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Agro-ecological engineering in China: a way towards sustainable agriculture

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Abstract: Sustainable development, as a “hot topic”, concerns not only economic development but also environmental protection. Agriculture, the base of other economic activities, has faced many difficulties that include over-growth population, land decrease, and land degradation and so on. Therefore, how to increase the food supply, to meet the over-growth population demands, is the main task all over the world at present, especially in the developing countries, such as China, but we also must protect agricultural environment for medium- and long-term development simultaneously. Hence, sustainable development in agriculture is the most important estate that we must concern. Its sustainable development determines the sustainability of other economic development to a great extent. Despite Chinese government has paid much attention to develop agricultural production and obtained great successions, there are also many shortcomings in Chinese agriculture. Therefore, China must seek new approaches for its development and environmental protection that suit local conditions and are based on local resources. Agro-ecological engineering, the application of ecological engineering in agriculture, is very thriving in China in recent decades. In this paper, the ecological, economic and social benefits of agro-ecological engineering are analyzed. The principles are discussed. The results indicated that agro-ecological engineering can meet the farmer’s short-, medium- and long-term benefits. In the meanwhile, it also concerns not only economic benefits but ecological and social benefits. Therefore, agro-ecological engineering is a way that leads to sustainable agriculture in the future in China.

Key words: agro-ecological engineering; sustainable agriculture; sustainable development; China

Introduction

With high rate of the world economic growth in this century, many unprecedented “ecological crises”, such as depletion of natural resources, environmental deterioration, soil erosion, decertification, and global change, have broken out all over the world. Many evidences indicate that environmental degradation has become one of the main limited factors for social economics further developing. The relationships between environment and development have brought to people broad attention. How to guarantee social economics development and protect environment simultaneously is the key problem that must be resolved at present and in the future. Therefore, since the idea of sustainable development was initially formulated in 1970s, it has been popularized by every government, and become the most familiar concept and objective to be based on the principle sustainability. Many scientists believe that sustainable development will be as the guiding principle for a global society entering the new millennium.

Sustainable development is “that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987). This is an ideal political formulation, providing the global community with illusion of a broad, coherent consensus, within which an almost endless array of objectives may be pursued (Jacob, 1994). Sustainable development is challenged in terms of the history of human-environment relationship. The defining character of that history is “development” as increasing consumption, through escalating production, achieved by advancing technological control of nature. Therefore, as traditional view of development, the higher economic efficiency of modern society has developed economics depend on the depletion of stocks of oil and other resources and have adverse environmental impacts, both of which lower their sustainability. “Sustainable”, in contrast, implies that the use of nature is in

some sort of long-term balance with natural resources (such as biogeochemical processes, including their flux). Its purpose is to organically integrate combination of development and environment and to achieve harmonious relationship between human and nature.

1 Sustainable development for agriculture

As the basis for humankind survival and a prerequisite for others economy development, agriculture is one of the most important estates for every country. However, agriculture is also directly and closely related with environment, its development mainly depends on the situation of natural resources and environment. There is a general perception in developed and developing countries that many agricultural practices are leading to environmental degradation, including soil erosion, land contamination, desertification, deforestation and loss of productivity. Environmental degradation, in contrast, restricts the development of agriculture. Furthermore, population over-growth has increased not only the needs for more food supply, but also the presses for environment. There is no reason that many people are not anxious for insufficiency of food supply. Therefore, human beings must face how to maintain sustainable development in agriculture, and protect the natural resources and ecological environment simultaneously for the further development. Whenever the ideas of sustainable development were formulated, it was rapidly accepted by agricultural department and organizations in the world. They advanced its own contents and aims combined with the characters of agriculture.

Edwards (Edwards, 1987) defined sustainable agriculture as "Integrated systems of agricultural production, with minimum dependence upon high inputs of energy, in the form of synthetic chemicals and cultivation, that substitute cultural and biological techniques for these inputs. These should maintain, or only slightly decrease, overall productivity and maintain or increase the net income for the farmer on a sustainable basis. They must protect the environment in terms of soil and food contamination, maintain ecological diversity and long-term structure, fertility and productivity of soils. Finally, they must meet the social needs of farmers and their families to strength rural communities in a sustainable manner."

In 1992, Food and Agriculture Organization defined sustainable development as "that demand to manage and protect nature and the basis of natural resources, reform techniques and organization, and lead them to develop that can guarantee and continually satisfied the needs of the present and future generations, the sustainable development (In the departments of agriculture, fishery and forestry) can protect land, water, and genetic resources of plant and animal, avoid environmental degradation, in the meanwhile, it is suitable in technology, feasible in economics, and can be accepted by global society."

