while at the same time contributing to water pollution.

This lack of water sources for irrigation has been compounded by deterioration in the structure of irrigation systems that have taken place since reforms. The decentralization of power limited the ability of the government to coordinate the labor necessary for many conservation projects, including irrigation systems (Muldavin, 1997). Since peasants have little personal economic incentive to contribute to large projects such as irrigation, necessary maintenance has not taken place. Thus we find that structural failures are the largest contributor to declines in irrigated areas (Nickum, 1998). The deterioration in the infrastructure of water conservation systems is one of the major factors limiting the technical efficiency of farmers (Kalirajan et al., 1996). Furthermore, irrigation water is often heavily polluted and in 1993 this contributed to an estimated 1 million tons in lost grain production (Johnson et al., 1997).

The pursuit of short-term economic profits through rural industrialization is also increasing competition for limited land. Within China, almost 2 million hectares of arable land were lost to state and communal construction projects from 1985 to 1996 (Ash & Louis, 1998). Even more critically, this trend increased during that same period. Farmland lost in this way is nearly irreversible due to the impacts of capital construction. In many areas, such as Zhejiang and Jiangsu province, the most agriculturally productive lands are adjacent to urban areas and the only way to perpetuate industrial growth is by paving over good farmland. China has made efforts to reclaim land in other areas; however, this land may be of relatively low quality (Ash & Louis, 1998).

The list of environmental problems goes on—salinization, deforestation, decreases in biodiversity, and dust storms. Although not all are a direct consequence of consumptive agricultural practices, they are all having serious impacts on the natural resource base of agriculture. They are also intimately related to the ecological changes that are related to the system of increasing consumption in agricultural. That is, not only are the ecological changes associated with consumptive agriculture reinforcing the need for unsustainable agricultural practices, but also they are contributing to a decline in environmental quality.

The ecological costs and benefits of agriculture

It is easy to be discouraged by the current state of Chinese agriculture. In spite of lip service by the government supporting sustainable agriculture, little has actually been done to address the economic conditions that have facilitated the spread of conventional agricultural systems. Invariably, the ecological unsustainability of modern Chinese agriculture is not a matter of simple technological failure, but rather it is a question of the social and political forces that have perpetuated modern consumptive agriculture. Price controls on natural gas have helped to keep domestic fertilizer prices artificially low, which have facilitated the excessive usage of agrochemicals. The spread of the market economy has tied the revenue of many local governments to industry (Wong, 1992). Thus local governments have little incentive to support agriculture, while rural industry is heavily promoted. The relative profitability of rural industry has provided even less incentive for farmers to make long-term investments in their land. The integration of many agricultural products into the market may have freed farmers from the inefficient allocation schedule of the central government, but it has put them under new pressure from the market. Unless these market forces are changed in such a manner as to make systems such as CEA viable, China's environment is likely to suffer well into the future.

Fundamentally, the forces that are driving unsustainable practices and environmental degradation are social and political. China's agricultural policies have demonstrated an urban bias and are often short sighted (World Bank, 1997). As China's market economy has developed, there has been a clear bias toward industry and urban areas and this has had a major effect on how farmers and other land managers utilize resources. Although China is rapidly developing a set of comprehensive environmental laws and controls, most of these target industry and involve end-of-pipe regulation. The bulk of Chinese agricultural policy focuses on maintaining food security through grain self-sufficiency and price controls on grain. At the same time, other agricultural products are left open to markets where there is little consensus between the prices of agricultural products and the ecological costs of agricultural practices. It is this failure of China to develop policies that properly prices the ecological costs and benefits of agricultural practices that has facilitated the expansion of chemical and machine agriculture. After all, when farmers profit only from the sale of a product, regardless of how it was produced, and more profits can be made outside of agriculture, there is little wonder why agriculture is developing along its current path.

Undeniably the decentralization of power in the agricultural sector, as exemplified by policies such as the Governor Responsibility System, has helped China's rapid economic development in some sectors. Unfortunately, this has also had the consequence of leaving government agencies at all levels starved for revenue and largely reliant on industry for income (Wong, 1992). The environmental consequences of consumptive agriculture and rural industry, such as water and air pollution, take place at levels different from where the economic benefits are felt. That is, while local governments benefit from local industrialization, there is no system that makes them accountable for the environmental consequences of supporting industry. It is not the decentralization of decision-making regarding natural resource use that is the problem. Rather it is the failure of the central government to, at the same time, make the long-term ecological consequences of management practices felt at the same level.

Can a truly sustainable agricultural system be implemented in China? I offer this not as hypothetical question regarding what sorts of different agricultural systems can be developed in the future. Rather I wish to examine what options are currently available within China that can, in a very immediate sense, help to increase ecological sustainability and alleviate some of the environmental problems that are impacting rural China. One system that has been proposed as a solution to the dilemma of sustainability is that of Chinese Ecological Agriculture (*zhongguo shengtai nongye*).

In the next section, I discuss the case of Chinese Ecological Agriculture (CEA) as an alternative form of agriculture available within China. CEA refers to a variety of related agricultural systems which, based on principles of ecology and a holistic approach to production, have been developed as a means to increase agricultural sustainability in China. For over 20 years CEA based systems have been researched and promoted by scientists and government officials as a sustainable alternative to modern agricultural systems.

Although theoretically CEA offers a sound methodology for increasing ecological sustainability and in practice may facilitate environmental protection, CEA has not been implemented outside a limited number of demonstration communities. An examination of both the characteristics of CEA that contribute toward its sustainability and the factors that are limiting the spread of CEA, highlight the fundamental contradictions of China's current path of economic development. While economic reforms have created many new opportunities for development, it has also priced long-term ecological sustainability well below short-term economic profit. We find that within rural China many of the forces that are perpetuating China's current economic development are also creating conditions that make the creation of a truly sustainable agricultural system problematic.

CHAPTER IV

CHINESE ECOLOGICAL AGRICULTURE

Chinese ecological agriculture (CEA), *zhongguo shengtai nongye*, was developed in China, largely under the influence of Ma Shijun, who conducted a large amount of research in the area in the 1980s. Since then CEA has been promoted as an environmentally sustainable system of rural development. In the past two decades it has received attention by both government officials and researchers as a means to facilitate rural development without compromising environmental quality. CEA does not involve a specific set of practices or methodology and is rather a diffuse set of ideas and principles that are being applied in a variety of ways. Consequently, specific definitions of CEA are often somewhat vague and confusing. Wang (1999) states that "CEA is an agricultural technological system, which is constructed by organizing rational agricultural structure according to local resources, and assembling the suitable component technology packages, in the light of the principles of ecology and economics, to achieve the overall economic, ecological and social benefits of the whole system" (p. 7). Sanders (2000) quotes the Chinese National Environmental Protection Agency, which states that CEA is:

> [A] comprehensive agricultural production system of intensive management with multiple layers and with multiple structures and functions. It was established on the basis of summing up successful experiences of various agricultural practices applying ecological and technological methods. In a word, eco-farming is a comprehensive agricultural production system which is managed intensively according to the principles of ecology and eco-economics. (p. 20)

A review of the theoretical principles behind CEA provides some further understanding of what CEA is, although a concrete definition is still elusive. Li and Min (1999b) present the most concise description of the principals behind CEA—holism, harmony, regeneration and cycling. CEA is holistic because it is a form of meta-farming that involves management of multiple systems, from crops and animal husbandry to forestry and aquaculture. Harmony refers to balancing human needs with environmental quality and regeneration and cycling refer to the tendency within CEA to maintain material and energy within the system. Cheng, Han, and Taylor (1992) provide a more extensive list of the conceptual underpinnings of CEA. They list five components: the holistic approach to natural resource use, the multidimensional use of space and time, the internal recycling of resources, environmental management, and exploitation of agricultural and nonagricultural options. Wang and Yan (1998) identify eight principals: exploitation and adaptation, competition and symbiosis, interlocking positive and negative feedback, proliferation and self-competition, circulation between wastes and products, diversity and dominance, structural growth and functional development, and extreme risk avoidance and opportunity.

CEA has been primarily promoted at the national level through the Ministry of Agriculture, the State Environmental Protection Agency, and five other state level organizations. In 1993, a total of fifty-one counties throughout the country were established as state level demonstration communities for CEA (see Table 1). These state-level demonstration communities are located in 34 provinces. It is estimated that by the early 1990s 3% of China's land area was being managed using CEA techniques (Ma, 1995). The central government hopes to have the number of demonstration counties expanded to 200 by the year 2000 and

1000 by 2020 (Li & Min, 1999a).

Table 1. Provinces and cities with state level CEA demonstration communities

Provinces and cities with CEA counties	State level CEA demonstration communities
Bejing	Daxing, Miyun
Tianjin	Baodi
Shanghai	Chongming
Hebei	Qianan, Guyuan
Shanxi	Hequ, Wenxi, Zhongyang
Inner Mongolia	Wengnuiteqi, Helingeer, Kelaqinqi
Liaoning	Dawa, Changtu
Jilin	Fuyu, Sub. Jilin, Dehui
Heilongjiang	Baiquan, Mulan
Shandong	Linzi, Wuhan, Linqu
Anhui	Shexian, Quanjiao
Jiangsu	Jiangdu, Dafeng
Zhejiang	Deqing
Jiangxi	Wuyuan
Fujian	Dongshan
Guangdong	Dongguan, Chaoan
Guangxi	Wuming, Dahua
Hunan	Cili, Changsha
Hubei	Jingshan, Honghu, Yicheng
Henan	Lankao
Shaanxi	Yanan
Gansu	Jingchuan
Ningxia	Guyuan
Sichuan	Meishan, Hongya, Dazu
Yunnan	Simao, Lufeng
Guizhou	Sinan
Xinjiang	Shawan
Hainan	Wenchang
Qinghai	Huangyuan

The construction of CEA systems has not been limited to state-level ecological counties. In 1986 the State Science and Technology Commission, the State Planning Commission, and other government organizations began to examine the possibility of establishing a "sustainable community". By 1996, 26 of these communities were established throughout China. CEA systems have been included in these projects. Furthermore, at the CEA projects have been initiated at provincial, county, and township levels. During 1994 the government established 100 demonstration areas, 100 provincial level pilot counties, and more than 2000 pilot townships and villages.

Although the central government has provided some funds for the construction of ecological communities, these have been fairly limited. For the most part the resources that are used for CEA system construction have come directly from the communities where the projects are implemented. It is expected, however, that the funds provided by the central government will increase with the expansion of the number of demonstration communities.

