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EMERGY ANALYSIS OF GRAIN PRODUCTION SYSTEM IN JIANGSU AND SHAANXI PROVINCES

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ABSTRACT: Efficiency and sustainability of grain production are now important in China. In this study, the grain production systems of Jiangsu and Shaanxi Provinces were compared, to analyze their efficiency and sustainability in terms of utilization of natural resources, inputs of purchased energy and materials, and outputs. Flows of energy and materials between environment and human society were identified, and the natural and human work involved in generating inputs as materials or energy were valued in terms of equivalent amount of solar energy required for their production using emergy method. The results showed environmental resources were continually playing a less important role in the systems, when inorganic subsidiary emergy inputs increased drastically while organic ones decreased or increased little. Deterioration of input emergy structure affected the systems′ efficiency and sustainability, resulting in emergy investment ratios and environmental loading ratios increasing while yield ratios and sustainability indices decreasing. In general, efficiency and sustainability of grain production in Jiangsu are worse than those in Shaanxi. This analysis also suggested that inorganic subsidiary emergy should be introduced properly, and peasants in Jiangsu should utilize natural conditions wisely while those in Shaanxi pay enough attention to soil and surface water conservation.
KEY WORDS: emergy analysis; grain production system; Jiangsu Province; Shaanxi Province

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1 INTRODUCTION

Grain production has always been top-priority issue concerned by government and people (MA *et al*., 2002). After China put household contract responsibility system in force, its domestic issue of grain was basically settled in the mid 1980s (MA and XU, 1999). However, in the days when idea of sustainable development is broadly accepted, efficiency and sustainability of grain production are now in question, which have prompted interest in reviewing grain production patterns we now adopt.

Emphasis has therefore been placed on enhancing efficiency and sustainability of grain production. As grain production is not only the course of grain plant assimilating and transforming materials and energy from nature to part of itself through photosynthesis, but also the course of human applying his knowledge or experience and introducing subsidiary materials and energy from human society to meet his purposes (HAO, 2002), such production is always considered as one synthetic eco-economic system. To analyze the system need dissect grain production process, assess its inputs and outputs, explore the cause to its unsustainability, and put forward pertinent countermeasures. An important question thus existed, how to handle physic-ecological and socio-economic data simultaneously?

Taking the form of currency, economy analysis is a familiar method to reflect the system′s function and efficiency. Although the method is simple and widely used (XIE, 1998), it neglects the environment′s contribution, and conclusion of one time can not be compared with others at another time. Energy analysis method has much progress in evaluating the system. However, it does not consider environment′s contribution either and mixes quality discrepancy of different energy. Many scholars thus hold dissidence to it (ODUM, 1996; BROWN and ULGIATI, 2001). The importance of grain production for China highlights the need for more suitable approaches to analyzing the system. In this study, method of emergy accounting developed by ODUM (1996) was selected as it offers a means of quantifying both socio-economic inputs′ work and environ-

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mental one. The aim is to compare efficiency and sustainability of the system in different parts of China, taking Jiangsu and Shaanxi provinces as cases. Here efficiency is intended as the ability to yield more but consume less, while sustainability as having less interference and stressing on ecosystem and socio-economy system.

2 METHOD

Emergy theory was founded by American ecologist H T ODUM, based on energy value theory, aiming to study ecosystem and human socio-economy system (CHEN and XU, 2002). More and more people have so far accepted the theory and its method. The theory deems eco-economic system is self-organizing one with dissipating structure, in which energy from the sun is transported and transformed from low-grade creatures to high-grade consumers. As part of energy dissipates, the quantity of energy becomes less. Since energy always converges at lower step to make less other energy at higher step, energy hierarchy appears. Thus, though energy decreases from lower step in the hierarchy to a higher one, the transformed energy increases ability.

In order to take into account the varied quality of energy, two terms—emergy and transformity were introduced (ODUM, 1996). Based on this, energy in any form can be transformed to same energy unit obtained by multiplying the energy in Joules (or grams) by specific solar transformity (solar emJoules per Joules or solar emJoules per gram), and the transformity can be derived from previous studies (BROWN and HERENDEEN, 1996; DAESEOK and SEOK, 2002). Readers holding interests in fuller treatment can refer to ODUM (1996), BROWN and ULGIATI (2001) *et al.*

By attempting to account for all the work previously involved in generating a kind of resources, product or service, emergy method sets out to provide a scientific basis for analysing grain-production system. One potential advantage is the capacity to value natural resources previously considered "free" (EDWARD and TORBJORN, 2003). And what′s most important is that energy from any sources can be totalled and various indices derived are more objective.

