International Journal of

Agricultural Research

ISSN 1816-4897

Academic Journals Inc.

www.academicjournals.com

International Journal of Agricultural Research 2 (7): 559-570, 2007
ISSN 1816-4897

Emergy Evaluation of Two Agricultural Systems with Different Economic Surroundings in Liaoning Province of Northeast China

[1]Gang Wu, [1,3]Fu Xiao and [1,2]Hong-Bo Shao
[1]State Key Laboratory of Urban and Regional Ecology,
Research Center for Eco-Environmental Sciences,
Chinese Academy of Sciences, Beijing 100085, China
[2]Institute of Life Sciences, Qingdao University of Science and Technology,
Qingdao 266042, China
[3]Graduate School of Chinese Academy of Sciences, Beijing 100039, China

Abstract: Emergy analysis was used in this study to analyze two agricultural systems in Liaoning province of Northeast China and compare resource use, productivity, environmental pressure and sustainability over a temporal scale of 25 years. Structure and development of indigenous economy was also considered when the development of agricultural production was analyzed. Chaoyang is an important base for agricultural production in Liaoning province, while Fushun is a main industrial base of Northeast China. Though having better climatic and ecological conditions compared to Chaoyang, Fushun agricultural production was invested in more non-renewable resources outside per unit area than Chaoyang did. The results of analysis demonstrated a growing reliance on purchased resources in two agricultural systems. The fraction of purchased inputs had grown by 1.88 times and 1.08 times from 1980 to 2005 in Chaoyang and Fushun agricultural systems, respectively. For the reason of higher dependence on purchased non-renewable resources, production process placed greater load on the environment. And the ecological sustainability of studied systems decreased dramatically during 25 years. In this process, Chaoyang agricultural production expressed a more rapid decrease on sustainability, with Sustainability Index (SI) decreasing from 1.25 to 0.11. The similar process of industrialization brought more pressure to the weaker environment of Chaoyang. In 1980, the Environmental Load Ratio (ELR) in Chaoyang agricultural system was 2.99, when this ratio in Fushun agricultural system was 2.30. In 2005, the ELR of Chaoyang agricultural system had increased to 11.61, when this ratio in Fushun agricultural system was 7.86. While the use of higher quality inputs resulted in the greater yields per area from two agricultural systems, efficiency of these investment did not increase correspondingly. Environmental protection and restoration rather than greater amount of purchased non-renewable resources should be a good strategy to reduce the loss of non-renewable indigenous resources in two systems.

Key words: Emergy analysis, agricultural system, ecology economics, environmental pressure, sustainability

INTRODUCTION

Agriculture is assuredly the primary measures through which human society accesses to ecological systems. It's a principal measures of providing food and fiber for populations and it fits the plan for economic (Odum and Odum, 1998). A market is necessary to buy the produce and to provide the

Corresponding Author: Dr. Hong-Bo Shao, State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China Tel: +86 10 82428469

money required for the fuels, fertilizers, labor, goods and services needed to grow, harvest and transport the crop. On the other hand, components of nature including farm area with solar energy, water, wind, soil are critical resources for growing. Fertilizer, chemicals, energy resources and farm equipment for planting, weeding and harvesting must be provided for agricultural system. Furthermore, because of its connection with nature, agricultural activity will affect environmental quality through soil and water mainly and be restricted mightily by quality of soil, precipitation, climate and many other ecological conditions (Bastianoni *et al*., 2001).

In China, industrial and agricultural production generally coexist in the same city or region but their ratio of structure is usually regulated according to its geographical position, natural environment and local ore or climatic resources, just as the two cities in this research. Fushun is an industrial city and also an important industrial base of northeast China. Industrial production is the primary foundation and key driving force to local economy. Agricultural production provides attachment for local people's subsistence. On the contrary, Chaoyang is an important base for agricultural production and supply in Liaoning province. Industrial production is mainly dependent on local ore recourse. Difference between their economic structures is reflected in their industrial and agricultural output value. By taking 2005 for instance, agricultural and industrial output value of Chaoyang are 67,171.4 dollars and 99,000.7 dollars, respectively. These values are about 26.3 and 38.7% of regional gross production value. While, in Fushun, agricultural and industrial output value of that year are 34,096.4 dollars and 255,326.4 dollars, respectively and about 7.3 and 54.3% of regional gross production value, respectively.

Agriculture is not a single behavior, which is not connected with local industrial and economic development. Economic growth and cultural development brought a shift from food and wood energy fueling society, to coal and oil as the main driving forces in agriculture (Odum, 1971; Goldember, 1992; Haden, 2003). Traditional agriculture mainly is dependent on locally available energy sources, such as sun, soil, wind and rain, in combination with human and animal labor (Haden, 2003). The industrial revolution expanded the range of available energy. More and more new auxiliary energy sources produced greater yields and more serious environmental impact simultaneously (Jay *et al*., 2006). Industrial and economic development can affect and be reflected in agricultural production (Haden, 2003).

In this study, two agricultural systems were studied to compare their development of resource use and environmental impact over the years studied. One of them is an agricultural subsystem of an agricultural city, Chaoyang. The other system belongs to an industrial city, Fushun. In China, because of historical reasons, it's after 1978 that the major transition from traditional agriculture to modern one occurred. Rural economy has improved stably in nearly thirty years. The emergy flows supporting Chaoyang and Fushun agricultural systems were evaluated for the years 1980, 1985, 1990, 2001 and 2005 to gain a detailed, comparative view of the changes in the resource flows of these two systems for instructing agricultural and industrial sustainable development in China.