CEA has been included in several documents from the central government relating to environmental protection and sustainable development. CEA was formally listed in the nation's Eighth Five Year Plan in 1991. In 1992 CEA became one of 10 "Strategies on Environment and Development" addressed by the central government in response to the 1992 United Nations Conference on the Environment and Development. CEA is also part of the Priority Program for China's Agenda 21. Several research institutes such as the Chinese Ecosystem Research Network, the Red Soil Ecological Research Station, the Agroecology Institute, and various others have initiated research into CEA and it is currently estimated that there are approximately 3,000 demonstration CEA sites throughout China. Although many government agencies continue to mention CEA specifically in publications and research in the field is taking place throughout the country, the use of CEA is still extremely limited compared to conventional agricultural practices. Although the central government has demonstrated a strong commitment to CEA, the use of CEA outside of government-sponsored communities is extremely limited.

In different literature, research in this area is referred to as ecological agriculture (Luo & Han, 1990), ecological engineering (Hu & Wang, 1998; Wang, Yan, & Mitsch, 1998), sustainable agriculture (Cheng, Han, & Taylor, 1992; Guo, 1999), and integrated farming systems (Li & Min, 1999b). Despite these different names and terminology, research in these areas is relatively the same. I chose to use the term CEA due to its relative abundance and because it lacks the Western connotations of some of the other terms. CEA, as I will demonstrate, is something uniquely Chinese.

Although CEA as a particular system of agriculture is relatively new, many of the practices used in CEA systems have roots in China's rich history of organic agriculture. F.H. King (1911) provides an excellent account of Chinese agricultural practices prior to modernization. He notes the intense use of land that is sustained through careful management and material cycling. He states:

> Almost every foot of land is made to contribute material for food, fuel, or fabric. Everything, which can be made edible, serves as food for man or domestic animals. Whatever cannot be eaten or worn is used for fuel. The wastes of the body, of fuel and of fabric worn beyond other use are taken back to the field; before doing so they are housed against waste from weather, compounded with intelligence and forethought and patiently labored with through one, three or even six months to bring them into the most efficient form to serve as manure for the soil or as feed for the crop. (King, 1911, p. 13)

Other researchers have noted the success of past Chinese agricultural practices to sustain productivity (Ellis & Wang, 1997; Wen & Pimentel, 1986). Certainly even prior to industrialization China has had its share of environmental problems caused by mismanagement (Elvin, 1998). However, the body of knowledge accumulated by Chinese farmers is still an important base for the development of sustainable systems.

This is not, of course, to understate the importance of modern practices on CEA systems. CEA is not simply a return to a traditional agriculture. Cheng et al. (1992) state that fundamental to the conceptual design of ecological agriculture in China is crossing recently introduced conventional innovation and modern technologies from the West with traditional organic practices followed for centuries in China. This is notable, as CEA does not shun the use of chemicals, machines, or other modern inputs (although the use of such inputs is generally limited). The idea is to tap the merits of past and present practices without compromising the sustainability of the system.

Although the characteristics of particular CEA systems vary depending on regional conditions, certain general trends are apparent. First of all CEA is not strictly limited to crop production systems. In contrast to industrial style agricultural systems, CEA manages farms as complex biological and socioeconomic entities. This leads to an emphasis on studying relationships between different aspects of a system rather than simply quantifying the production of a single part of that system. Certain agricultural productivity goals are, of course, necessary to meet socioeconomic goals; however, they are not pursued at the expense of another part of the system, such as the water quality. At the same time, it is acknowledged that humans, as a dominating force in the system must be considered. Thus we see an emphasis on keeping the different parts of the farm balanced. This leads naturally into another important CEA principle, the cycling of materials and energy within the system. As I will demonstrate in more detail later, wastes from one system of production are often used as inputs for another.

CEA systems can operate at a variety of spatial scales. Farmers take advantage of small spatial variations that may help productivity. Such is the case in the dike-pond system where different crops are planted at different levels along a dike. In this way CEA systems take advantage of small variations in temperature, moisture, slope, and soil quality. Otherwise unproductive areas are used in a manner that not only increases the productivity of the system, but also helps alleviate environmental problems such as soil erosion. The principles of CEA may also be applied at a much larger scale. Cixi City, Zhejiang province has a population of 1 million and has created specialized production systems for each of four ecosystems within the city's 1567.5 square kilometers. CEA systems are then developed that are appropriate to the physical characteristics of each region.

CEA systems also take advantage of temporal variations in crop growing seasons in order to sustain production throughout the year. Multiple cropping systems may be extremely complex. Within Wusi village, Zhejiang Province, a three-year rotating cropping system is used. Barley, rice, green manure, and rapeseed are planted in various combinations in three different plots. Multiple cropping systems in Cixi City involve soybeans, watermelon, bok choy, and medicinal herbs. In this system, watermelon is planted between soybean rows and then harvested after the soybeans. This allows for sustained yield without compromising soil quality.

In many ways CEA is very similar to Western ideas of organic farming or sustainable agriculture. However, it is important to note some significant differences in how CEA systems are researched and implemented. Most notably, CEA systems do not avoid the use of chemicals or other synthetic inputs. Furthermore, CEA systems utilize traditionally non-agricultural practices to meets goals. That is, instead of focusing only on creating income and using materials from agricultural activities, a CEA system may incorporate forest systems, biogas tanks, animal systems, and even industrial systems (Li & Min, 1999b; Wang et al., 1998; Wu, Xu, & Wu, 1989). Rather than attempting to specialize in one particular product or crop, CEA systems increase diversity. Although quantification of these systems does take place (Dalsgaard, Lightfoot, & Christiansen, 1995; Gong & Lin, 2000), there tends to be greater emphasis on identifying and maintaining relationships (Wang et al., 1998).

Examples of CEA systems

For the most part CEA systems are constructed with the goal of raising the income of farmers within a given region. Although coordination of CEA systems generally takes place at village levels or higher, the production systems themselves may only take up a portion of a village or township. A CEA system may be bounded based on physical limitations, such as in the Yangwenwu watershed. Other systems may simply be a conglomeration of several farms as in one Deqing county system. For the most part, however, CEA systems are extremely flexible and can be constructed at spatial scales from individual households to entire counties.

The agricultural products produced by CEA systems are as diverse as the systems themselves and include bamboo, grain, vegetables, fruit, nuts, pork, fish, turtles, biogas, and pearls. Materials from the system, such as biogas and some vegetables, are used within the CEA system itself. Some of the products such as vegetables are sold in local markets while high value products such as meat and pearls may be exported to nearby urban areas. In some cases products are processed in township village enterprises and then exported to other countries.

A well-constructed CEA system is more than simply a set of "sustainable" practices. Nonetheless, some practices are more conducive to integrated systems than others. Some common practices involved in CEA systems are:

- Intercropping and multiple cropping
- Organic fertilizers
- Water-saving cultivation techniques
- Cultivating duckweed and/or fish in paddy rice fields
- Agroforestry
- Using biogas tanks or animals to dispose of crop residue

This is by no means a complete list of practices involved in CEA systems. In most cases a combination of the above practices is involved in a system. I merely offer them as tangible examples of practices used in CEA. Environmental, social, and economic variability among different regions has a great impact on how a system will be managed. Even changes over time may strongly impact the management practices in a system (Lo, 1996).

<u>Dike-pond systems</u>

This system is one of the best-documented systems currently being used in China. Traditionally systems of this sort have been utilized in the Zhujiang Delta due to the ecological suitability of the area. The dike-pond system integrates agriculture and aquaculture into one system and is especially suited for flood prone areas. Ponds are dug and the earth used to construct raised dikes on the lowland areas surrounding the pond. Fish are then raised in the pond while crops are grown on the dikes. The ponds can vary in size, but are often less than 500 square meters. Within Zhejiang province, systems such as these have been created for several families by digging several ponds in a 'patchwork' pattern.

Lo (1996) provides a description of the history of dike-ponds in the Zhujiang delta. The nutrient cycling between the fish and the crops plays an important role in maintaining the fertility of the system. The rich organic matter that collects at the bottom of the pond is extremely nutrient rich and makes an excellent fertilizer. Fish droppings continuously refresh the nutrients in the pond sediment. The fish, in turn, are fed with crop residues from other parts of the system. The linkages become even more complicated as farmers take advantage of the different microclimates on the dike. The surface of the dike adjacent to the water is used to raise water tolerant crops and ducks. At higher levels perennial crops are grown.

In the past, mulberry trees were grown on the dikes and the leaves from the trees used to feed silkworms. The waste from the worms was then returned to the ponds. The system, however, is fairly flexible and farmers have changed the system in response to changing economic and environmental conditions. Lo (1996) notes that at different times farmers have also grown sugar cane, elephant grass, and vegetables along the dikes. Wong (1999) identifies examples of this system where the eels and crustaceans have also been grown in the ponds due to their higher economic yields. Both Lo (1996) and Wong (1999) note the ecological advantages of this system.

Livestock-biogas-crop systems

Another common system involves linking animal and crop production through a means of composting, such as an anaerobic biogas digester. A biogas digester is a large, sealed tank where organic waste is mixed with certain bacteria. Then, under anaerobic conditions, the bacteria break down the organic waste and produce methane gas and nutrient rich residue.

The methane can be taken off and used as a source of fuel. The material residue can be applied directly to crops as organic fertilizer.

Chen (1997) describes a system in Meixian, Guangdong where biogas digesters were used to help meet domestic fuel needs and provide fertilizer. Meixian is a village in rural Guangdong where fuel shortages are a problem. Several families in this village constructed biogas digesters in the late 1980s and a survey was conducted on how the biogas digesters changed their management practices. Digesters with a volume of approximately 8 cubic meters were constructed underneath pigsties and dung, urine, and food wastes were washed into the digester daily. Every year, digester sludge is removed and used as fertilizer for fruit trees.

Chen found that methane produced from the biogas digesters were capable of entirely replacing the domestic coal needs of all the families. Not only is biogas a renewable resource, but also the cost of constructing a biogas digester in 1994 was approximately the same as the cost of coal for one year. Since digester sludge was used as a fertilizer, several of the families were able to reduce the amount of chemical fertilizer they applied to their crops.

Wu, Xu, and Wu (1989) also describe using biogas generators in an animal-biogas-cropping system. They researched a densely populated community in Jiangsu province and created a rather complex system to increase productivity. In addition to biogas digesters, they included mushroom cultures, human digestion, and earthworm cultures in their decomposition subsystem. By increasing the ways in which wastes were recycled they were able to increase the rate at which nutrients could be returned to the system. The byproduct of this, of course, was increased productivity from mushroom growth and decreased need to purchase fertilizer.

They also took advantage of complicated cropping systems that included growing seven different crops in a period of three years.