3 CASE STUDIES

Jiangsu Province, located in the east part of China, covers an area of 102.6×10^3km^2, of which 69% is plain. The temperate monsoon climate there is characterized by affluent precipitation and warm temperature. In 1980, there were 50.8567×10^6 people depending on agriculture, with net income of 217.90 yuan(RMB) per capita. And in 2000, the number became 49.7227×10^6 while net income became 3595.09 yuan. As peasant population decreased, cultivated land per peasant increased from 0.091ha in 1980 to 0.101ha in 2000. In the system, rice, wheat and maize are mainly planted, while soybean and tomato scatter.

Shaanxi Province is located in hinterland of China, covering an area of 205.6×10^3km^2, and topography there is various. The climate is of continental monsoon, with daily temperature between 7–16℃ and annual precipitation 400–1000mm. In 1980, 23.25×10^6 people took part in agricultural activities, managing 3.816×10^6ha cultivated land, and the number became 10.13×10^6 in 2000 with 3.114×10^6ha cultivated lands. Cultivated land per peasant increased from 0.164ha to 0.307ha. Each peasant′ s net income was 142.20 yuan in 1980 and 1443.86 yuan in 2000. Wheat, maize and rice are main crops in the system, and tomato, soybean, millet and broomcorn millet also play important role.

Following general analysis process given by emergy analysts (ODUM, 1996; BROWN *et al.*, 2001), the study drew energy system diagram of gain production system, worked out emergy analysis table of the system in the two provinces (omitted here), and calculated relative indices. From Fig. 1, we can see grain-production activity is driven by environmental emergy and subsidiary one. In environmental inputs, those from the sun, wind, rain and geothermal heat are regarded as free renewable emergy, while topsoil as non-renewable one. Furthermore, subsidiary inputs can be divided into inorganic (electricity, diesel, fertilizer, pesticide, plastic, agricultural machinery, etc., they are purchased and non-renewable) and organic ones (labor, draught animal, seed and manure, they are indige-

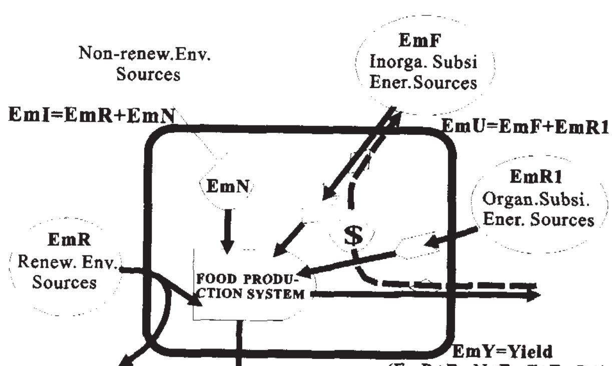

Fig. 1 Energy system diagram of grain production system

nous and renewable). The flows were aggregated into renewable environmental inputs (EmR), non-renewable environmental inputs (EmN), purchased inorganic emergy inputs (EmF), indigenous organic emergy inputs (EmR1), total environmental inputs (EmI), total subsidiary emergy inputs (EmU) and finally the total emergy (EmY) being required to support the yield (Table 1). These aggregated flows of emergy were used to derive indices of input emergy structure, system′s efficiency and sustainability as basis for comparing the two systems (Table 2, 3, 4 and 5). Thus results and conclusions of emergy analysis are obtained by integrating the information given by these parameters. The data dealt with here were taken from Statistical Yearbooks of the two Provinces and Chinese Natural Resources Series, the years selected are 1980 and 2000.

4 RESULTS

4.1 Subsidiary Emergy Inputs

Table 2 shows organic subsidiary emergy had decreased in the past 20 years (decreased by 39.7%) in Jiangsu, while such index increased by 17.7% in Shaanxi. Consequently, such variation results in organic subsidiary energy input to grain production per hectare of Shaanxi Province more than that of Jiangsu Province now, although that was not the case in 1980. Additionally, in organic subsidiary emergy inputs, labor emergy holds rather large portion in both provinces. For example, the proportion was 0.64 and 0.66 in Jiangsu in 1980 and 2000, while 0.43 and 0.50 respectively in Shaanxi (Table 3).