Besides the formers, in the literature, there are hundreds of definitions of sustainable agriculture, but virtually all of them involve: (1) adequate economic returns to farmers; (2) maintenance of natural resources and productivity indefinitely; (3) minimal adversity for environmental impacts; (4) optimal production with minimal external inputs; (5) satisfaction of human needs for food and income; (6) provision for the social needs of farm families, and (7) combination of short-, medium-and long-term benefits together.

In a brief word, sustainable agriculture must promote environmental, ecological, economic and social stability and sustainability.

2 Current situation of agriculture in China

Although Chinese has gained high development in agriculture in the past 40 years, there are many shortcomings that require us strive to overcome. First, China is one of the largest agricultural countries in the world. The farmer in China makes up 80 percent of its population which are nearly 22 percent of the world's population, but the Chinese rely on only 7 percent of the world's arable land. This is a heavy burden. Second, the base of agriculture is very poor. Third, the agricultural

environments have seriously degraded and natural resources are insufficient.

At present, the problems have been faced by Chinese agriculture include:

(a) Shrinking of arable land: although China is the third biggest country in the world in area, it possess about 144 million hm^2 cultivated land that makes up only 7 percent of the world's arable land and 0.11 hm^2 per capita, only one third of the world average. In the past 15 years, about 5.4 million hm^2 arable lands have been decreased, nearly 3.6×10^4 hm^2 arable lands are diminished per annual, or correspond to loss of the ability of 2.5 billion kilograms grain production per year (EPRCC, 1997). In the meanwhile, the population is increasing continuously. Therefore, the conflict between population and arable land is obvious increasingly.

(b) Soil erosion: soil erosion is one of the main causes that cultivated land lose in China. Natural elements (such as physiognomy, topography, rainfall and vegetation etc.) are the internal factors of soil erosion and human activity as an external factor. These factors are as below: First, Chinese macro-topography is very complicated. In China, mountainous land, plateau and hills make up 33%, 26% and 10% respectively. It means that there are very easy to cause soil erosion in China. Second, precipitation is concentrated in a period in most regions in China and causes erode intensity increased. Third, the coverage of vegetation (especially forests) is very low. Chinese forests' distribution is very inequilibrium. Furthermore, the structure of forest is very simple and its ecological function very poor. Therefore, they do not protect soil from eroding. Forth, China possess of 12 hundred million population, and the farmer makes up 80 percent of the Chinese population. But they rely on a few of arable lands, so the other lands (such as woodlands and grasslands etc.) must be reclaimed continually to meet the people's demands for sufficient food. Therefore, it is not surprised that China is one of the most seriously countries in soil erosion in the world. At present, a common perception is that the areas of soil erosion in China, including water and wind erosion, are 3.67 million km^2 , nearly two fifth of it whole territory. In other words, almost all valleys are suffered by different degrees of soil erosion. Such as in Loess Plateau, the soil erosion area is 45×10^4 km^2 , makes up to 79 percent of the total area in the region that is 54×10^4 km^2 , lost soil 1.6 billion tons per annual. In Yangtze River Valley, soil erosion area is 56.2×10^4 km^2 , nearly one third of the whole area in the Valley (180×10^4 km^2), and the loss of top soil is 2.24 billion tons per annual (Mao, 1994).

(c) Desertification: Because of the worse natural conditions, there is the second largest ecotone in the world that locates from northeast to northwest of China. Its area is about 256.6×10^4 km^2 . At present, there are 262×10^4 km^2 of lands, 79 percent of the total area in this region, which have been suffered by desertification and about 170 thousand hm^2 lands turn to desert every year. In the "Three North region" (northeast, northwest and north of China), there are about 1.33 million hm^2 cultivated lands and 0.1 billion hm^2 grasslands that are threatened by wind and sand (EPRCC, 1997).

(d) Deforestation: in the past 40 years, almost 60 million hm^2 woodlands, about half of the current existence of total forest areas, had been damaged (Mao, 1994). This is a main factor that leads to soil erosion and dersitification in China. At present, per capita possesses only 0.11 hm^2 woodlands and make up 11.9 percent of the world average.

(e) Water resources shortage: agricultural production requires and consumes more fresh water than any other human activity. For example, a corn crop that produces approximately $7000 \text{ kgh}^{-1} \text{m}^2$ of grain takes up and transpires approximately 4 million liters $\text{h}^{-1} \text{m}^2$ of water during the growing season only; to produce one kilograms of corn grain under irrigation requires the availability of approximately 1400 liters of fish water (Postel, 1989). In China, water resources distribute unequally, 81 percent locates in the south to the Yangtze River, and in the large regions of northern China, only 19 percent of total water resources. Because of excess exploitation and utilization, most regions are short of water resources.