Figure 5. Biogas tanks in Fushan Village, Zhejiang

Fushan village in Zhejiang Province has incorporated four large-scale biogas tanks into their recently completed Integrated Ecological Farm. All of the tanks are used in combination with large-scale animal production systems. Two of the tanks are used to digest chicken excrement. These tanks produce 200 cubic meters of methane daily, which is then either stored in gas tanks or used for community enterprises such as tea and vegetable processing, chicken hatching, and heating for animal sheds. The two tanks used to process pig excrement produce 500 cubic meters of methane daily, which is also used for heating and processing purposes (see Figure 5). The residue from these tanks is further processed to remove pollutants before it is piped into rice paddies as fertilizer.

Biogas tanks are not beneficial simply because they provide fuel and fertilizer. They are also an extremely useful means of disposing of organic wastes. In Southern China, the disposal of agricultural residues such as rice stalks has been extremely problematic and has lead to polluting practices such as simply burning rice stalks. One village in Zhejiang has constructed a biogas facility that uses rice stalks as a source of organic matter and pipes methane directly to village households.

Biogas digesters are only productive in certain areas due to the temperature requirements of the bacteria. Consequently, their use is limited to climates that remain warm throughout the year, such as in southern China. The construction of large-scale biogas digesters and the use of practices such as warming organic materials before placing them in digester tanks have helped overcome some of these climatic limitations. Of course, the scaling up of digester tanks and the incorporation of warming facilities require resources beyond that of individual farmers and are only possible for villages and townships. Wen et al. (1992) estimate that 4,700,000 peasants families in China are currently using biogas digesters for cooking and lighting. Sanders (2000) notes that the use of biogas digesters is fairly common in CEA systems constructed in warmer climates.

Intercropping and multiple cropping systems

As with the dike-pond system and the livestock-biogas-crop system, intercropping multiple cropping systems are often integrated with other CEA techniques. The differences between systems may be rather arbitrary depending on how the system is being managed and which techniques are being implemented. By taking advantage of spaces between crop rows, farmers are able to increase the over all productivity of a piece of land (see Figure 6). Since CEA systems seek to take advantage of regional variability, the variations of each system are nearly limitless and many CEA systems involve some sort of intercropping or multiple cropping (Guo, 1999; Song, Fan, & Wang, 1997; Wang et al., 1998; Wang, 1999; Wu et al., 1989).

Given the limited amount of arable land in China, farmers have, for hundreds of years, exercised creativity in how crops are grown. Intercropping is one way in which farmers have managed to maintain productivity with limited resources. Wen and Pimentel (1992) note that in northeast China farmers are increasingly intercropping corn with sweet clover. For every two rows of corn, a row of sweet clover is planted. Not only does the clover fix nitrogen and provide a source of green manure, but also sweet clover from 1 ha of intercropped field is sufficient to feed three cows for a year (Tang, 1988).

Some researchers have even developed a technique for cultivating oyster mushrooms in the furrows of cornfields (Wen, Tang, Zheng, & He, 1992). In experimental plots in Shandong province, crop residues were placed between cornrows and inoculated with oyster mushroom spores when the corn was 60-70 cm tall. Average corn yield was 22% higher than in control plots while the mushrooms provided additional economic benefits.

Figure 6. Intercropping soybeans and Chinese cabbage in Cixi Village, Zhejiang

In some climates, multiple cropping has also been very successful. Wu et al. (1989) designed a system that involved a very complicated cropping system. After a year of irrigated paddy rice, two crops were planted without irrigation during the second year. First barley or wheat was intercropped with broad bean, early corn, and late rice. Broad bean and cotton followed this. A second system was designed that involved growing five different crops in two years. This was accomplished by carefully timing the intercropping of plants so that some plants were seedlings while others were ready for harvesting. These systems also involved linkages to animal production and biogas digesters.

Rice production systems

Rice production is a socially, economically, and environmentally important part of Chinese agriculture and several CEA systems focus on rice production. Since water is a limiting resource, especially in northern China, research has been conducted to identify techniques, which could reduce water consumption. Some research indicates that shallow irrigation techniques that involve carefully time irrigation significantly reduce water requirements while actually increasing yield (Wen et al., 1992). In many cases common duckweed is also planted in irrigated rice paddies. The duckweed has a symbiotic relationship with a nitrogen fixing blue-green algae and is also used as feed for pigs, checks and fish. It also helps to control weeds and can be used as green manure after the rice is harvested (Wen & Pimentel, 1992).

The practice of raising fish in rice paddies is also used in many CEA systems. The fish help control pest populations and also provide nutrients through there excrement. In some of these systems, fish are raised within the paddies themselves. In this case deep ditches are dug where the fish can remain even if the paddies are drained. At other times, the fish are raised in a fishpond connected to the rice paddy. As necessary, fish are then moved from the rice paddy to the fishpond through shallow ditches. There is evidence that fish-rice paddy systems are beneficial to both rice and fish (Chen, 1999).

CEA versus conventional agriculture

Given the diversity of CEA systems it is somewhat difficult to identify characteristics that tie together the different systems outlined above. There are, however, several underlying general factors, which not only common to CEA systems, but also help facilitate the sustainability of CEA systems. Although it would be presumptuous to assume that one could easily conclude that any given CEA will survive indefinitely, CEA avoids many of the environmental problems inherent in conventional agricultural practices.

First of all, relative to conventional agricultural systems, CEA systems rely very little on fossil fuels for energy. Mechanical energy is derived from biological sources such as humans or draft animals so fossil fuels are not required for combustion engines. For the most part, it is human labor and not animal labor that replaces the need for external energy inputs. Wang notes that construction and maintenance of CEA systems in Deqing County in Zhejiang Province relied almost entirely on human labor (Wang, 1999). Other authors have noted the importance of human labor to CEA systems (Gong & Lin, 2000; Li & Min, 1999b; Wang, 1999). Needless to say, the 'fuel' for human labor is reproduced within the very agricultural systems where the labor is utilized. Furthermore, the 'waste' from humans does not contribute to global warming, acid rain, or any of the other number of environmental problems related to fossil fuels. Finally, human waste or 'night soil' has been used in China for hundreds of years as an agricultural input (King, 1911). Although there are problems related to disease transmission that require careful handling, given the current sewage problems encountered in many parts of China, it may be time to revisit the practice of applying 'night soil' to select crops.

Notably, CEA does not utilize human labor simply because the inputs and outputs are renewable and easily cycled back into the environment. CEA systems require such complex and intense land management that it if frequently only through the use of human labor that adequate precision can be obtained. CEA is inherently a very intensive form of agriculture that requires very careful and precise management of land. Practices such as intercropping and multicropping are not easily assisted by machines due to the close proximity of plants and the heterogeneous nature of fields. For similar reasons, 'stereocropping' on hillsides and patchwork aquaculture-agriculture systems also require large amounts of labor. The high demand for human labor by CEA is not surprising and it has been estimated that American organic farming systems require 20% more labor than comparable non-organic systems (Pimentel, 1993).

The manufacturing of synthetic fertilizers is an energy intensive, fossil fuel driven process, and therefore CEA is more sustainable because it relies very little on such manufactured inputs. Soil fertility is maintained through the use of animal manure, green manure, biogas residue or compost, rather than through the use of externally produced chemicals. Although CEA systems do not necessarily exclude the use of synthetic fertilizers or pesticides entirely, they invariably use more organic and fewer synthetic inputs than conventional agricultural systems. As in the case of human labor, the use of organic materials as fertilizer allows a large amount of material to be cycled within individual systems rather than escaping the system where they might appear as waste or pollution. Biogas digesters do not simply provide a means for disposing of organic waste; they are also a source of fertilizer (see Figure 7). The disposal of non-economically profitable organic waste such as rice husks or peanut shells is a problem in many areas and farmers have resorted to the air-polluting practice of simple burning. Within CEA systems, however, rice husks may be reused either as inputs in biogas tanks, as mulch to facilitate bamboo shoot growth, or as fodder for animals. Since fertilizers are produced on farms, transportation costs are reduced and farmers are less vulnerable to price fluctuations.

Figure 7. Nutrient rich digester effluent flowing into a rice paddy in Fushan Village, Zhejiang

Again, keeping organic matter within the system reduces the quantity of unwanted outputs. At the same time, since these outputs are converted to useful inputs in the form of manure, biogas, or digester effluent, CEA systems do not need to apply as many synthetic inputs. In an indirect manner, the environment benefits since resources do not need to be consumed and new wastes do not need to be produced for the production, processing, and transport of synthetic inputs. Thus, we see a cascading effect of decreasing consumption rather than the increasing consumption evident in conventional agricultural systems.

The ability of a CEA system to successfully maintain such internal recycling and production can only be accomplished by increasing the complexity of agricultural systems. Consequently, CEA systems do not include simply crop production, but also integrate subsystems such as biogas tanks, animal husbandry, and aquaculture. The more subsystems that are included in a CEA system, the more opportunities there are both for sources of production and sinks for waste. This complexity reduces the risk of the farmer since even if part of the system fails due to climactic variation, disease, or another factor, it is unlikely that the entire system will be impacted. Furthermore, farmers are provided some insulation from market variations since individual components of the system can be adapted to changing market demands (Wong & Yee, 1999).

In terms of ecological sustainability, the spread of CEA would certainly be beneficial to China's agricultural sector. Not only would it help reduce some of the environmental problems such as soil erosion, water contamination by fertilizers and pesticides, air pollution by combustion engines, but also it would reduce the reliance of the agricultural sector on fossil fuel derived inputs such as synthetic fertilizers. Risk of crop loss due to pest infestations and climatic variation would be reduced and many CEA systems could be put in place with relatively little capital investment. Biodiversity in agricultural systems would increase and ecosystem stability would increase. The benefits offered by CEA make it appear a logical option for a community interested in regional development.

Unfortunately, many of the most important ways in which CEA contributes to ecological sustainability do not have any immediate economic consequence. In particular, the ways in which CEA benefits China as a whole are not passed on proportionately to the farmers and decision makers who are responsible for resource management. At the same time, the societal impacts of consumptive agricultural practices are not proportionate to the economic benefits they provide to farmers. Water pollution from fertilizer runoff is a consequence that is felt downstream, while the short-term productivity facilitated by chemical fertilizers directly benefits individual farmers. Although pest resistance to pesticides will likely be a problem in the future, the economic returns of one season's crop are of immediate consequence. When inputs such as fertilizer are kept at artificially low prices, there is little reason for farmers to utilize organic inputs. Biodiversity may offer some benefits to society as a whole, but offers nothing to the individual farmer who promotes biodiversity in his or her fields.