MATERIALS AND METHODS

Descriptions of the Systems

Chaoyang is located between Inner Mongolia Plateau and northeast Plain to the west of Liaoning province, China. It lies between north latitudes 40°24′ and 42°20″, east longitudes 118°50′ and 121°20′. Chaoyang has a continent monsoon climate of the north temperature zone. For the reason of mountains to the south of Chaoyang, warm and wet air current from the ocean can hardly affect this region. While dry and cold air from the Mongolia Plateau brings on the semi-arid and semi-wet, arid climate comes easily in Chaoyang. Its annual average rainfall is usually around 450 mm. Vegetation of this region belongs to semi-arid warm temperate deciduous broad-leaved forest zone but in an intermediate zone between North China floras and Mongolia Plateau. There is a transition to arid steppe zone to the north as well as an intrusion of more vegetation from Mongolia flora.

Chaoyang is an agricultural region. Area of agricultural system covers 6612 km^2. Crop production and stock breeding are primary components of agricultural economics in this area. Because of the lower precipitation and lack of water resource in Chaoyang region, 78% of irrigation water came from groundwater. Corn, cereal, sorghum, soybean and wheat are staple crops. Mode of agricultural production in Chaoyang changed from traditional farming to modern agriculture along with expanding economy and developing technology just the same as the most of else regions of China. Because of cultivation for ages, soil fertility had decreased. Erosion areas, judged by the provincial territorial survey in 1986, were more than 1,837,988 ha and 80% of gross land areas. Erosion in the worst degrees was about 50% of total erosion areas.

Fushun lies between north latitudes 41°41′ and 42°38″, east longitudes123° 39′ and 125°28′. It has an oriental continent monsoon climate of the warm temperature zone which is cool and wet. Annual average rainfall in this area is from 750-800 mm. Vegetation of this region belongs to conifer-broad leaved mixed forest zone. In combination with some species in north China and Mongolia flora, plants of this area mainly belong to Changbaishan Mountain flora.

Fushun is an integrative heavy industrial region based on energy and material process. The area of agricultural system covers 1696.07 km^2. Agricultural production is foundation for local industrial production and economic development. Staple crops in this area are rice, corn, soybean, sorghum and cereal. Erosion areas were 273,961 ha and nearly 25% of gross land areas according to the provincial territorial survey in 1986. Erosion areas in the low and moderate degrees were 253,337 and 20,624 ha, respectively.

Overview of Emergy Analysis Method

Emergy analysis is a technique of quantitative analysis which determines the values of valuable and invaluable resources, services and commodities in common units of the solar energy which took to make them (Bastianoni *et al*., 2001). This method has been applied to studies in a variety of both temporal and spatial scales to evaluate history, assess environmental policies and management, energy policies and simulate models as decision support (Odum and Odum, 1988; Odum, 2000; Ulgiati *et al*., 1994). Emergy is defined as the sum of all inputs of available energy directly and indirectly required by a process to provide a given product or service, when the inputs are expressed in units of the same form of energy, usually solar emjoules (sej) (Odum, 1996; Brown and Ulgiati, 1997). Sunlight, fuel, electricity, human service and all other resource flows can be put on a common basis by expressing them in the emjoules of solar energy required to produce them (Brown and Ulgiati, 2004a). Transformity, the conversion factor of all the process inputs into solar energy, is the basis of emergy analysis. Transformities have been calculated for a wide variety of resources, commodities and renewable energies and can be found in past works (Odum, 1996).

Terms from Odum (1996) refer to the emergy flows supporting a system. R is the sum of the renewable emergy flows supporting the system, such as sun, rain, wind; N is the sum of nonrenewable resources from within the system boundary; F is the sum of all imported energy and materials; Y is the yield from the system. Various emergy indices and ratios provide insight into the organization of a system. The emergy self-sufficiency versus the imported resource dependence of a system can be determined by emergy analysis. The degree to which the energy and materials dissipated by a production process are of a renewable or non-renewable character can be calculated from the results of an emergy analysis. More over, the Emergy Yield Ratio (EYR), the Environmental Load Ratio (ELR) and the Sustainability Index (SI) are main indicators based on emergy accounting which have been introduced to compare the sustainability of different production processes (Ulgiati and Brown, 1998).

Emergy Evaluation of Chaoyang and Fushun Agricultural Systems

Table 1 denoted the specific inputs that comprise the renewable resources, non-renewable resources and purchase resources identified for each system. Results of quantifying annual inputs to each system in raw units (joules, grams, dollars) for six years were multiplied by transformities to calculate the quantity of solar emjoules. For comparison, these values were quantified for area in solar emjoules per kilometer per year.

For Chaoyang agricultural system, the rain and wind input were alternatively the largest of the climatological renewable emergy sources. The larger one was taken to represent the total climatological renewable flows during different years. Rain input was the largest of the renewable emergy sources in Fushun agricultural system and was taken to represent the total renewable emergy input. These were done to avoid double counting, because of the same source of all the climatological renewable energy flows (Lefroy and Rydberg, 2003). Irrigation water and top soil loss, which were not replaced within an annual cycle, were considered as the non-renewable resources involved in agricultural production. Emergy ratios and indices were calculated by aggregating data from Table 1. The percentage of renewable and locally free resources quantified the main reliance of each agricultural production process. The Emergy Yield Ratio (EYR) compared units of exported emergy (Y) with emergy imported (F), which quantifies the effectiveness of purchased resources to direct local resources towards the production of agricultural yield. The Environmental Load Ratio (ELR) of a system was formulated as the ratio of purchased and non-renewable resources (F+N) to renewable resources (R) , which indicates the pressure a process places on local ecosystems due to the input of energy and materials that are not renewable or locally available. The Sustainability Index (SI) was calculated as the ratio of EYR to ELR, which measures the production of a system relative to the environmental pressure (Ulgiati and Brown, 1998; Haden, 2003).