(f) Degradation of land quality: a large of pesticide, herbicide and fertilizer are always used by farmers to obtain higher grain production, however, the physical properties of soil are altered by the usage of chemical fertilizer. Moreover, lots of waste water pour into the rivers and enter to irrigation systems without any treatment, it results in arable lands being polluted seriously. Thus, the arable land quality is degraded increasingly. According to investigation, about 30 percent of arable lands's production are very low. Furthermore, there are about 6.67 million hm^2 cultivated lands that are affected by pollution and 36.7 million hm^2 sloping fields that are suffered by serious soil erosion (Mao, 1994).

Therefore, the main problems that we face are not only environmental pollution, as well as the developed countries face, but also over-growth of the human population, deterioration of resources, deficiency of energy sources and insufficiency of food supply. In other words, China needs to protect its environment, in the meanwhile, it must increase production with limited resource to meet the needs of its people. For this reason, China must seek new approaches for its development and environmental protection that suit local conditions and are based on coal resources.

3 The principles of agro-ecological engineering

3.1 Definition of agro-ecological engineering

Agro-ecological engineering is the application of ecological engineering in agriculture. Many types of Chinese agriculture that have being existed for thousands of years may be considered native and spontaneous agro-ecological engineering (such as the mulberry field and fishpond system in subtropical regions). However, as an applied science, agro-ecological engineering was not emerged until 1979 when Ma (Ma, 1979) first proposed ecological engineering as a science and addressed the theory of ecological engineering. Later, many scientists were engaged in discussing the definition according to the characteristics of agriculture (Ma, 1985; Ye, 1985; Luo, 1987).

In 1987, Ma and Li published a book *Agro-ecological Engineering in China*. In this book, they defined agro-ecological engineering as: An agro-ecosystem in which the principles of maximum utilization of space and resources by organisms in symbiotic communities mutual coordination and promotion among components and multi-step, multi-pathway use transformation of substances and energy are effectively applied. Its propose is to establish highly efficient and sustainable agro-ecosystems that utilize natural resources rationally and maintain ecological stability.

This may be a relatively complete definition. It elucidates the principles, characteristics and goals of agro-ecological engineering with concise words.

3.2 Principles of agro-ecological engineering

Because it involves sciences of ecology, economics and society, the practices and designations of agro-ecological engineering must be based on the principles of these disciplines. The following principles may play a role in the agro-ecosystem.

3.2.1 Principle of niche

Not only in natural ecosystem but also in man-made ecosystem, every species occupies a temporal and spatial hierarchy. It means that each species possesses its own unique niche. Niche is the basic regulation of species interaction in ecosystem. Different species forms a relatively stable ecosystem through competition and complementarity or symbiosis for niche. Usually, the higher niche differentiation of an ecosystem can utilize environmental resources more effectively and maintain higher productivity for a longer period than that of the mono-species community. However, the properties of an ecosystem are not equal to but more than the simple sums of those its species. All organisms of an ecosystem are inter-related and interactive. The inter-relationships among species of an ecosystem include dependency, promoting, inhibition, transformation, and causal multiplicity.

The function of an organism is always affected directly or indirectly by those of other

organisms and their complex interactions. When a certain component is to be modified, the effect of such treatment of functions of other components and the whole system must be considered. Therefore, the designation and implementation of agro-ecological engineering must consider these factors, and the space and resources must be utilized maximally by organisms in symbiotic communities.

All natural organism survives through competition for space and resources as well as symbiosis for sustainability. Those species lacking either competition or symbiosis are weaker in vitality and will eventually be replaced by others. This is a common rule exists in both natural and man-made ecosystem. Although relationships from mutualism to competition may exist among organisms of a co-ecosystem, agro-ecological engineering promotes symbiosis. In such harmonious relationships of close association components of a co-ecosystem cooperate with and benefit from each other. Symbiosis among organism or production section can serve to economize raw materials, energy, time and space, as well as to acquire multiple benefits. The greater the differences among the symbiosis and the more diversified the ecosystems, the more benefits the symbiosis can derive (Wang, 1990).