Furthermore, as I will discuss in the next section, the land, labor, and property requirements of CEA that contribute to its long-term sustainability are in direct competition with activities that, in China's current economic system, offer greater short-term profit. We find that the very things that make CEA sustainable are the same things that are required for short-term profit. Since the ecological impacts of production practices are not included in the valuation of land, labor, and property, these resources will invariably be shifted away from sustainable systems such as CEA and toward systems where economic output is the bottom line. Unfortunately, this is exactly that appears to be taking place in Zhejiang Province.

CHAPTER V

CHINESE ECOLOGICAL AGRICULTURE IN ZHEJIANG

In spite of a growing body of literature touting the benefits of CEA as a sustainable agricultural system, few authors have examined the political and economic dimension of CEA. Sanders (2000) provides an excellent account of the factors that have facilitated the construction of CEA systems in seven different communities. Although he identifies several factors, such as decollectivization and lack of motivated and politically powerful change agents, as limiting the implementation of CEA in other areas, he does not address the larger political and economic trends, which are creating these conditions. Until the larger political and economic constraints to CEA are addressed, sustainable agricultural systems will never be implemented on more than a demonstration basis.

In a sense, the question is one fundamental to sustainable agriculture throughout the world. Why would farmers and other land managers perpetuate the growth of an unsustainable agricultural system when other, more sustainable systems are also available? That is, why would people choose to utilize agricultural practices that rely on nonrenewable resources and undermine environmental quality when more environmentally friendly alternatives exist?

In order to answer this question, I will focus on the case of CEA in Zhejiang province. Zhejiang province is located on the East Coast of China, south of Shanghai. Economic development in Zhejiang province has taken place very rapidly since the 1980s. The average per capita income in this province was 3575.03 yuan/year in 1998, compared to a national average of 2039.58 yuan/year. The gross industrial output in Zhejiang for 1998 was 1,133,800 million yuan. This was almost twice the output of Shanghai for the same year (National Bureau of Statistics, 1999). At the same time, throughout China's history Zhejiang province has been one of the country's most agriculturally productive regions. Its climate and geography have made it highly suitable to agriculture and there is evidence of past agricultural systems in this region that have been sustainable (Ellis & Wang, 1997). Nonetheless, agriculture in Zhejiang province is moving in the same direction as the rest of the country.

Zhejiang province provides an excellent example of an area of high agricultural productivity whose ecological sustainability is being rapidly undermined by economic development. It may seem that due to the physical endowments of the area combined with its long history of agriculture, Zhejiang province would be an excellent setting for CEA and CEA systems have been implemented in several communities. We find, however, that the construction of CEA within this province is only within areas that are already highly developed. CEA communities are used as isolated trophies for environmental friendliness and, in fact, continue to be subservient to efforts to perpetuate short-term economic development. Furthermore, the political and economic conditions of the province make it very unlikely that CEA will spread beyond isolated demonstration communities. Thus, the very economic prosperity that makes CEA viable as a trophy project, also exclude the possibility that CEA will be implemented on a widespread basis. The factors, which make CEA a viable option for individual, well-developed communities, are the same factors that make conventional agriculture the only viable option for most communities.

Fundamentally, the very characteristics of CEA systems, which make them sustainable, are in direct competition with the continued short-term economic development in the region. The land, labor, and organizational requirements of CEA are often at odds with the requirements of rural industry and sideline agricultural activity. On the other hand, the consumptive activities of conventional agriculture help facilitate economic growth by stimulating growth in related industries and providing a labor force for industry. Communities with ample endowments of capital may construct a CEA system; however, even in these communities ecological sustainability continues to be subservient to economic profit.

Is CEA a viable alternative to conventional agricultural systems in China? Due to current political and economic conditions, it is unlikely that CEA will ever be implemented on a widespread basis. Since the factors that are necessary to agricultural sustainability are being absorbed by other sectors or undermined by current efforts to promote economic growth, it is unlikely that any system that offers a level of sustainability comparable to CEA will find opportunity for use. Thus, we find that in Zhejiang province, the rapid economic development that is being promoted so highly by both national and local governments is also creating conditions that make a truly sustainable form of agriculture nearly impossible.

Land and management requirements

One of the largest constraints to Chinese agricultural production is arable land. The oft quoted statistic that China is feeding over 1/5 of the world's population with only 7% of the world's arable land certainly drives home the problem of available agricultural land. Of course, production is not simply a matter of how much land there is, but also the quality of the land and how it is managed. This is no less the case for CEA. As I mentioned before, one of the most important features of CEA is that it links multiple agricultural systems into a single, self-sufficient system. Invariably, the construction of multiple production systems, whether they are different cropping systems, animal husbandry, or aquaculture, require that these systems be in very close proximity, if not adjacent. The larger the distance between each of the systems, the more energy and time must be dedicated toward transport of materials. Consequently, CEA requires sufficient land to support multiple systems in close proximity.

Animal husbandry is one important aspect of CEA. Most importantly it provides a source of organic fertilizer. In contrast to 'modern' Western agricultural systems, animal husbandry in CEA does not necessitate the purchase of animal feeds or consume crops that may be used by humans. Instead, they are fed either crop residue or crops grown specifically for animal consumption. In Tengtou County, aquatic plants are used both as a means of cleaning water supplies and as a source of fodder. These plants are grown in irrigation canals so precious arable land is not used. Pig urine and feces are used either directly as organic fertilizer or placed in a biogas tank where they are anaerobically digested to produced both organic fertilizer and methane gas used for cooking.

Animal waste is not, of course, the only source of organic material for biogas tanks. In Qixian Township, rice straw that would otherwise be burned is used in a biogas tank that is being used to provide cooking fuel for the entire village. The slurry that remains after digestion in the biogas tank can also be used as fertilizer. Although many of the biogas tanks constructed in the 1980s were constructed for individual households, these small-scale tanks often encountered problems. They were poorly constructed or too small to be run efficiently.

Many individual households could not afford the cost of construction and as many rural areas developed electrical power became a cheap and easy alternative to biogas. Development of larger biogas tanks that could service an entire village helped to overcome some of the problems encountered by the household size biogas tanks. However, locating and constructing these systems requires sufficient land and capital. Furthermore, coordination among several households is necessary to supply sufficient organic waste.

Other subsystems commonly used in CEA systems also require coordination of land of at least several acres. In spite of the fact that the size of individual fishponds and orchards are relatively small (approximately 500 square meters) the fishpond-forest checkerboard system used in Deqing county still requires the coordination of several acres for maximum efficiency. Since a pig farm has also been integrated into this system, additional land is necessary to contain the entire system and maintain proper linkages between subsystems.

This is not, of course, to overstate state the ability of CEA to adapt to different spatial scales. Cixi City is utilizing CEA principles on a county level while at the same time Deqing County is applying CEA to the plots of individual farmers. There are sacrifices that are made by applying CEA principles at any level. However, CEA's greatest strength is not in the individual practices that it may involve, but rather in its ability to create a system of mutually sustaining linkages. That is, the more subsystems that are integrated into the system, the more opportunities there are for minimizing unwanted waste and the need for inputs.

Land and management limitations

One of the most important policy changes that have taken place in China since the formation of the People's Republic was the adoption of the Household Responsibility System (HRS). This system essentially dismantled the agricultural communes and returned management of land to individual households. Although quotas on certain agricultural products such as grain and cotton have remained in different forms, farmers were given the opportunity to sell surplus crops and cash crops on the open market. Official recognition of the HRS took place in 1982 and in only two years 94% of the work groups had switched to this system.

Interestingly the adoption of the HRS did not take place without some resistance. Zweig (1997) notes that, in particular, work groups, which had been operating very successfully under the communal system, were resistant to change. Still, as Kate Xiao Zhou (1996) points out, initial adoption of the HRS was in many cases a movement of farmers against the existing communal system and had widespread farmer support. Although the initial adoption of the HRS was likely motivated in many areas by dissatisfaction with the commune system, there is evidence that many farmers are aware that a certain amount of collective organization is necessary for efficient land management. Both Sanders (2000) and Muldavin (1996) note instances of farmers who have voluntarily formed collectives even after the institution of the HRS. In other words, to many farmers the communal system of the Mao period may not have been an efficient form of agriculture, but neither is the fragmented land management that is part of the HRS.

Fundamentally, the spread of CEA is not limited by inadequate amounts of land so much as by the lack of coordination among landholders. In spite of the initial increases in production that are commonly attributed to the institution of the HRS and related agricultural reforms, decollectivization has created circumstances that are facilitating unsustainable agricultural practices. Muldavin (1997) describes a 'mining of ecological and communal capital' that took place as a response to the new economic opportunities and decrease in social security that took place after reforms. This involved the rapid consumption of natural resources, such as trees grown by agricultural collectives, and physical capital such as agricultural machinery. During this same period there was little effort made to restore natural capital through activities such as replanting or to maintain physical capital through activities such as organizing groups to fix irrigation equipment. This decimation of capital can be attributed both to the new economic opportunities and the insecurity felt by farmers regarding land tenure immediately after the Cultural Revolution (Prosterman, Hanstead, & Ping, 1996).

The HRS in combination with the new market economy may have created new incentives for individuals to increase productivity, but it also essentially dismantled the existing system that linked individual benefits to societal benefits. As Muldavin (1997) notes many farmers in Heilongjiang had little incentive to dedicate labor away from household plots of land to assist in activities that benefited the community, such as maintaining irrigation equipment. The communal system had many serious problems, including its inability to provide sufficient incentive for individuals and its frequently authoritarian management. However, it also provided a means for coordinating and motivating individuals to participate in activities that benefited society as a whole. Although a return to communes as they were prior to reforms would likely do more harm then good, without a system that links individual benefits to societal benefits, there is little incentive for groups to initiate construction of systems such as CEA.

Rozelle, Veeck, and Huang (1997) provide further evidence of the environmental degradation that is related to rural reforms. In fact, they estimate that up to 5.7 million metric tons of grain has been lost to environmental degradation. Sanders (2000) explicitly describes the relationship between decollectivization and the potential of farmers to construct a CEA system. In his study of seven CEA communities, he found that four villages were collectively organized, while the remaining three villages had strong collective norms and influence. He states that, in each village, the environmental problems, such as deforestation and soil erosion, were caused by decollectivization and were sufficient to elicit a reversion to collective forms. Some level of collectivization is essential to CEA for two basic reasons. First, only collectively organized communities have sufficient land area for CEA systems and, second, collective organization provides an essential basis for the coordination of CEA systems.