RESULTS

Renewable Resources

The analysis showed that the renewable emergy flow (R) supporting the Chaoyang agricultural system was the highest in 1990, at 3.44E20 sej $year^{-1}$, because of a higher annual average rainfall. For the same reason, Fushun agricultural system had the greatest amount of renewable emergy inputs, at 1.44E20 sej $year^{-1}$, during 1995. Due to covering larger area, Chaoyang agricultural system had the greater input of total renewable resources in the six years studied (Table 1).

When area was considered, the result was different slightly. Fushun agricultural system had the greater input of renewable resources per km^2 in every year investigated. There was the greatest difference of 4.70E16 sej $year^{-1}$ km^{-2} in 1995. In 1995, Fushun agricultural system had total renewable emergy inputs, at 8.99E16 sej $year^{-1}$ km^{-2}. The local renewable emergy per unit area supporting Chaoyang agricultural system in 1995 was 4.30E16 sej $year^{-1}$ km^{-2}, or 47.8% of Fushun agricultural system. In 2001, renewable inputs per unit area of these two systems had the slightest difference of 0.86E16 sej $year^{-1}$ km^{-2}. Local renewable emergy inputs contributing to Chaoyang agricultural system accounted for 82.9% of Fushun agricultural system in 2001.

Non-renewable Resources

The amount of non-renewable resources (N) contributing to Chaoyang agricultural system in the form of soil erosion and irrigation water, with most of this in the form of soil erosion, decreased from 1980 to 2005. Due to the shrinkage of cultivated land and water saving, contribution of irrigation water decreased. Total locally available non-renewable emergy that contributed to production in 2005, at 5.31E20 sej $year^{-1}$ decreased by 1.88% from 1980, at 5.21E20 sej $year^{-1}$ (Table 1).

From 1980 to 2005, non-renewable resources used for Fushun agricultural system showed fluctuation and a downward tendency, with irrigation water being the dominant emergy flow. The

Table 1: Overview of the evolving agricultural system of Chaoyang and Fushun imported and yielding emergy