3.2.2 Principle of ecosystem balance

Ecosystems are rich in information networks comprising physical and chemical communication flows that connect all parts and steer or regulate the system as a whole. Accordingly, ecosystem can be considered cybernetic in nature, but control functions are internal and diffuse rather than external and specified as in human engineered cybernetic devices. Redundancy-more than one species or the component capable of performing a given function-also enhances stability. The degree to which stability is achieved varies widely, depending on the rigor or the environment as well as on the efficiency of internal controls. The stability actually achieved by a specific ecosystem depends not only on its evolutionary history and on the efficiency of its internal controls, but also on the input of the environment and perhaps also on its complexity. Functional complexity seems to enhance stability, but cause and effect relationships between complexity and stability are little understood. Some suggested that a diversity of species should enhance the stability of the biotic community, but species diversity per se has not proven to be strongly correlated with stability. However, the theory of redundancy suggests that a moderate diversity of species, each capable of performing key functions, should contribute to controlled responses.

3.2.3 Principle of energy and material flux

Energy and material flux, as the two important processes of ecosystems, are the links of ecosystem structure and function. Therefore, the flow of energy and cycling of material are the basic interactions inherent in the ecosystems. The goal of human activities is to obtain higher outputs of material and energy by changing the efficiencies and ways of material and energy flux and regulating the ecosystems.

Energy is the dynamic base of ecosystems. It provides energy sources for life maintenance and other ecological processes operation in ecosystems. Some incoming solar energy is transformed and upgraded in quality by the community, but most of it is degraded and passes through and out of the system as low quality energy. Energy can be stored and then "fed back" or exported, but it can not be reused. In contracts to energy, matter, including water and vital nutrients (carbon, nitrogen, sulphur, phosphorus etc.) can be used over and over again. Food chains are another important concept for the implementation of agro-ecological engineering. According to the two laws of thermodynamics, energy inflow balances the outflow and each energy transfer is accompanied by dispersion of energy into unavailable heat (i. e. respiration). Secondary productivity trends to be about 10% at successive trophic levels. The unavailable part of energy consists of two parts. One part is used in grazing food chain and loses a great deal in the form of transpiration. At the same time a large amount of energy enters directly into the detritus food chain and participates in the

biogeographical without any economical effect.

Biogeochemical cycles are recycling pathways through which the chemical elements, including all elements of protoplasm, tend to circulate in the biosphere in characteristic paths from environment to organisms and back to the environment. These more or less circular paths are known as biogeochemical cycles. The movement of the elements and inorganic compounds that are essential to life can be conveniently designated as nutrient cycles. Although the flow of energy and cycling of materials exist both in natural and man-made ecosystems, basic features of this process differ greatly between them. One distinct characteristic of the material and energy flow in man-made agricultural ecosystems is that a relatively high proportion of the produce is transferred to outside of the systems. In order to keep system sustainable, supplementary input of materials and energy should be provided through soil improvement measures, crop cultivation technologies, insect and pest protection measures and production processing measures. These subsidies come either from biological sources or from fossil energy.

3.2.4 Principle of market regulation

In the periods of market economy, market regulation plays a role as a lever that regulates the balance between supplies and demands. Thus, market regulation is the basic principle of economics. Contrasted with natural ecosystem, the outputs of agro-ecosystem as products are finally reflected its value through the market. Thus, the designations and practices of agro-ecological engineering must consider this principle. In conventional agriculture, the products are always simples, it is easily suffered the risks of market. Agro-ecological engineering, adversely, usually takes a comprehensive or integrated approach. It expands the narrow views formed in traditional agriculture. The components of agro-ecological engineering practice may include farming, animal husbandry, fishery, forestry, horticulture, and sideline production. Sideline production includes small processing industries and cottage industries. Food supplies means not only grains but also eggs, meat, milk, fish, fruit, and vegetables. In other words, agro-ecological engineering emphasizes multi-management and multi-products in order to minimize the risks suffered from market.

Besides the above, there are some other principles, such as regeneration (Wang, 1990), also play a vital role in designation of agro-ecological engineering.

4 Role of agro-ecological engineering

4.1 Maximum utilization of natural resources

The basic unit of study and treatment of agro-ecological engineering is a complex system-agro-ecosystem. In an agro-ecosystem, all niches are full with by different species. These species are arranged according to their different physiological and ecological characteristics (such as phenophase, size, shape, etc.). Therefore, the structures of agro-ecosystem are more complex than that of monocultural agriculture. In spatial structure, they have multi-layer in both aboveground and underground and the resources (such as radiative energy, nutrient and water etc.) of different levers can be used by different species. In temporal structure, they have different phenophase and the resources can be used seasonally. It says that the agro-ecosystem have complementarities in temporal, spatial and resources. Moreover, land resources in agro-ecological engineering means not only arable land but also grassland, mountains, seabeaches, and inland water surfaces. It expands the conception of land resources and increases the efficiency of land usage. Thus, the definite resources in a region can be utilized maximally in agro-ecological engineering.