In spite of the environmental degradation related to decollectivization and the importance of collective organization to CEA, land management by individual households continues to be the norm. Consequently, farmers have only the resources provided by their own plot of land to consider. Within Zhejiang Province, the average farming household has only 1 mu (approximately 1/15 acre) on which to farm. This is scarcely sufficient land to grow crops to survive, much less to incorporate livestock, aquaculture, or forestry. In particular, the small amount of land available to farmers strongly limits the ability of farmer to use manure as fertilizer. Kung and Cai (2000), in their study of farmer fertilizer practices, found instances of farmers who were interested in applying higher levels of organic fertilizers, but were unable to find adequate sources. Kung and Cai (2000) and Pennarz (1998) note that many farmers even prefer to use manure instead of chemical fertilizers. However, without sufficient land to raise animals they have little choice but to use chemical fertilizers. Nor is importing manure from other regions a viable option. Pimentel (1993) estimates that due to the high water content, manure cannot be efficiently transported more than about 10 km.

The issue of land as a limiting factor to CEA is not a matter of land area, but land management. Since the dismantling of the communes and the reduction of management decisions to the household levels, the coordination of multiple production systems is difficult. Individual farmers are driven by new economic forces to maximize short-term production on their small plots of land without regard for the impacts on adjacent ecosystems. They have neither the economic resources, nor the political clout to organize a sufficient number of other farmers into an effective CEA system. Village and county governments are in such a position; however, due to Zhejiang's proximity to the trading center of Shanghai, immediate economic profits are more easily found in rural industry. Due to pressure from the central government to continue rapid economic development, there is little interest in facilitating development in the relatively unprofitable agricultural sector. Sanders (2000) sampled several CEA communities and found that it was only in instances where strong and powerful leaders were interested in constructing CEA systems and a certain amount of collective organization already existed that CEA systems were successfully constructed. In other words, some unique individuals have taken the initiative to construct CEA systems, but even in these cases they are motivated by rewards such as the prestige offered by national awards and not simply concerned about environmental problems.

Labor requirements

The construction and maintenance of a CEA system invariably requires the use of more human labor then a comparable chemical and mechanical based system. Wang (1999) notes that construction and maintenance of CEA systems in Deqing County relied almost entirely on human labor. Other authors have noted the importance of human labor to CEA (Gong & Lin, 2000; Li & Min, 1999b; Wang, 1999). CEA is inherently a very intensive form of agriculture that requires very careful and precise management of land. Both the technologies involved in CEA, such as biogas tanks, and the management practices that guide CEA systems, such as recycling organic wastes and using complex intercropping regimes, require large amounts of labor.

Consider the labor requirements of organic fertilizers, one of the most important practices in CEA. Compared to chemical fertilizers, organic fertilizers have a much lower concentration of nitrogen, potassium, and phosphorus (of course organic fertilizers benefit the soil in many other ways such as increasing organic content, micronutrient content, and water retention). Therefore, in order to apply nutrient levels comparable to synthetic fertilizer applications, it is necessary to collect, transport, and apply much higher levels of manure. The practice of green manure, growing cover crops, which are then turned into the soil, is another useful means to increase soil fertility, but this also requires labor in the form of planting and tilling. Certainly machinery is being used in facilitating the application of organic fertilizers and completely replacing machine labor with human labor is not an inherent goal of CEA. Simply, machines are better suited to the application of the homogenous pellet, powder, and liquid forms of synthetic fertilizers.

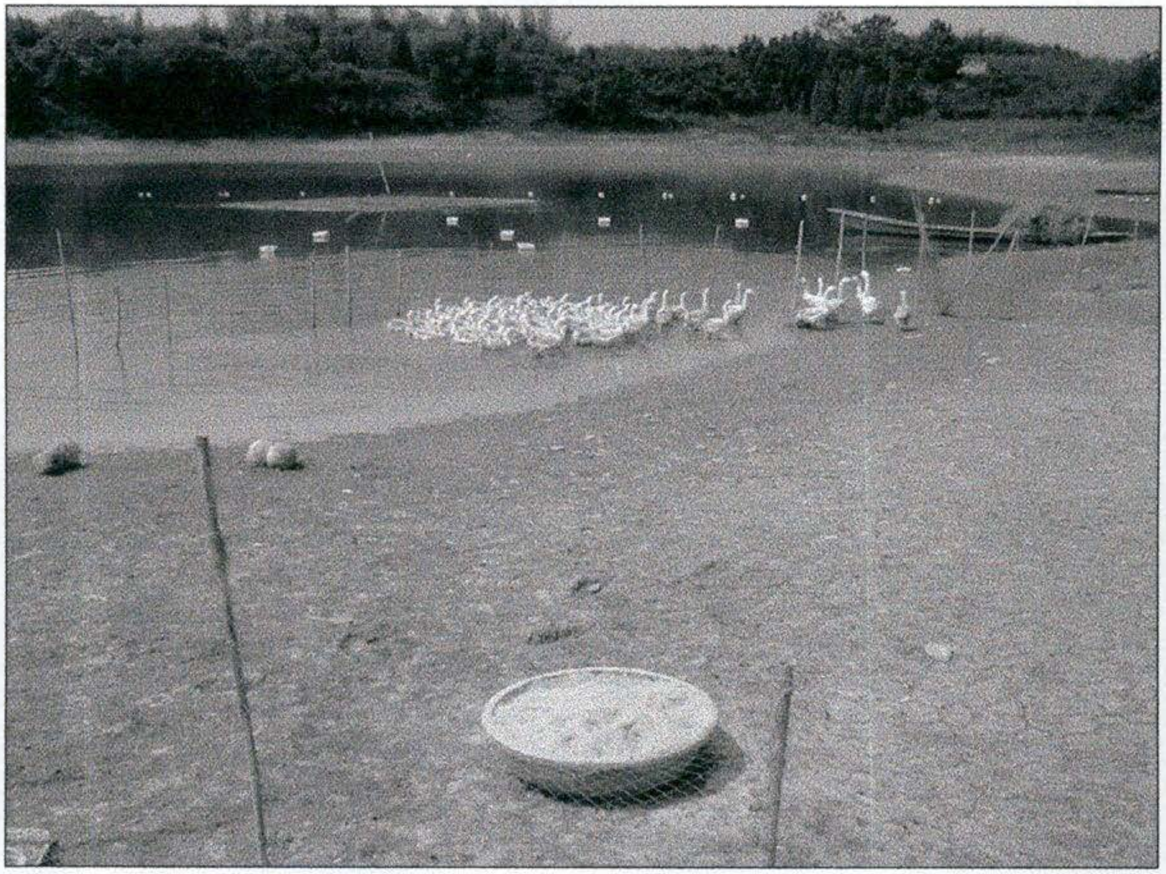

Figure 8. Raising geese, pearl oysters, and fish in Yangwenwu Watershed, Zhejiang

The practice of 'stereo-cropping' also necessitates the use of human labor over machine. 'Stereo-cropping' generally refers to the practice of growing different crops, trees, and vegetables at different vertical levels. Systems utilizing this practice have been developed for hilly regions of China. The *ding-lin yao-guo gu-nong tang-yu* (top-forest, hillside-fruit trees, valley-rice, pond-fish) system is an excellent example. This system links together cropping systems that each takes advantage of spatial variations of a hillside. As the name implies, the top of the hill is left forested, fruit trees are planted in the middle, while rice is planted in the valley and fish are raised in the middle pond. By planting crops that are appropriate to different slopes, soil erosion and nutrient runoff and leaching are reduced. A system like this was constructed in the Yangwenwu watershed in Deqing County. The watershed itself is less than 100 ha in size and the topography is extremely diverse. This complex topography has allowed land managers to incorporate a variety of production systems including fish, pearls, ducks, pigs, bamboo, and fruit and nut trees (see Figure 8). However, the steep slope of hillside plots and relatively small size of each system makes the use of machines simply impractical.

Figure 9. Aquaculture-agriculture system in Deqing County, Zhejiang

Even on topologically homogeneous plots, small variations in cropping practices make human labor the only practical energy source for management. Intercropping not only increases the overall production from a single area of land, but it may also decrease pest infestations, increase individual crop yield, and reduce the risk of crop failure. Due to the spacing of different crops, however, there often is not room for machines to be used for harvesting or tilling. A smaller scale form of 'stereo cropping' is also being used in Zhejiang Province. This involves planting one or two rows of soybeans along the banks of ponds and irrigation canals (see Figure 9). Again, due to the complexities of these systems human hands are the most efficient machines for these systems.

Surplus of labor?

China is often seen as a land of abundant labor and certainly that is true to a certain extent. It would, however, be quite an oversimplification to look only at China's large population and assume that farmers are in a constant state of labor surplus. In fact, increasing opportunities for non-agricultural employment combined with a government policies advocating industrial growth, have had a major impact on labor in the agricultural sector. Zhejiang Province, in particular, offers an interesting case in terms of rural labor. Due to its proximity to Shanghai and other large urban areas, Zhejiang has enjoyed a large amount of economic development and industrialization. Even rural areas enjoy a high amount of market access and consequently there are many employment opportunities in rural and urban areas. Furthermore, in spite of the fact that the Chinese government often states that agriculture is a key sector to national development, industry is still consistently given priority over the agricultural sector.

The problem lies in the short-term profits that can be made rural industry. While Chinese policy makers are certainly aware of the importance of the agricultural sector, the only means to accomplish short-term goals of economic growth is through the support of industry. Government investment in the agricultural sector has decreased consistently over the past twenty years, often with negative impacts on agricultural production (Muldavin, 1997). At the same time, increasing amounts of resources have been dedicated toward non-agricultural sectors such as light manufacturing. Such a shift in investment had an obvious impact on where profits could be made and generally those who had possession of fixed productive assets such as buildings and transportation who were able to make more money than those who possessed land (McKinley, 1996).

The movement of labor away from agriculture is evident in national employment statistics. While in 1978, over 70% of the population was employed in agriculture, in 1998 only 48% of the population was so employed (National Bureau of Statistics, 1999). On the other hand, in the same period there was a doubling of the number of people employed in manufacturing and construction. Even these statistics are deceptive. Frequently farmers or other individuals in their households will engage in diverse sideline activities that supplement their agricultural income (Ho, 1994; Pennarz, 1998). These sideline activities impact the amount of labor that is available for agricultural activities. Furthermore, significant portions of the population have migrated to cities and circumvented the governmental *hukou* residency system, which restricts people from relocating to other parts of the country. In spite of the fact that this migrant population is not visible in official statistics, it further demonstrates the movement of labor away from agriculture.