Table 2 also shows inorganic subsidiary emergy density increased from 1.99×10^{15}sej/ha to 6.717×10^{15}sej/ha in Jiangsu,while from 691×10^{12}sej/ha to 2.986×10^{15}sej/ha in Shaanxi, having increased by 237.5% and 332.1% respectively. When these inputs, in both provinces, increased drastically while organic ones decreased or increased little, the ratio of organic subsidiary inputs to inorganic ones continued to decrease, with the ratio being 1.20 in 1980 and 0.21 in 2000 in Jiangsu, and respectively 2.28 and 0.62 in Shaanxi. Notably, chemical fertilizer is always the main body of inorganic subsidiary emergy inputs. Table 3 shows that the ratio of chemical fertilizer emergy to total inorganic subsidiary emergy inputs had decreased from 0.65 to 0.51 in Jiangsu. Oppositely, such ratio had been increasing in Shaanxi, from 0.48 to 0.57.

Table 1 Emergy inputs and outputs of grain production systems in the two provinces

Item	Jiangsu Province ($\times10^{21}$sej)		Shaanxi Province ($\times10^{21}$sej)	
	1980	2000	1980	2000
Renewable environmental resources (EmR)	4.973	4.791	4.108	3.311
Non-renewable environmental resources (EmN)	0.134	0.095	2.938	2.013
Inorganic subsidiary emergy (EmF)	6.904	22.473	2.244	7.806
Organic subsidiary emergy (EmR1)	8.290	4.811	5.106	4.839
Output (EmY)	20.301	32.170	14.396	17.969

Table 2 Emergy density of production systems in Jiangsu and Shaanxi provinces

Item	Emergy density in Jiangsu Province			Emergy density in Shaanxi Province		
	1980 (10^{15}sej/ha)	2000 (10^{15}sej/ha)	Variation (%)	1980 (10^{15}sej/ha)	2000 (10^{15}sej/ha)	Variation (%)
Renewable environmental input	1.435	1.435	0	1.268	1.268	0
Non-renewable environmental input	0.039	0.028	−28.2	0.906	0.769	−15.1
Inorganic subsidiary emergy	1.990	6.717	237.5	0.691	2.986	332.1
Organic subsidiary emergy	2.386	1.439	−39.7	1.574	1.853	17.7

Table 3 Input emergy structures of production systems in Jiangsu and Shaanxi provinces

Input emergy structure index	Expression	Jiangsu Province		Shaanxi Province	
		1980	2000	1980	2000
Ratio of organic subsidiary emergy to inorganic subsidiary emergy	EmR1/EmF	1.20	0.21	2.28	0.62
Ratio of labor emergy to total organic subsidiary emergy	EmLab/EmR1	0.64	0.66	0.43	0.50
Ratio of fertilizer emergy to total inorganic subsidiary emergy	EmFer/EmF	0.65	0.51	0.48	0.57
Ratio of environmental emergy to total emergy	EmI/EmY	0.25	0.15	0.49	0.30
Ratio of non-renewable environmental emergy to total environmental emergy	EmN/EmI	0.03	0.02	0.42	0.38

4.2 Environmental Emergy Inputs

The ratio of environmental emergy to total emergy inputs shows the role environment plays in grain production. In Shaanxi, the number was 0.49 in 1980, but in 2000 it became 0.30 (Table 3). Similarly, the proportion decreased in Jiangsu, from 0.25 to 0.15 (Table 3).

Renewable environmental emergy density in Jiangsu is always higher than that in Shaanxi, relating to its better natural condition. However, Table 2 shows non-renewable environmental emergy density in Shaanxi was much higher than that in Jiangsu, indicating grain production activity in the former has inflicted serious destruction on local environment. For example, in Shaanxi, the net topsoil emergy loss was 906×10^{12}sej/ha in 1980, while total inorganic subsidiary emergy input that year was only 691×10^{12}sej/ha (Table 2). After many years of administering, situation has been ameliorated. However, the area of soil erosion was 128.8×10^{3}km^2 in 2000, covering 62.61% of total area (MWR and CAS, 2002). So the proportion of topsoil emergy loss to total environmental emergy inputs was still 0.38 in 2000. In Jiangsu Province, the average proportion was only 0.02 in the past 20 years (Table 3).

4.3 Emergy Investment Ratio (EIR)

EIR means the ratio of purchased inorganic subsidiary emergy fed back from economy system to indigenous ones. In 2000, such ratios were 4.59 and 1.47 in Jiangsu and Shaanxi respectively (Table 4), indicating purchased emergy amounted to 4.59 and 1.47 times the value of indigenous inputs in the two provinces. Compared with the ratio of 1980, it had increased by 240% and 359.4% respectively. As EIR, to a certain degree, reflects situation of economy development for a region (BROWN and ULGIATI, 1997), such increase verifies that economic power of both provinces was strengthened during those years.