4.2 Improving agricultural environment

Agro-ecological engineering is always designed as an ecosystem with multi-component and multistory. It means that its vegetative cover is higher than that of monoculture. Therefore, agro-

ecological engineering is suggested to have the ability to improve agricultural environments better. Such as in agroforestry systems and shelterbelts, the canopy of tree species can reflect solar radiancy, reduce wind speed and surface temperature and increase air humidity. Zhao (Zhao, 1993) reported that shelterbelts in North China Plain could reduce wind speed by 20%—40% and thereby improved surface soil moisture by 13%. Furthermore, abundant vegetative cover, including nonliving plant residues (litters), can intercept rainwater in rainy season and reduce water erosion and rapid runoff. Biological barrier hedges is always used as a technology for preventing soil erosion in sloping land. Organic matter, turnover from litter, is important to soil water retention, soil structure, and cation exchange capacity. It is also the source of a large portion of the nutrients needed by plants. Moreover, organic matter harbors large numbers of soil microbial species that can be helpful to meliorate soil physical and chemical properties and accelerate the material cycle. Overall, agro-ecological engineering can control soil erosion and desert encroachment (such as up-and middle-river shelterbelts of Yangtze River Three North Shelterbelts), improve ecosystem's microclimate and ameliorate soil quality and tilth. It also had been reported to have functions for mitigating greenhouse effects (Wang, 1995).

4.3 Maintaining agro-ecosystem health

When an ecosystem is designed and practiced according to the principles of agro-ecological engineering, the following fundamental approaches are often applied: (1) adding new food chain components; (2) promoting parallel connections of symbiosis; (3) multi-layer use of wastes as resource; and (4) the restoration of ecosystems. The temporal and spatial difference of each species can increase the complexity of ecosystem and resist disturbance (such as pest, climate fluctuation etc.). Therefore, adding food chain and increasing species diversity can enhance the stability of ecosystem. A stable ecosystem has a potential for self-regulation when disturbed. Transformation of waste into useful resources is an important excrement are used to generate methane as fuel, to substitute for fertilizer, to cultivate edible fungi, and to raise earthworms and maggots as feed for fish, pigs and poultry (Mitsch, 1991; Yan, 1992). Thus, the waste materials can be purified in the ecosystem.

Agro-ecological engineering also pays great attention to using organic fertilizers and biological pest control. Chemical input, while not excluded, is limited to a certain extent. It does not pollute the ecosystem. If it is necessary, human intervention always play an important role in maintaining the ecosystem's stability. Therefore, the designations and practices of agro-ecological engineering can always maintain the ecosystem's health for protecting environments and increasing productivity.

4.4 Enhancing ecosystem productivity

Productivity is the index of an ecosystem's stability and activity. Usually, the complexity and species diversity can increase the ecosystem stability and productivity (Odum, 1978). Although some ecologists have questioned the universality of this contention (Krebs, 1985), most studies have confirmed the relationship (Sugden, 1990). The goal of human activities for managing ecosystem is often to maintain its stability and obtain higher productivity. In contrast to monoculture, the complexities and diversities of agro-ecosystem are increasing greatly. Many studies about agroforestry, one type of agro-ecological engineering, show that the productivity are higher than that of farming system or tree plantation (Feng, 1992; Wang, 1992; Zhao, 1993).

4.5 Increasing economic incomes

Contrasted with monoculture, agro-ecological engineering can increase farmer's economic incomes by introducing better varieties and crops with higher economic value, providing multiple products and allowing farmers to earn additional income in their villages small processing industries. It is expected to overcome or mitigate the risks of monoculture, particularly those of irregular rainfall, market fluctuations, pest outbreaks, insufficient weeding and high fertilizer

costs. Therefore, it is not neglected the farmer's short-term economic benefits in emphasizing the protection of environments for medium-term and long-term benefits.

4.6 Enhancing social benefits

Agro-ecological engineering emphasizes not only agriculture but also small village industries. It means the surplus labor forces of the country can be planted well. Furthermore, agro-ecological engineering provide multiple products that can play an important role in maintaining the market stabilization.

From above, the agro-ecosystems, which designed based on the principles of agro-ecological engineering, are capable of achieving quality, high production with low consumption, and yielding plenty of economic and environmental benefits. The ultimate goal for the development of agro-ecological engineering is to achieve integrated ecological, economic and social effects, or in other words, to implement the concept of sustainable development in the rural area.

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