No.	Item	Emergy or energy flows 1980	1985	1990	1995	2001	2005
A. Agricultural system of Chaoyang							
Renewable resources (R)							
1	Sunlight (sej year^{-1})	3.12E+19	3.12E+19	3.12E+19	3.12E+19	3.12E+19	3.12E+19
2	Wind (sej year^{-1})	2.76E+20	2.76E+20	2.76E+20	2.76E+20	2.76E+20	2.76E+20
3	Rain, geo-potential (sej year^{-1})	2.61E+16	5.33E+16	6.18E+16	5.11E+16	3.47E+16	4.29E+16
4	Rain, chemical (sej year^{-1})	1.45E+20	2.96E+20	3.44E+20	2.84E+20	1.93E+20	2.39E+20
	Total renewable[a] (sej year^{-1})	2.76E+20	2.96E+20	3.44E+20	2.84E+20	2.76E+20	2.76E+20
	Renewable per unit area (sej year^{-1} km^{-2})	4.18E+16	4.48E+16	5.20E+16	4.30E+16	4.18E+16	4.18E+16
Non-renewable resources (N)							
5	Irrigation water (sej year^{-1})	5.59E+19	5.54E+19	5.29E+19	5.05E+19	4.76E+19	4.57E+19
6	Soil. (sej year^{-1})	4.75E+20	4.75E+20	4.75E+20	4.75E+20	4.75E+20	4.75E+20
	Total non-renewable[b] (sej year^{-1})	5.31E+20	5.31E+20	5.28E+20	5.26E+20	5.23E+20	5.21E+20
	Non-renewable per unit area(sej year^{-1} km^{-2})	8.03E+16	8.03E+16	7.99E+16	7.95E+16	7.91E+16	7.88E+16
Purchased resources (F)							
7	Fertilizer (sej year^{-1})	1.83E+20	1.50E+20	1.85E+20	3.42E+20	3.63E+20	3.37E+20
8	Plastic film (sej year^{-1})	1.54E+15	1.88E+17	4.33E+17	8.15E+17	7.35E+17	1.46E+18
9	Pesticides (sej year^{-1})	2.43E+18	2.21E+18	3.86E+18	2.37E+18	1.74E+18	2.52E+18
10	Electricity (sej year^{-1})	8.74E+19	1.19E+20	1.57E+20	2.54E+20	3.43E+20	7.74E+20
11	Labor and services (sej year^{-1})	2.28E+19	5.90E+19	1.67E+20	4.22E+20	6.57E+20	1.57E+21
	Total Purchased resources[c] (sej year^{-1})	2.96E+20	3.30E+20	5.14E+20	1.02E+21	1.37E+21	2.69E+21
	Purchased resources per unit area (sej year^{-1} km^{-2})	4.47E+16	4.99E+16	7.77E+16	1.55E+17	2.07E+17	4.06E+17
Yield (Y)							
12	Food crops (j year^{-1})	1.07E+16	9.99E+15	1.65E+16	1.90E+16	2.48E+16	3.23E+16
13	Economic crops (j year^{-1})	6.21E+14	3.43E+15	1.12E+15	1.60E+15	1.07E+15	9.66E+14
14	Vegetable (j year^{-1})	3.95E+14	8.57E+14	1.14E+15	2.19E+15	1.49E+15	2.91E+15
15	Fruit (j year^{-1})	7.42E+13	9.80E+13	1.18E+14	3.80E+14	1.24E+14	5.45E+14
16	Aquatic production (j year^{-1})	5.74E+11	8.59E+11	1.84E+12	3.81E+12	7.55E+12	1.22E+13
17	Livestock production (j year^{-1})	8.35E+14	1.20E+15	1.73E+15	2.29E+15	2.31E+15	7.55E+15
	Total yield (j year^{-1})	1.26E+16	1.56E+16	2.06E+16	2.55E+16	2.98E+16	4.43E+16
	Yield per unit area(j year^{-1} km^{-2})	1.91E+12	2.36E+12	3.11E+12	3.86E+12	4.51E+12	6.70E+12
	Transformity (sej j^{-1})	8.75E+04	7.42E+04	6.74E+04	7.18E+04	7.26E+04	7.86E+04
B. Agricultural system of Fushun							
Renewable resources (R)							
1	Sunlight (sej year^{-1})	7.04E+18	6.83E+18	6.72E+18	6.66E+18	6.64E+18	6.63E+18
2	Wind (sej year^{-1})	5.67E+19	5.50E+19	5.41E+19	5.36E+19	5.35E+19	5.34E+19
3	Rain, geopotential (sej year^{-1})	1.15E+16	1.46E+16	1.13E+16	1.59E+16	8.86E+15	1.27E+16
4	Rain, chemical (sej year^{-1})	1.05E+20	1.33E+20	1.03E+20	1.44E+20	8.06E+19	1.16E+20
	Total renewable (sej year^{-1})	1.05E+20	1.33E+20	1.03E+20	1.44E+20	8.06E+19	1.16E+20
	Renewable per unit area (sej year^{-1} km^{-2})	6.18E+16	8.09E+16	6.35E+16	8.99E+16	5.04E+16	7.26E+16
Non-renewable resources (N)							
5	Irrigation water (sej year^{-1})	8.42E+19	7.67E+19	6.97E+19	8.16E+19	7.04E+19	7.95E+19
6	Soil. (sej year^{-1})	2.67E+19	2.59E+19	2.55E+19	2.53E+19	2.52E+19	2.52E+19
	Total non-renewable (sej year^{-1})	1.11E+20	1.03E+20	9.52E+19	1.07E+20	9.56E+19	1.05E+20
	Non-renewable per unit area(sej year^{-1} km^{-2})	6.54E+16	6.23E+16	5.88E+16	6.66E+16	5.98E+16	6.55E+16
Purchased resources (F)							
7	Fertilizer (sej year^{-1})	4.97E+19	6.23E+19	7.49E+19	9.28E+19	9.88E+19	1.21E+20
8	Plastic film (sej year^{-1})	2.73E+16	2.91E+17	5.54E+17	8.36E+17	7.25E+17	6.56E+17
9	Pesticides (sej year^{-1})	7.73E+17	9.09E+17	1.04E+18	1.10E+18	1.48E+18	1.93E+18
10	Electricity (sej year^{-1})	7.21E+19	8.10E+19	1.51E+20	1.53E+20	1.70E+20	3.50E+20
11	Labor and services (sej year^{-1})	7.89E+18	1.59E+19	4.19E+19	9.65E+19	1.32E+20	3.34E+20
	Total Purchased resources (sej year^{-1})	1.31E+20	1.60E+20	2.69E+20	3.44E+20	4.04E+20	8.07E+20
	Purchased resources per unit area(sej year^{-1} km^{-2})	7.69E+16	9.74E+16	1.66E+17	2.15E+17	2.52E+17	5.05E+17
Yield (Y)							
12	Food crops (j year^{-1})	5.39E+15	5.11E+15	6.84E+15	3.73E+15	6.38E+15	7.08E+15
13	Economic crops (j year^{-1})	4.09E+13	1.21E+14	5.59E+13	1.45E+14	1.82E+14	7.50E+13
14	Vegetable (j year^{-1})	5.35E+14	8.09E+14	6.50E+14	5.30E+14	5.70E+14	5.93E+14
15	Fruit (j year^{-1})	1.22E+13	1.31E+13	3.16E+13	1.08E+14	1.31E+14	1.66E+14
16	Aquatic production (j year^{-1})	3.41E+12	9.88E+12	1.70E+13	1.57E+13	2.87E+13	4.49E+13
17	Livestock production (j year^{-1})	2.29E+14	4.55E+14	7.97E+14	2.39E+15	3.14E+15	3.40E+15

Table 1: Continued

No. Item	Emergy or energy flows 1980	1985	1990	1995	2001	2005
Total yield (j year^{-1})	6.21E+15	6.52E+15	8.39E+15	6.92E+15	1.04E+16	1.14E+16
Yield per unit area(j year^{-1} km^{-2})	3.66E+12	3.96E+12	5.18E+12	4.31E+12	6.52E+12	7.11E+12
Transformity (sej j^{-1})	5.57E+04	6.08E+04	5.57E+04	8.60E+04	5.56E+04	9.05E+04

Raw data about natural, resources and production for calculation mainly came from City Records of Chaoyang, Liaoning University Publishers, Office for Historical Records of Chaoyang, 1996; Soil erosion diversion and soil and water conservation planning of Chaoyang, Workstation for soil and water conservation of Chaoyang, 1988 and Local resource of Fushun, 1996, Fushun Planning Committee, Liaoning People Publishers

amount of non-renewable emergy flows supporting Fushun agricultural system in 1980 was the greatest, at 1.11E20 sej year^{-1}. In 1990, non-renewable inputs of Fushun agricultural system reached its lowest degree at 9.52E19 sej year^{-1}. The amount of locally available non-renewable emergy resources supporting Fushun agriculture in 2005 decreased by 5.41% from 1980, also due to the shrinkage of cultivated land. The fluctuation of non-renewable inputs was concerned with annual change of precipitation and water storage. Dam was built to impound and collect water for irrigation in Fushun agricultural system.

As far as total quantity was concerned, more locally available non-renewable resources were used up by Chaoyang agricultural production than by Fushun. Similarly in terms of emergy consumption per unit area, more non-renewable emergy per unit area contributed to Chaoyang agricultural production in comparison with Fushun agricultural production in different years.