The increase in sideline activities and migration of labor outside of agriculture are a direct result of the declining profitability of farming in comparison to sideline activities. Ho (1994) traces the growth of non-agricultural development in rural Jiangsu province. Beginning in the late 1970s he notes a rapid movement of labor away from agriculture. This movement accelerated after 1983, with the institution of the HRS. According to Ho, this did not impact aggregate agricultural production due to labor surpluses prior to reforms and increases in laborsaving practices and modern inputs. There is significant evidence that in spite of the decreasing labor allocated to agriculture, the HRS did contribute to increases in agricultural production (Kalirajan et al., 1996; Putterman, 1993). However, as discussed earlier, this replacement of labor with laborsaving practices and modern inputs have also had strongly negative impacts on the environment and reduced the sustainability of agricultural production. Kung and Cai note how reduced labor has impacted the ability of some farmers to utilize organic fertilizers (2000).

Quite simply, farmers can make more money either diverting their energy toward sideline activities or changing occupations. The increasing availability of agrochemicals and machinery also provides the means by which farmers can reduce the amount of labor they must apply toward agriculture. Consequently, for a farmer to have incentive to adopt a CEA system, that system must not only maintain production levels that are equal to those of other systems, but it must also provide sufficient income to justify the additional labor that they require. Prosterman, Hanstead, and Ping (1996) have shown that many farmers are still unwilling to invest in land management strategies that do not provide short-term economic returns. As long as rural industry and sideline activities remain more profitable than agriculture and chemical and mechanical inputs provide a technological means to reduce agricultural labor, it seems unlikely that many areas will have the incentive to dedicate labor to CEA.

CHAPTER VI

CONCLUSION

The limits to CEA

Although the topics of land and labor provide convenient areas to focus our discussion of the obstacles to CEA, it is by now clear that issue is not quite so simple. There are a variety of conditions that are preventing the widespread application of CEA systems while at the same time facilitating the use of less sustainable practices. The management of land is directly related to technological factors such as the availability of different agricultural inputs, political factors such as the ability of farmers to organize into groups, and economic factors such as the profitability of agricultural and non-agricultural labor. Furthermore, changes in social relations among individuals have certainly had an impact on how and why certain decisions are made regarding agricultural practices. The fragmentation that took place with the institution of the Household Responsibility System (HRS) has reduced the resources available to individual farmer households while at the same time opening them to market forces. Without a certain amount of collectivization, farmers are unable to bring together the necessary land and coordinate management of systems as complex as CEA. Even where sufficient collectivization exists, such as in township-village enterprises and village conglomerates, very few communities have adopted CEA (Sanders, 2000). Rural labor, although abundant in an aggregate sense, is finding more profitable opportunities in non-agricultural sectors. Even in situations where farmers remain in agriculture, the lure of profit often causes them to shift part of their time toward sideline production (Pennarz, 1998).

The problem is that both the HRS and the development of rural industry are both fundamental aspects of the Chinese government's plan for national economic development. Thus we get at the heart of the many factors preventing the spread of CEA. *CEA is fundamentally at odds with the national government's development plans.* In other words, as long as China continues to promote rapid economic development and industrialization, CEA will never be more than an interesting irregularity perpetuated by academics or politicians looking for prestige building projects. Consider Zhu Rongji's 2001 report on the 10th Five-Year Plan. In the section regarding agriculture he writes:

> Accelerating restructuring of agricultural production and the development of the rural economy. This is the fundamental way to improve economic returns in agriculture and increase farmers' income. While effectively protecting the cultivated land and stabilizing our grain production capacities, we need to restructure the patterns of farming, focusing on improving strains, quality and economic returns. Great efforts need to be exerted to promote the industrial management of agricultural production, to support leading enterprises, and to spread the practice of farmers working with companies or producing crops on a contract basis. (p. 3)

The increasing integration of China's farmers into the economy is seen as a basic step toward increasing agricultural production and facilitating rural development. Short-term economic returns are the primary measure of success in agriculture while increasing the linkages between farmers and businesses is seen as a way to empower farmers. The desire to link agriculture to the economy is widespread among policy makers. Another official in agricultural policy stated, "The rural economy would be enlivened if hundreds of millions of farmers more fully enjoyed and exercised their own choices under the market economy (Cao, 1998)." Clearly, increasing market integration is, to China's policy makers, essential to rural development.

Interestingly this push toward market integration is even evident in the Zhejiang communities where CEA is currently being used. It is quite evident that the ecological benefits offered by CEA are less important than their potential for short-term profit. Frequently, CEA has been used as a means to facilitate economic growth. A CEA project was initiated in the Yangwenwu watershed as a means to alleviate the poverty of the area. In the 1980s Fushan village began exploring CEA as a means to facilitate modernization. Since then, Fushan has incorporated CEA principles into large-scale farming and animal husbandry projects. Tengtou village also initiated a CEA project with the goal of facilitating economic development. Anji County used CEA as a means to take advantage of their natural bamboo forests to facilitate economic development. Clearly one of the strongest factors motivating the construction of a CEA system in Zhejiang province is the hope of economic returns.

Although CEA systems will facilitate a certain amount of short-term economic growth, the strength of CEA systems is in long-term ecological sustainability and not short-term profitability. The success of CEA systems in facilitating economic growth generally took place immediately after reforms, before many regions were fully integrated into China's new market economy. Consequently, CEA has facilitated economic development in some regions, but only because of the economic growth that was taking place throughout the region.

Today, things are different and as China's market continues to develop in a manner that fails to integrate ecological consequences, CEA will not be able to compete economically with other, more profitable, activities. In the communities noted above, once the limited economic returns offered by CEA were exhausted, communities begin to dedicate resources toward other activities. That is, once a CEA system was constructed, resources were reallocated to other more profitable activities. In 2000, Fushan village was just completing construction of a large meat processing plant. Anji County had recently constructed a bamboo park, which it is hoped will promote ecotourism in the area. Tengtou Village had also recently constructed a 'living' museum where tourists can observe traditional agricultural techniques and enjoy daily pig races and goat fights. Tengtou Village was also hoping to increase exportation of agricultural products and it was nearly impossible to encounter an official who was not looking for international investment. Other places such as Xialu Town are moving away from agriculture entirely and promoting the growth of more profitable enterprises such as textiles.

Unfortunately, while most communities in China are concerned about environmental quality, the market to which communities must cater fails to incorporate the environmental impacts of agricultural practices. Consequently, as farmers and rural communities are incorporated into such a market, the incentives to use sustainable practices are reduced. Resource intensive practices such as applying agrochemicals are more economically viable than sustainable systems such as CEA, regardless of their long-term ecological impacts. In the same way, preferential treatment of rural industry has facilitated its relative profitability and helped draw essential resources, such as land and labor, away from more ecologically sustainable activities.

The high profits enjoyed by some CEA subsystems such as freshwater pearl production, or organic food production relies on specialized markets, which are easily flooded. Due to Zhejiang province's high per capita income and proximity to Shanghai, many farmers are capable of profiting from such specialized activities. However, it seems likely that opportunities like these will only decrease in the future.

Thus as economic growth outside the agricultural sector made CEA less profitable, the spread of CEA as a system of agricultural production also declined. Dedicating resources toward ecotourism, textiles, or meat processing are not, in themselves, a threat to sustainability. However, they demonstrate that the ecological benefits that are offered by CEA are clearly less important than the short-term profits that can be made in other sectors. Thus CEA is used, not as a system of sustainable agriculture, but rather as a springboard to more profitable enterprises.

While in the past, CEA has been promoted as a way to increase the prestige of a community, it is likely that the appeal of being an 'ecological community' will decrease in the future. Currently a host of awards are available for communities that construct CEA systems. Cities offer awards such as "Shaoxing City's Star Township" and "Science and Technology Demonstration Township." Provinces offer awards such as the "Zhejiang Provincial Ecological Construction Demonstration Township". While at the national and international levels, communities can receive recognition for being a "National Ecological Construction Township" or be elected to the Global 500 Roll of Honor of the United Nations Environmental Program. Sanders (2000) found in his study of CEA communities that the political prestige of operating an 'ecological community' did influence the construction of CEA systems; however, the prestige offered by receiving these awards only decreased as more awards are given out. In other words, the more communities that received awards for being 'ecological communities' the less other communities would see it as a means to promote their village or county as some place special.

The failure of CEA practices to spread beyond government demonstration communities is not simply because it cannot compete with the short-term economic gains of other sectors or because it cannot provide the same prestige as rapid economic development. CEA also encounters problems because it is in direct competition with more profitable sectors. The success of rural industry in China hinges on the large labor force that is available in rural China and CEA requires that labor remain in the agricultural sector. Fragmentation of communal resources also makes possible and in some cases even necessitates the increased consumption of agricultural inputs by individual households. Since communes no longer manage machines and land, farmers must purchase these individually. Furthermore, the market vulnerability of farmers brought about by the dismantling of the communes in combination with the impetus of economic profit mean that farmers must strive for rapid, short-term returns. This is most easily accomplished through the use of chemical fertilizers and pesticides. CEA, on the other hand, strives to reduce the amount of inputs. Reducing chemical inputs undermines China's burgeoning agrochemical businesses. It may be difficult to incorporate some hybrid crops into CEA systems, since CEA systems may be unable to provide the short-term, intense fertilizer inputs required by many hybrids. Finally, growing cash crops is an aspect of most CEA systems, however, due to the complexity of CEA, specialization in cash crops is difficult.

Ecological sustainability and economic profit

The failure of CEA is not something inherent in CEA itself so much as it is a failure of China's growing market economy. The widespread success of consumptive agricultural practices is simply another example of the failure of China's market to incorporate the environmental consequences of production. It would be easy to blame CEA for its failure to compete economically with conventional agricultural systems. Perhaps, however, it is not a failure of CEA to meet market demands so much as it is a failure of the market to incorporate long-term ecological sustainability. If Chinese agriculture continues to develop in the same direction as it has been moving in the past two decades, nonrenewable resources will continue to be depleted, water and air will continue to be polluted, topsoil will continue to erode, and soil quality will continue to decline. In spite of the growing number of environmental problems, however, sustainable agricultural practices have yet to be recognized by China's market as distinct from consumptive agricultural practices.

It is evident that conventional Chinese agriculture, in spite of relying on nonrenewable resources and contributing to declines in soil quality and air and water pollution, is capable of providing short-term economic returns in China's current economic system. CEA, in spite of the long-term ecological sustainability it offers, cannot compete in terms of short-term economic profit and requires more labor and collectivization than is currently available in China. The question that remains to be answered is, why Chinese leaders are so willingly allowing the agricultural sector to continue on a path that will in the long run, only undermine the very economic growth that it professes to promote. When environmental degradation and ecological unsustainability threaten the agricultural sector why is it consumptive agriculture that still offer the most economic gain?