EIR of Jiangsu, on average, was 3.32 times that of Shaanxi, indicating grain production level of the former was higher than that of the latter. However, as great deal of purchased emergy is input in Jiangsu, the grain's market competing ability is lower. Oppositely, grain of Shaanxi has competing advantage.

4.4 Emergy Yield Ratio (EYR)

In 1980, the EYRs of Jiangsu and Shaanxi were respectively 1.34 and 1.96, and in 2000 the number became 1.18 and 1.42, having decreased by 11.9% and 27.6% respectively (Table 4). As EYR is the ratio of the emergy of a product to the emergy of the inputs received from economy (SIMONE *et al.*, 2001), such decreases indicate grain production system's function of the provinces is now turning inferior, input emergy being transformed less efficiently and return on the same investment becoming less. When considered subsidiary emergy inputs, such decreases coincide with the law of diminishing return.

Although inorganic subsidiary emergy and total subsidiary emergy inputs introduced to grain production system in Jiangsu were higher than those in Shaanxi whether in 1980 or in 2000, EYR of the former had been always lower than that of the latter (Table 4).

4.5 Environmental Loading Ratio (ELR)

ELR is the ratio of total non-renewable emergy inputs, external and local, to renewable environmental emergy inputs and indigenous organic subsidiary emergy, and such ratio in both provinces had simultaneously increased. In Jiangsu and Shaanxi, for example, the ratios were 0.53 and 0.56 in 1980 respectively, while in 2000 the numbers were 2.35 and 1.20, having increased by 343.4% and 114.3% respectively (Table 5). As the ratio acts as a indicator for the system's function, the continuing increases mean the systems' function is now degenerating, inflicting more pressure on local environment.

ELR of Jiangsu's grain production system was not high in 1980, even lower than that of Shaanxi's. However, such ratio in 2000 was nearly 2 times that of Shaanxi's, indicating pressure inflicted by grain production is much higher than what Shaanxi's grain pro-

Table 4 Efficiency indices for production systems in Jiangsu and Shaanxi provinces in 1980 and 2000

Efficiency index	Expression	Jiangsu Province			Shaanxi Province		
		1980	2000	Variation (%)	1980	2000	Variation (%)
Emergy investment ratio	EmF/EmI	1.35	4.59	240	0.32	1.47	359.4
Emergy yield ratio	EmY/EmU	1.34	1.18	−13.6	1.96	1.42	−27.6

Table 5 Sustainability indices for production systems in Jiangsu and Shaanxi provinces

Sustainability index	Expression	Jiangsu Province			Shaanxi Province		
		1980	2000	Variation (%)	1980	2000	Variation (%)
Environment loading ratio	(EmF+EmN)/(EmR+EmR1)	0.53	2.35	343.4	0.56	1.20	114.3
Sustainability index	EYR/ELR	2.53	0.50	−80.2	3.50	1.18	−66.3

duction activity did.

4.6 Sustainability Index (SI)

Sustainability index, in Jiangsu, was 2.53 in 1980 and 0.50 in 2000, decreased by 80.2%. Similarly, the index of Shaanxi's decreased from 3.50 to 1.18, decreased by 66.3%. As SI can reflect compatibility of socio-economy system with its surrounding environment, such decreases indicate grain production is now having more interference on eco-environment, and the systems are less sustainable.

The SI of Jiangsu's grain production system was lower than that of Shaanxi's whether in 1980 or in 2000, indicating the system of Jiangsu is less sustainable than that of Shaanxi. According to relative judgment (ULGIATI and BROWN, 1998), grain production system of Jiangsu was already consumer-oriented one in 2000. Although the system of Shaanxi still had contributions to socio-economy system that year, it cannot be regarded as a main energy source for the province any longer.

5 DISCUSSION

The aim of this study is to use emergy method to analyze efficiency and sustainability of grain production systems in different parts of China. This method provides an analytical framework and the results provide much insight into the systems in the provinces and underlying reasons.

5.1 Variation of Input Emergy Structure

As chemical fertilizers and agricultural machinery had respectively substituted for manures and draught animals in Jiangsu, input organic subsidiary emergy per hectare decreased. Oppositely, as peasants in Shaanxi have limited money, they should input more indigenous organic subsidiary emergy to maintain increasing need for grain. Since each peasant in Jiangsu has less cultivated land and other organic subsidiary emergy inputs are decreasing, peasants there produce grain more intensively, resulting in proportion of labor emergy to total organic subsidiary emergy being larger than that in Shaanxi.