Purchased Resources

Purchased resources putted into Chaoyang agricultural system chiefly included fertilizer, plastic film, pesticides, electricity and labor. The amount of purchased resources involved in agricultural production increased dramatically, from 4.93E21 sej year^{-1} in 1980 to 3.16E22 sej year^{-1} in 2005. Emergy flows in the form of fertilizer, electricity and labor made the greatest contribution to Chaoyang agricultural production, totally reaching more than 99% of purchased emergy. Fertilizer had been the dominant emergy flow of purchased resources until 1995. It represented from 61.89% of the total purchased inputs in 1980 to 12.55% in 2005. There was a dramatic increase in the quantity of human labor from 7.73% of the total purchased resources in 1980 to 58.49% in 2005 and had been the greatest purchased inputs after 1995. Plastic film has begun to play its role in Chaoyang agricultural production and spread the technology to the whole region since 1980. Purchased emergy in forms of plastic film, labor and electricity had increased dramatically, at 94169, 6776 and 785%, respectively, over the period from 1980 to 2005. The quantity of fertilizer and pesticides emergy flows increased not so fast at 84 and 3.5%, respectively.

Fushun agricultural system had the similar composition and distribution of purchased emergy as Chaoyang did. Electricity, human labor and fertilizer were the first three purchased emergy flows supporting Fushun agricultural production, totally reaching more than 99% of purchased resources, with the quantity of electricity always being the greatest flow. Similar trend of fertilizer and labor inputs was found in Fushun agricultural system that 1995 proved to be a turning point. Proportion of fertilizer decreased from 38.1% in 1980 to 15.0% in 2005 and has been the third greatest purchased inputs after human labor since 1995. Human labor respectively accounted for 6.0 and 41.4% of the purchased resources in 1980 and 2005 and was the fastest growing flow of the whole purchased emergy. The amount of labor and plastic film inputs increased by 4136 and 2303%, respectively, during the years from 1980-2005. The emergy support provided from electricity, pesticides and fertilizer grew at 385, 150 and 143%, respectively.

It's obvious that Chaoyang agricultural system had greater inputs of nearly every kind of purchased emergy compared to Fushun. But when area was considered, every purchased input per unit area except for human labor proved significantly greater for Fushun agricultural system compared to Chaoyang. For this reason, the emergy of purchased and totally used resources per unit area was greater for Fushun agricultural system as Table 1.

Both totally purchased and the whole used resources for agricultural production per unit area represented increase every year. With regarded to purchased inputs, the growth rate of purchase inputs supporting Chaoyang agricultural production is greater in comparison with Fushun, from 4.47E16sej year^{-1} km^{-2}in1980 to 4.06E17 sej year^{-1} km^{-2}in 2005. That was an 8.1 times of increase in 25 years. The amount of purchased resources inputted in Fushun agricultural system increased by 5.6 times during 25 years. This input accounted for 7.69E16 sej year^{-1} km^{-2} in 1980 and 5.05E17 sej year^{-1} km^{-2} in 2005.

In terms of totally used emergy resources per unit area, the amount of this flow for Chaoyang agricultural system in 1980 was 1.67 E17 sej year^{-1} km^{-2} , which accounted for 82% of this emergy flow to Fushun agricultural system. In 2005, this input had increased to 5.27E17 sej year^{-1} km^{-2} , which represented 82% of the whole used emergy in Fushun agricultural system.

Yields and Transformities

The multiple products totally yielded from Chaoyang agricultural system increased from 1.26E16 j year^{-1} in 1980 to 4.43E16 j year^{-1} in 2005, with a 2.5 times or more of increase (Table 1). The emergy assigned to the yield from the agricultural system was calculated by total renewable, non-renewable and purchased inputs (Jay *et al*., 2006), which increased from 1.10E21 sej year^{-1} in 1980 to 3.48E21 sej year^{-1} in 2005. Agricultural production yielded from Fushun agricultural system totaled to 6.21E15 j year^{-1} in 1980 and 1.14E16 j year^{-1} in 2005, with emergy assigned to the yield 6.11E20 sej year^{-1} and 1.48E21 sej year^{-1}, respectively. The per unit area yield of production from Fushun agricultural system was greater compared to Chaoyang agricultural system. The per unit area yield, in joule, from Chaoyang agricultural system grew at a faster rate. In 1980, it accounted for 52% of the per unit area yield from Fushun agricultural system. When it came to 2005, the per unit area yield from Chaoyang agricultural system had increased to 94% or more of the per unit area agricultural yield of Fushun. As a result, transformities were calculated for two agricultural systems as Table 1 showed.

Emergy Ratios and Indices

Due to the increase of production reliance on purchased resources, the fractions of renewable and locally free resources decreased in Chaoyang and Fushun agricultural system. Table 2 represented fraction use of locally renewable, free and purchased resources in Chaoyang and Fushun agricultural system, respectively over the years studied. The percentage of purchased input for Fushun agricultural system prominently increased from 0.38 of total inputs in 1980 to 0.79 of total inputs in 2005, which

Table 2: Emergy indices for the two systems over studied years were calculated by aggregating data from Table 1