There is no easy answer to such an inquiry and the topic itself warrants more research. Nonetheless, it is this question that is at the heart of the limits to Chinese Ecological Agriculture. A variety of possibilities exist regarding the future of Chinese agriculture. Many assume that continued economic growth will provide sufficient capital and technology to combat China's growing environmental problems while increasing agricultural productivity. Perhaps, by increasing food imports China can decrease the pressure on domestic food sources. This may reduce the pressure on some of China's natural resources, such as arable land, as grain is purchased abroad. However, it may also contribute to degradation of other resources, such as water and air, as polluting industries move from more developed countries into China to take advantage of a rural labor force desperate for jobs. Furthermore, increasing reliance on foreign food sources may force Chinese farmers to increase their use of chemicals in order to compete with countries where food production is cheap and easy. It is likely that technological advances and capital investment will help alleviate some environmental problems and perhaps even provide the means for more sustainable agricultural practices. However, the creation of topsoil lost to erosion or the replacement of extinct species whose habitat has been destroyed by farmers desperate for land, is not something that is easily accomplished no matter how much money is dedicated toward that task. There seems little logic in continuing practices that are known today to contribute to soil degradation, air and water pollution, and climate change, while assuming that solutions to these problems will be found in the future. Dismissing the forces that are driving China's agricultural sector toward unsustainable practices as simply temporary problems that can be solved when necessary oversimplifies the issue.

CEA is really only one small casualty to larger set of political and economic forces that are driving China toward ecological unsustainability. Muldavin (1997) notes that much of China's rural economic development has been driven by the consumption of natural and physical capital that accumulated prior to reforms. Others have also noted the relationship between the growth of China's market economy and environmental degradation (Smith, 1997). The problem is not necessarily in the growth of China's market economy so much as it is in the values that are a part of that market. Specifically, it is the failure of the market to incorporate the environmental consequences of production practices. Nowhere is this more evident than in the agricultural sector.

Many of the decisions lie in the hands of local governments and resource managers. It is for the most part farmers and local officials who decide how natural resources will be used. Even in the case of existing CEA communities, construction of CEA systems were initiated and largely funded at the local level. Consequently, it is insufficient for the central government to simply provide recognition of CEA communities and technical support for these systems. It must alter the system in such a way that makes CEA communities an economically viable option for those who must dedicate resources toward their construction. By bringing the ecological costs and benefits of production practices onto the market the central government would create conditions favorable for sustainability rather than simply favorable for rapid economic growth.

There must be incentives for people to remain in the agricultural sector. Clearly the preferential treatment of industry has benefited only a portion of China's population and contributed to vastly different levels of development in urban and rural areas (McKinley, 1996). Promotion of rural development should include incentives for agriculture and, in particular, sustainable practices such as used in CEA. This can be accomplished by increasing control over the market in order to bring long-term ecological costs in line with short-term economic profits. Rather than using the agricultural sector as a source of cheap food and materials for industry, China's rural areas could become self-sufficient and stable communities that are allowed to develop in slower, but more sustainable fashion. Industry, after all, need not be the only sink for China's growing population and material consumption need not be the only sign of development. Such a shift would not only decrease the economic pressure on many farmers to utilize unsustainable practices, but also provide incentives for agriculture to increase the use practices that promote biodiversity and ecological stability. Perhaps, by reprioritizing the role of agriculture and industry in development, China will be able to enter onto a more sustainable path of development.

The coordination of land and resource management must also be increased. Although a return to collective agriculture as it was prior to reforms would not necessarily make CEA a more viable system, it is clear that some sort of collective management is necessary. Increasing collectivization would help link the environmental impacts of individual farmers' practices with the community resources that are necessary for the prevention of these impacts. That is, farmers must have the resources and institutions that, first of all, help organize management of resources and infrastructure and, second of all, make individual farmers accountable for the impacts of their agricultural practices. A successful management organization would not simply act as a regulatory institution, but also help coordinate collective action that would benefit the whole community. Thus farmers who mismanaged their land would be accountable for the societal costs of their activities. In the same way, farmers would also benefit from utilizing practices that benefited the community. At the same time, coordination between farmers would be increased so that sufficient resources would be available for the construction of a holistically managed system such as CEA.

There is some evidence that township village enterprises (TVE) have the management potential required by CEA (Sanders, 2000). It seems likely that TVEs could, in the future, serve as an excellent institution for increasing farmer coordination. However, TVEs are primarily profit oriented and currently there is little reason for TVEs to concern themselves with ecological sustainability. Until ecological impacts are incorporated into the market it is unlikely that most TVEs would construct a CEA system without some other form of incentive. Similarly the revenues of local governments are often strongly tied to the success of local industry (Wong, 1992). So unless the national economic system is altered, the profitability of conventional agriculture and rural industry will continue to take precedence over more sustainable alternatives such as CEA. A new set of relationships between private organizations and local governments would be necessary to bring together the necessary resources and regulatory infrastructure. However, such private-public relationships and such community organizations as described above can only be developed if the China's market is changed in such a way as to make them viable.

The central government still retains a large amount of control over important parts of the agricultural sector. The China National Agricultural Means of Production Corporation still controls over 90% of domestically produced fertilizer while the State Planning Commission controls the allocation of imported fertilizer (World Bank, 1997). Government grain bureaus, although still largely inefficient, retain large amount of control over cereal production and distribution. Furthermore, China is not burdened by the foreign debt from which many other developing countries suffer and this gives them leverage when negotiating with foreign countries. Initiatives such as China's Green Food program, which certifies organically produced food, are a step in the right direction. China has the potential to alter its market for agricultural products in such a manner as to incorporate the ecological consequences of production practices into the price of the products. Decisions regarding agricultural practices could continue to be made at the local level while changes in incentives and price structures would provide incentive for more sustainable practices. Subsidies toward agricultural inputs such as synthetic fertilizers could be reallocated toward agricultural systems that have been able to demonstrate ecological sustainability, such as many CEA communities.

Certainly removing the obstacles to CEA is no easy task and, in many ways, they are not obstacles that lie only within China's borders. As China moves closer to entry to the WTO, agricultural subsidies remain a contentious issue. China is strongly opposed to entering the WTO with developed nation status since it would reduce the amount of subsidies it could provide to the agricultural sector (Lin, 2001). Although reducing the amount of subsidies to agriculture would likely have a negative impact on farmers and increase economic pressure to use synthetic chemicals and machines, the pressure on China is intense to open its agricultural markets. As China becomes even more integrated into the world economy, the pressure to remain economically competitive will only increase. Unless China takes steps in support of ecological sustainability today, environmental quality could be the price that China will pay to remain competitive.

The future of Chinese agriculture is far from certain. Agricultural policies, such as China's grain self sufficiency policy, will likely be repealed or significantly changed in the future. This will likely free even more of China's agricultural commodities to market forces. Through the influence of international organizations like the WTO, China's agricultural sector will increasingly interact with world markets. This will provide both opportunities to buy cheap food abroad and challenges to remain competitive on an international basis. It is likely that as China continues to shift from a central planned economy and into a market economy deeply integrated into the world economic system, the utilization of natural resources in China will change drastically. In some cases, pressure to produce some crops, such as grain, will decrease as China makes purchases abroad. In other cases, the rising demand for products such as meat may cause a growth in areas such animal husbandry. The impact of these changes on China's long-term ecological sustainability rely on how China expands its market and how it negotiates its integration into the world economy. While China has the resources to achieve ecological sustainability, a great deal must still be done before China, as a whole, enters onto such a path.

This does not mean that CEA, as a system of production, is entirely useless. CEA is currently not compatible with China's economic and political system, but this does not mean that lessons cannot be learned from CEA. It seems likely that consumptive agriculture will continue to be the norm in China into the near future. Certainly, many of the problems relating to environmental degradation will not disappear any time soon and as environmental problems continue to increase it seems likely that China will be forced to reconsider its current agricultural system. Perhaps technological advances will provide the means for future agricultural systems which will not only be ecologically sustainable in the long-term, but also profitable in the short-term. However, over 1.2 billion people still relying largely on the Chinese agricultural sector for food, levels of soil fertility are declining, air and water pollution are increasing, and forest and aquatic resources are dwindling. The problems related to ecological unsustainability are being encountered today. Perhaps it is time to stop looking for future solutions to today's environmental problems and to instead consider what may be standing in the way of the solutions we already have.

BIBLIOGRAPHY

Altieri, M. (1998). Ecological impacts of industrial agriculture and the possibilities for truly sustainable farming. *Monthly Review, 50*(3), 60-72.

Ash, R. F., & Louis, R. (1998). China's land resources, environment, and agricultural production. *China Quarterly, 156*, 836-879.

Barker, R., & Chapman, D. (1990). The economics of sustainable agricultural systems in developing countries. In C. Edwards & R. Lal & P. Madden & R. Miller & G. House (Eds.), *Sustainable Agricultural Systems* (pp. 478-494). Ankeny.

Berry, W. (1996). *The unsettling of America : culture & agriculture* ([3rd ed.] ed.). San Francisco: Sierra Club Books.

Brown, L. R. (1988). The vulnerability of oil-based farming. *Bulletin of science, tehcnology, and society, 8*(1), 41-46.

Brown, L. R. (1997). *The agricultural link : how environmental deterioration could disrupt economic progress*. Washington, D.C.: Worldwatch Institute.

Cao, M. (1998, 12/09/1998). New System Enlivens Farming. *China Daily*.

Carter, C. A., Zhong, F.-N., & Ts*ai, F. (1996). *China's ongoing agrigultural reform*. San Francisco: 1990 Institute.

Chen, R. (1997). Livestock-biogas-fruit systems in South China. *Ecological Engineering, 8*, 19-29.

Chen, X. (1999). Chinese Ecological Agriculture Technology. In Z. Wang & X. Ye & Q. Li (Eds.), *Chinese Ecological Agriculture and Intensive Farming Systems* (pp. 53-66). Beijing: China Environmental Science Press.

Cheng, X., Han, C., & Taylor, D. (1992). Sustainable Agricultural Development in China. *World Development, 20*(8), 1127-1144.

Clayton, A. M. H., & Radcliffe, N. J. (1996). *Sustainability : a systems approach*. London: Earthscan Publications.

Dalsgaard, J. P. T., Lightfoot, C., & Christiansen, V. (1995). Toward quantification of ecological sustainability in farming systems analysis. *Ecological Engineering, 4*, 181-189.

Daly, H. E. (1996). *Beyond growth : the economics of sustainable development.* Boston: Beacon Press.

Daly, H. E., & Townsend, K. N. (1993). *Valuing the earth : economics, ecology, ethics.* Cambridge, Mass.: MIT Press.

Davidson, C. (2000). Economic Growth and the Environment: Alternatives to the Limits Paradigm. *Bioscience, 50*(5), 433-441.

Ellis, E. C., & Wang, S. M. (1997). Sustainable traditional agriculture in the Tai Lake Region of China. *Agriculture, Ecosystems, and Environment, 61*, 177-193.