As purchased emergy had already been input excessively in Jiangsu, the pace of inorganic subsidiary emergy increasing in Shaanxi is faster than the former. With agriculture modernization developing in Jiangsu, chemical fertilizers' proportion to total inorganic subsidiary emergy, affected by increasing of other inorganic subsidiary items, started to decrease. Oppositely, as purchasing ability of peasants in Shaanxi is limited and the effect of chemical fertilizers is over-weighted, they often choose them first.

As inorganic subsidiary emergy introduced increased drastically while organic one decreased or increased little and environmental resources remained, environmental resources are playing a less important role than before in both provinces, particularly in Jiangsu. Additionally, input environmental emergy in Jiangsu was most renewable while non-renewable one occupies large portion in Shaanxi.

As grain production system is driven by inputs from environment and human society, they should be introduced proportionally to form one appropriate structure. Therefore, the variation of input structure in the two provinces will surely affect the system's efficiency and sustainability.

5.2 Grain Production System's Efficiency

With economy developing, peasants have more money to introduce industrial inorganic emergy, accompanied by indigenous organic emergy, to grain production process. As a result of inorganic subsidiary emergy inputs drastically increasing while environmental emergy inputs remaining, EIR started to increase rapidly in the two provinces. As Jiangsu shares higher economy development than Shaanxi does, grain production system's EIR is always higher than that in the latter, indicating free environmental resources were utilized more profoundly.

Although more and more emergy was invested on grain production, the two systems' EYR decreased continually. The reason is that structure of input emergy has not been optimized when scale of inputs was enlarged. Facturaly, organic subsidiary emergy inputs have not been added according to inorganic ones, which also result in such ratio of Jiangsu being lower than that of Shaanxi.

An efficient grain production system should use less inputs but yield more outputs, so grain production system's EIR increasing while EYR decreasing indicate the two provinces' systems are now transforming input resources with low efficiency.

5.3 Grain Production System's Sustainability

A general definition of sustainable agriculture is "the ability to maintain production over long time frames despite major ecological and socio-economic perturbations and stress" (ALTIERI, 1987), so sustainable grain production system should have high EYR but low ELR.

As Jiangsu′s agriculture activity shares superior natural conditions and subsidiary emergy introduced was most organic in 1980, grain production system′s ELR was lower than that of Shaanxi′s. In the course of introducing inorganic subsidiary emergy drastically when organic ones decreased and environmental input remained, such ratio in Jiangsu continued to increase. Although the ratio of Shaanxi′s also increased fast, it was still lower than Jiangsu′s in 2000, because of inorganic subsidiary emergy introduced there less than that of Jiangsu and the system′s organic ones having increased little. As the stress on environment brought by grain production is increasing while the systems′ emergy yielding ability is decreasing, SIs for the two systems are decreasing. The reason of this decrease also lies in the fact of people laying particular emphasis on inputting more inorganic subsidiary emergy, which leads the grain production systems in the two provinces to become unsustainable.

5.4 Countermeasures

The findings in this study have profound implications on grain production. As east part of China shares superior natural conditions, people there should utilize the advantage scientifically, for example, to alter traditional cropping system, to increase multiple crop index. Of course, man′s behavior should not exceed renewable environmental resources′ carrying capacity. While in west part of China, as soil erosion is very serious, people there should pay attention to soil and surface water conservation.

To maintain grain production system efficient and sustainable, subsidiary emergy should be input. As industrial subsidiary emergy with high quality should be accompanied by organic ones with low quality (ODUM, 1996), we should introduce the two kinds scientifically. Organic ones, particularly manures should be added while inorganic ones input appropriately, proportional to organic inputs.

6 CONCLUSIONS

Emergy analysis indicates the variation of input emergy structure and difference of system′s efficiency and sustainability. Subsidiary emergy inputs′ rapid increase leads to worse emergy structure and decreasing efficiency and sustainability. As peasants in Jiangsu lay more emphasis on inorganic subsidiary emergy while ignoring adding organic ones proportionally, efficiency and sustainability of Jiangsu′s grain production system are therefore lower than those of Shaanxi′s. Aiming to alter the situation, pertinent countermeasures were put forward. However, no single means can work efficiently in isolation. Only can concerted measures increase grain production system′s EYR on one hand and decrease its ELR on the other hand, namely prompt grain production practice efficient and sustainable.

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