Name of index	Expression	System	1980	1985	1990	1995	2001	2005
Fraction of use locally renewable	R/U	Chaoyang	0.25	0.26	0.25	0.16	0.13	0.08
		Fushun	0.30	0.34	0.22	0.24	0.14	0.11
Fraction of use that is free	(N+R)/U	Chaoyang	0.73	0.71	0.63	0.44	0.37	0.23
		Fushun	0.62	0.60	0.42	0.42	0.30	0.21
Fraction of use purchased import	F/U	Chaoyang	0.27	0.29	0.37	0.56	0.63	0.77
		Fushun	0.38	0.40	0.58	0.58	0.70	0.79
Emergy yield ratio	Y/F	Chaoyang	3.73	3.51	2.70	1.79	1.59	1.30
		Fushun	2.65	2.47	1.74	1.73	1.44	1.27
Environmental load ratio	(F+N)/R	Chaoyang	2.99	2.91	3.03	5.44	6.84	11.61
		Fushun	2.30	1.97	3.54	3.13	6.19	7.86
Sustainability index	EYR/ELR	Chaoyang	1.25	1.21	0.89	0.33	0.23	0.11
		Fushun	1.15	1.25	0.49	0.55	0.23	0.16

demonstrated that agricultural production of this system more heavily relied on purchased resources. Chaoyang agricultural system used greater amount of locally free resources in forms of wind or rain, soil and irrigation water compared to Fushun. Dramatic turn was taken in 1995 when the fraction of purchased emergy was involved in Chaoyang agricultural system, at 0.56 of the whole used resources in 1995, exceeding the fraction of locally free resources and became the greatest fraction use. In 2005, Chaoyang agricultural systems had the highest percentage of purchased resources, which grew to 0.77 of totally used resources from 0.27 in 1980. The same turn was found from Fushun agricultural system in 1990. This transition indicated a reduced dependence on local resources.

The Environmental Load Ratio (ELR) and the Emergy Yield Ratio (EYR) are the main indices used to represent the sustainability of an economy or production process. When they are combined with the Sustainability Index (SI), a general measure of ecological sustainability is given. Table 2 describes the comparison of changes registered in the ELR, EYR and SI of these two agricultural systems for the years studied. For both Chaoyang and Fushun agricultural systems, the ELRs have been rising rapidly over the years studied. In 1980, ELRs for Chaoyang and Fushun agricultural systems were 2.99 and 2.30, respectively. And they had their greatest ELRs of 11.61 and 7.86 in 2005, respectively.

The Emergy Yield Ratio is especially applicable when analyzing agricultural systems where purchased resources are utilized to concentrate natural energies to produce yields (Jay *et al*., 2006). The lower Emergy Yield Ratio of Fushun agricultural system compared to Chaoyang agricultural system indicated its smaller contribution to the surrounding economy. The EYR decreased in Fushun agricultural system over the years studied, from 2.65 in 1980 to 1.27 in 2005. While for Chaoyang agricultural system, the EYR significantly decreased from 3.73 in 1980 to 1.30 in 2005.

The Sustainability Index is derived by dividing the EYR by the ELR of the system. For these two agricultural systems, increase of the ELRs and decrease of the EYRs over the years studied drove the Sustainability Indices down commensurately. For Chaoyang agricultural system, this decline respected even more noticeable. In 1980, the SI of Chaoyang agricultural system was 1.25, accounting for about 1.1 times of SI of Fushun agricultural system. After 1995, the SI of Chaoyang agricultural system decreased dramatically and came lower than the SI of Fushun agricultural system. In 2005 the Sustainability index of Chaoyang agricultural system has decreased to 0.11 and accounted for 0.69 of SI of Fushun agricultural system.

DISCUSSION

System Inputs

Locally renewable input supporting an agricultural system is a quantity relative to indigenous climate. The analyzed result of renewable emergy inputs per unit area indicated the advantage of renewable resources in Fushun agricultural system.

Irrigation water and top soil loss were included as the non-renewable resources for Chaoyang and Fushun agricultural production. Cultivation, exploitation and deforestation combined with heavy wind in Chaoyang region were primary reasons for serious soil erosion in this area. And because of the richness in water resources associated with rice cultivation, irrigation water became a mainly non-renewable inputs for Fushun agricultural system. Transforming all these inputs to a common basis showed the flatter agricultural surrounding for Chaoyang agricultural system. The great amount of emergy input in form of soil erosion resulted in a higher input of non-renewable resources for Chaoyang agricultural system. As a result, emergy associated with locally available resources to Fushun agricultural system was more evenly distributed between renewable and non-renewable inputs and Chaoyang agricultural production depended more on non-renewable resources from nature. Locally available non-renewable resources once became the mainstream of totally utilized emergy for Chaoyang agricultural production.

There was a dramatic increase in the quantity of human labor emergy from 1980-2005 for these two systems, which resulted in a rank transition between labor and other inputs in 1995. The reason for this increase partly was the rise of the amount of human labor contributing to agricultural production. But the primary reason was that farmers received more monetary income, with 39 times of increase, from 1980-2005. This increase indicates the total feedback of emergy from the economy to agriculture in the form of purchased serviced increase (Haden, 2003).

The higher annual emergy use per unit area for Fushun agricultural system indicates the higher average intensity of development in this system. Calculation of emergy inputs per unit area in different forms demonstrated that industrialized agriculture was earlier developed in Fushun agricultural system. Electricity became the greatest purchased input for Fushun agricultural system. But for Chaoyang agricultural production, fertilizer and then labor was alternately the largest purchased resource. And until now, more purchased resources annually used per unit area, in any forms except for human labor, were contributed to Fushun agricultural production compared to Chaoyang. Even though, the above analysis of locally available emergy demonstrated the superior ecological surrounding and resources foundation for agricultural production in Fushun. Industrialization of this area was the important driving force to industrialized agriculture.

Because of more highly depending on locally available resources, agricultural system usually develops more slowly than industrial system (Brown and Ulgiati, 2001, 2004b). And more feedback from surrounding economy system will improve indigenous agricultural production. As an industrial district, it's more easily for Fushun to provide purchased resources to its agricultural production compared to Chaoyang. Relatively weaker industrial and economic foundation was the reason for the smaller contribution of purchased resources per unit area to Chaoyang agricultural production.