Elvin, M. (1998). The Environmental Legacy of Imperial China. *China Quarterly, 156*, 733-756.

Gong, J., & Lin, H. (2000). Sustainable development for agricultural region in China: case studies. *Forest Ecology and Management, 128*, 27-38.

Guo, Q. (1999). Mechanisms for sustainable agriculture: effets of the garden-plantation system in Shaanbei, China. *Journal of Sustainable Agriculture, 13*(4), 23-37.

He, B. (1991). *China on the Edge.* San Francisco: China Books and Periodicals, Inc.

Ho, S. (1994). *Rural China in transition: non-agricultural development in rural Jiangsu, 1978-1990.* New York: Oxford University Press.

Hu, D., & Wang, R. (1998). Exploring eco-construction for local sustainability: an eco-village case study in China. *Ecological Engineering, 11*, 167-176.

Johnson, T., Liu, F., & Newfarmer, R. (1997). *Clear Water, Blue Skies: China's Environment in the New Century.* Washington D.C.: The World Bank.

Kalirajan, K. P., Obwona, M. B., & Zhao, S. (1996). A decomposition of total factor productivity growth: the case of Chinese agricultural growth before and after reforms. *American Journal of Agricultural Economics, 78*(2), 331-339.

King, F. H. (1911). *Farmers of forty centuries.* Madison: Democrat Publishing Co.

King, L. (1990). Soil Nutrient Management in the United States. In C. Edwards & R. Lal & P. Madden & R. Miller & G. House (Eds.), *Sustainable Agricultural Systems* (pp. 89-106). Aukeny: Soil and Water Conservation Society.

Kung, J., & Cai, Y.-S. (2000). Property rights and fertilizing practices in rural China. *Modern China, 26*(3), 276-301.

Li, W., & Min, Q. (1999a). Eco-county construction in China. *Journal of Environmental Sciences, 11*(3), 284-289.

Li, W., & Min, Q. (1999b). Integrated farming systems: an important approach toward sustainable agriculture in China. *Ambio, 28*(8), 655-663.

Lin, M. (2001, 5/18). *China Not to Enter WTO as a Developed Nation*, [Listserve]. China News Daily. Available: www.cnd.org [2001, 5/18].

Lo, C. P. (1996). Environmental impact on the development of agricultural technology in China: the case of the dike-pond ('jitang') system of integrated agriculture-aquaculture in the Zhujiang Delta of China. *Agriculture, Ecosystems, and Environment, 60*, 183-195.

Luna, J., & House, G. J. (1990). Pest Management in Sustainable Agricultural Systems. In C. Edwards & R. Lal & P. Madden & R. Miller & G. House (Eds.), *Sustainable Agricultural Systems* (pp. 157-173). Ankeny: Soil and Water Conservation Society.

Luo, S., & Han, C. (1990). Ecological Agriculture in China. In C. Edwards & R. Lal & P. Madden & R. Miller & G. House (Eds.), *Sustainable Agricultural Systems* (pp. 299-322). Ankeny: Soil and Water Conservation Society.

Ma, Z. (1995). China's Past Speaks to Sustainable Future. *Forum for applied research and public policy, 10*(4), 53-56.

MacKenzie. (1996, 3/2000). *Oil as a finite resource: When is global production likely to peak?*, [On-line]. World Resources Institute. Available: http://www.igc.org/wri/climate/jm_oil_000.html [2001, 5/21].

Matson, P. A. (1997). Agricultural intensification and ecosystem properties. *Science, 275*, 504-510.

McKinley, T. (1996). *The Distribution of Weath in Rural China.* Armonk: M.E. Sharpe, Inc.

Meadows, D. L., Goldsmith, E., & Meadow, P. (1975). *Limits to growth.* No. Hollywood,: Center for Cassette Studies CBC m.

Muldavin, J. (1996). Impact of reform on environmental sustainability in rural China. *Journal of Contemporary Asia, 26*(3), 289-322.

Muldavin, J. (1997). Environmental degradation in Heilongjiang: policy reform and agrarian dynamics in China's new hybrid economy. *The Annals of the Association of American Geographers, 87*(4), 579-614.

National Bureau of Statistics. (1999). *1999 China Yearbook*, [On-line]. National Bureau of Statistics. Available: http://www.stats.gov.cn/yearbook/ml/1999_e.htm [2001, 5/1].

Nickum, J. (1998). Is China living on the water edge? *China Quarterly, 156*, 880-889.

Norgaard, R. B. (1994). *Development betrayed : the end of progress and a coevolutionary revisioning of the future*. London ; New York: Routledge.

Odum, H. T. (1994). *Ecological and general systems : an introduction to systems ecology* (Rev. ed. ed.). Niwot, Colo.: University Press of Colorado.

Odum, H. T., & Odum, E. C. (1976). *Energy basis for man and nature*. New York: MacGraw-Hill.

Pennarz, J. (1998). Adaptive Land-Use Strategies of Sichuan Smallholders-Subsistence Production and Agricultural Intensification in a Land-Scarce Poverty Area of China. In F. Christiansen & J. Zhang (Eds.), *Village, Inc.: Chinese Rural Society in the 1990s*. Honolulu: University of Hawaii Press.

Pimentel, D. (1984). Energy Flow in Agroecosystems. In R. B. Lowrance, Stinner; House, Garfield J. (Ed.), *Agricultural Ecosystems: Unifying Concepts*. New York: John Wiley & Sons.

Pimentel, D. (1993). Economics and energetics of organic and conventional farming. *Journal of Agricultural and Environmental Ethics, 6*(1), 53-60.

Pimentel, D., & Pimentel, M. (1996). *Food, energy, and society* (rev. ed. ed.). Niwot, Colo.: University Press of Colorado.

Prosterman, R., Hanstead, T., & Ping, L. (1996). Can China feed itself? *Scientific American*, 90-96.

Prosterman, R., Hanstead, T., & Ping, L. (1998). Large-scale farming in China: and appropriate policy? *Journal of Contemporary Asia, 28*(1), 74-29.

Putterman, L. G. (1993). *Continuity and change in China's rural development : collective and reform eras in perspective*. New York: Oxford University Press.

Rozelle, S., Veeck, G., & Huang, J. (1997). The impact of environmental degradation on grain production in China, 1975-1990. *Economic Geography, 73*(1), 44-67.

Sanders, R. (2000). *Prospects for sustainable development in the Chinese countryside : the political economy of Chinese ecological agriculture*. Aldershot, Hants, England ; Brookfield, Vt., USA: Ashgate.

Shiva, V. (1991). *The violence of the Green Revolution : third world agriculture, ecology, and politics.* London ; Atlantic Highlands, N.J., USA: Zed Books.

Smil, V. (1984). *The Bad Earth.* London: Zed Press.

Smil, V. (1990). Energy Costs of Chinese Crop Farming. In T. C. Tso (Ed.), *Agricultural reform and development in China :achievements, current status, and future outlook.* Beltsville: IDEALS, Inc.

Smil, V. (1993). *China's Environmental Crisis: An Inquiry into the Limits of National Development.* New York: M.E. Sharpe.

Smith, R. (1997). Creative Destruction: Capitalist Development and China's Environment. *New Left Review, 222*, 3-40.

Song, S., Fan, T., & Wang, Y. (1997). Comprehensive sustainable development of dryland agriculture in Northwest China. *Journal of Sustainable Agriculture, 9*(4), 67-84.

Stone, B. (1989). Developments in Agricultural Technology. *China Quarterly.*

Tang, D. (1988). Developing ecological agriculture and promoting sustainable agriculture. *Ecological Economics, 19*, 9-13.

Tivy, J. (1990). *Agricultural ecology.* New York: Wiley.

US Embassy Beijing. (1996a). *Agricultural pesticide use in China*, [On-line]. US Embassy Beijing. Available: http://www.usembassy-china.org.cn/english/sandt/index.html [2001, 5/1].

US Embassy Beijing. (1996b). *Chemical Fertilizers--Blessing for Chinese Agriculture or Curse for China's Environment*, [On-line]. U.S. Embassy Beijing. Available: http://www.usembassy-china.org.cn/english/sandt/index.html [2001, 5/1].

US Embassy Beijing. (2001). *Dust Storms and Over-Population*, [On-line]. US Embassy Beijing. Available: http://www.usembassy-china.org.cn/english/sandt/estnews-contents.html [2001, 4/13].

Wang, Q., Halbrendt, C., & Johnson, S. R. (1996). Grain production and environmental management in China's fertilizer economy. *Journal of Environmental Management, 47*, 283-296.

Wang, R., & Yan, J. (1998). Integrating hardware, software, and mindware for sustainable ecosystem development: principles and methods of ecological engineering in China. *Ecological Engineering, 11*, 277-289.

Wang, R., Yan, J., & Mitsch, W. (1998). Ecological engineering: a promising approach towards sustainable development in developing countries. *Ecological Engineering, 11*, 1-15.

Wang, Z. (1999). Theoretical Basis of Chinese Ecological Agriculture. In Z. Wang & X. Ye & Q. Li (Eds.), *Chinese Ecological Agriculture and Intensive Farming Systems* (pp. 1-16). Beijing: China Environmental Science Press.

Wen, D., & Pimentel, D. (1986). Seventeenth century organic agriculture in China: Cropping systems in Jiaxing region. *Human Ecology, 14*, 1-28.

Wen, D., & Pimentel, D. (1992). Ecological resources management to achieve a productive, sustainable system in northeast China. *Agriculture, Ecosystems, and Environment, 41*, 215-230.

Wen, D., Tang, Y., Zheng, X., & He, Y. (1992). Sustainable and productive agricultural development in China. *Agriculture, Ecosystems, and Environment, 39*(1), 55-70.

Wong, A., & Yee, C. (1999). New developments in integrated dike-pond agriculture-aquaculture in the Zhujiang Delta, China: ecological implications. *Ambio, 28*(6), 529-534.

Wong, C. (1986). Intermediate technology for development: small-scale chemical fertilizer plants in China. *World Development, 14*(10), 1329-1346.

Wong, C. P. W. (1992). Fiscal reform and local industrialization. *Modern China, 18*(2), 197-128.

World Bank. (1997). *At China's Table: Food Security Options*. Washington D.C.: The World Bank.

Wu, S., Xu, S., & Wu, J. (1989). Ecological agriculture within a densely populated area in China. *Agriculture, Ecosystems, and Environment, 27*, 597-607.

Zhou, K. (1996). *How the Farmers Changed China*. Boulder: Westview Press.

Zweig, D. (1997). *Freeing China's Farmers: Rural Restructuring in the Reform Era*. Armonk: M.E. Sharpe.