Ratios and Indices

Fraction Use of Input

Analysis of fraction use of every input revealed the same trend in Fushun and Chaoyang agricultural systems that the fractions of renewable and locally free resources decreased for the years studied. In terms of locally resources, nonrenewable resources, such as groundwater and topsoil, made more contribution to agricultural production of Chaoyang. Conversely, Fushun agricultural system relied more greatly on locally natural ecological processes with higher fraction of renewable energies. Heavy reliance on renewable resources means a high dependence upon the variability of climatic input, such as rain. Difference of average annual precipitation between Chaoyang and Fushun leaded to the distinction in chief crop from these two agricultural systems. On the face of it, having an adverse climatic condition, natural ecological environment of Chaoyang simultaneously was subjected to a more excessive burden from its agricultural production compared to Fushun did.

Fraction of purchased resources correspondingly increased in Fushun and Chaoyang agricultural systems, since the conjugated relationship between fractions of locally free and purchased resources. As can be seen, the fraction of purchased resources involved in Fushun and Chaoyang respectively exceeded the fraction of free and became the highest percentage in1990 and 1995. It's partly that Chaoyang region had a relatively sufficient rainfall at 681.1 mm in 1990, which brought a heavy input of renewable resource. But the chief reason is the comparatively later start of agricultural modernization in Chaoyang.

As contrasted with natural ecosystems, crop system must use purchased resources to maintain its monoculture with low diversity (Altieri, 1995). During the years studied, fraction of use purchased outside had increased by 1.88 times in Chaoyang agricultural system and 1.08 times in Fushun agricultural system correspondingly. Economic growth brought an agricultural system with large dependence on outside resources. High dependence on purchased resources makes modern agricultural system more susceptible to economic fluctuations (Rydberg and Jansen, 2002). Changes in the amount and price of energy and equipment could adversely affect agricultural production.

Transformity and Emergy Yield Ratio

Till 2005, the margin between the fractions of use purchased resources in two systems have been narrow, which reflected the similar utilization structure of resources and the related agro-technology level of Chaoyang and Fushun agricultural systems. Advanced agro-technology and great amount of purchased inputs, such as fertilizer and pesticides, are doubtless factors to raise production. But this effectiveness is not infinite.

A production process relying on higher fraction of more diluted but free, environmental services and products often has a lower efficiency but greater potential. On the contrary, a system using greater amount of concentrated energies is usually more efficient but less stable (Jay *et al*., 2006). The lower transformity (except for years of 1995 and 2005) and greater yield per unit area of Fushun agricultural system relative to Chaoyang agricultural system demonstrates the benefits of investing in higher quality, non-renewable energies (Table 1). It indicates that Fushun agricultural system, with lower transformity, had the greater amount of yield when equal emergy inputs to each system. A higher transformity in Chaoyang agricultural system means greater amount of energy, which was lost as higher quality outputs and were produced by concentration and transformation from lower quality resources. Therefore, less energy is lost due to energetic transformations in the production process for the use of greater amount of higher quality resources in Fushun agricultural system.

But there are two leaps of transformities for Fushun agricultural system in 1995 and 2005, respectively. A considerable decrease in production caused by flood and consequently calculated more renewable inputs in the form of rain can answer to the leap of transformity for Fushun agricultural system in 1995, since transformity is the ratio of emergy input to available energy output. Except for these reasons, the leap of transformity for Fushun agricultural system in 2005 simultaneously resulted from double or more increase in emergy inputs of electricity and labor from 2001 to 2005. The similar increase was also found in the amount of electricity and labor inputs for Chaoyang agricultural system from 2001-2005.

When removing the effect of flood in Fushun region for years of 1995 and 2005, transformities of Fushun agricultural system shows relatively stable and lower over the years studied compared to Chaoyang agricultural system. It indicates that modernized agricultural production pattern had been established in Fushun agricultural production before 1980, without investing more advanced agro-technology to dramatically improve production. Fluctuation of transformities in Fushun agricultural system was mainly caused by the fluctuation of climatic factors, such as precipitation. While transformities of Chaoyang agricultural system expressed the lowest point in 1990, decreased transformity reflected the raised efficiency of Chaoyang agricultural production after 1980. And the lowest point in 1990 indicates the limited efficiency of auxiliary resources. A greater amount of purchased resources may result in a higher output. But production on unit area is limited by locally natural environment and technical specification. In the fact of adverse environmental condition, Chaoyang agricultural system would not have great potential for development. A more dependence of purchased and non-renewable flows will possibly lead to waste of infinite resources and degeneration of locally natural environment.

The emergy yield ratio is a emergy indicator of the yield compared to inputs other than local, which gives a measure of the ability of the process to exploit local resources (Brown and Ulgiati, 1997). Systems with a higher fraction of indigenous emergy produce a greater return per investment of non-renewable energy. Decreased EYR in Fushun and Chaoyang agricultural systems indicated their smaller net contribution to the economy beyond their operation. And lower EYR in Fushun agricultural system reflected a less efficient system compared to Chaoyang. Till 2005, EYR of Chaoyang agricultural system had approached to the EYR of Fushun agricultural system. The results of analysis demonstrated that even though large amounts of non-renewable resources and modern agro-technology were introduced, Chaoyang and Fushun agricultural production processes had not made correspondingly greater contribution to indigenous economy. There are indeed problems of inefficiency and waste in production processes of these two systems.

Environmental Load and Sustainability

Bringing a greater amount of renewable inputs, precipitation higher than usual should make calculations of ELR decrease. But heavy rain may actually do damage to production and environment. In 1995 and 2005, Fushun region gained a high annual average rainfall of 1178.9 and 951.5 mm, respectively, which resulted in a crop failure, in spite of a large amount of renewable emergy inputs from rain (Table 1). Abundant rainfall should be good news for an arid area such as Chaoyang. In 1990, Chaoyang region gained an higher annual average rainfall of 681.1 mm than usual, which resulted a high yield of agricultural produce without high dependence on purchased non-renewable resources.

Regardless of climatic fluctuation, growth of Environmental Load Ratios for these two agricultural systems indicates the environmental costs of using more purchased resources. The greater Environmental Load Ratio for Chaoyang agricultural system compared to Fushun agricultural system reflects its weaker supporting from environment.

With a higher yield ratio and a higher environmental loading, Chaoyang agricultural system had a sustainability index approximately similar to Fushun agricultural system. Decreased yield ratio and increased environmental loading produced a sharply dropped sustainability index in two agricultural systems. Due to the growth of fraction of purchased inputs, EYR in Chaoyang and Fushun agricultural system had been approximately equal till 2005. But development of agricultural production resulted in a heavier loading on Chaoyang indigenous environment. Lower level of sustainability can be observed and anticipated in Chaoyang agricultural production process from this study.

Under the condition of finite locally renewable resources, environmental protection and restoration should be a good strategy to reduce the loss of non-renewable indigenous resources in two systems. The utilization ratio of non-renewable resources should be raised for decreasing the fraction of purchased non-renewable inputs, which expresses close relationships to yield ratio and environmental loading and sustainability. As an agricultural region, environmental condition should be a major limiting factor. Due to an adverse natural environment, effects of agricultural production process on environment should be particularly paid attention to in Chaoyang agricultural system.

Quantified comparisons of the inputs of two agricultural systems on a common basis, emergy analysis provides a facility to study the sustainability and environmental impact of their processes. The results demonstrated that more dependence on non-renewable energies for large yields may be not a good strategy for regions with degraded ecological environment. Now in China, some regions are developing in the economic and natural environment even worse than Chaoyang. The results from Chaoyang agricultural system may be a good use of reference for regional economic development under the similar condition to Chaoyang.

Different form former emergy analysis on single agricultural system in some areas of China, this study took Fushun agricultural system as a reference case to reveal effects from industrialization to agricultural system by quantified presentation. Results from two agricultural systems demonstrated that, except for locally natural environment, economic surrounding should be a more interrelated factor to modern agricultural production. This deduction should be followed to study by quantifying analysis.

ACKNOWLEDGMENT

This work was jointly supported by Achievement Transformation Foundation of Agricultural Science and Technology (No. 05EFN216600446), National Natural Science Foundation of China (No. 40473054) (To Wu Gang) and National Science and Technology Supporting Plan (No. 2006BAC15B03) (To Shao HB).

REFERENCES

Altieri, M.A., 1995. Agroecology: The Science of Sustainable Agriculture. West View Press, Inc., Boulder, CO, USA., pp: 54-63.

Bastianoni, S., N. Marchettini, M. Panziere and E.Tiezzi, 2001. Sustainability assessment of a farm in the Chianti area (Italy). J. Cleaner Prod., 9: 365-373.

Brown, M.T. and S. Ulgiati, 1997. Emergy-based indices and ratios to evaluate sustainability: Monitoring economies and technology toward environmentally sound innovation. Ecol. Eng., 9: 51-69.

Brown, M.T. and S. Ulgiati, 2001. Emergy measures of carrying capacity to evaluate economic investments. Population and Environment: J. Interdisciplinary Studies, 22: 473.

Brown, M.T. and S. Ulgiati, 2004a. Energy quality, emergy and transformity: H.T. Odum's contributions to quantifying and understanding systems. Ecol. Model., 178: 201-213.

Brown, M.T. and S. Ulgiati, 2004b. Emergy analysis and environmental accounting. Encyclopedia of Energy, 2: 333.

Goldember, J., 1992. Energy, technology and development. Ambio, 21: 14-17.

Haden, A.C., 2003. Emergy evaluations of Denmark and Danish agriculture. Ekologiskt Lantbruk NR., 37: 51-53.

Jay, F., M. Stewart, A.W. Diemont, E. Powell, M. Stanton and S. Levy-Tacher, 2006. Emergy evaluation of the performance and sustainability of three agricultural systems with different scales and management. Agric. Ecosyst. Environ., 115: 128-140.

Lefroy, E. and T. Rydberg, 2003. Emergy evaluation of three cropping systems in southwestern Australia. Ecol. Model., 161: 195-221.

Odum, H.T., 1971. Environment, Power and Society. John Wiley and Sons Inc., New York.

Odum, H.T., 1988. Self-Organization, Transformity and Information. Science, 242: 1132-1139.

Odum, H.T., 1996. Environmental Accounting: Emergy and Decision Making. John Wiley and Sons, New York, pp: 304-311, 370.

Odum, H.T. and E.C. Odum, 1998. Environment and Society in Florida. St. Lucie Press, Boca Raton, FL., pp: 49.

Odum, H.T., 2000. Handbook of Emergy Evaluation: A Compendium of Data for Emergy Computation Issued In a Series of Folios. Folio 2. Emergy of Global Processes. Center for Environmental Policy. University of Florida, Gainesville, Florida, USA.

Rydberg, T. And J. Jansen, 2002. Comparison of horse and tractor traction using emergy analysis. Ecol. Eng., 19: 13-28.

Ulgiati, S., H.T. Odum and S. Bastianoni, 1994. Emergy use, environmental loading and sustainability. An emergy analysis of Italy. Ecol. Model., 73: 215-268.

Ulgiati, S. and M.T. Brown, 1998. Monitoring patterns of sustainability in natural and man-made ecosystems. Ecol. Model., 108: 23-36.