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Energy Flow and Emergy Analysis of the Agroecosystems of China*

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Abstract An agricutural energy systems analysis of China was carried out using the new measure emergy spelled with a "m". Emergy is defined as the energy of one kind previously required directly and indirerctly to make a product or service. Solar emergy is the available solar energy used up directly and indirectly to make a service or product, its unit is solar emjoules (abbreviated sej). Emergy provides a common denominator for measurment of the value of environmental resource and economy in an ecological-economic system. An emergy analysis of Chinese agroecological-economic system is presented, showing its emetgy input (environmental resources emergy, applied fossil-emergy and other renewable energy), and emergy yeild (main crops, livestock and fishing production) providing an overview of Chinese agriculture, giving some indices to evaluate the national agricultural environment resource basis and production, in order to recommend the effect of national agroecological system and its sustainability.

Keywords emergy analysis, energy flow, agroecosystems, China

1 Introduction

An important problem facing humanity today is how to analyse rationally and deal with integration of human and natural processes. Neither economics nor ecology alone adequately addresses the problems the world society presently faces. People have been searching for a type of common criterion for many years, which can measure nature, environmental resources as well as human economy. Money circulates only among people for their services but does not flow through nature; it can not express the contribution of nature and environmental resource for human economy. Energy flows through nature and human society, but the quality and value of different types of energy are different, and should not be added. In this study, a new emergy analysis theory and method is used

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to evaluate the contribution of natural resources to agriculture and the ability of differnt energy forms to contribute to the economy. Emergy analysis of agriculture is great different from previous agricultural energy analysis, it not only analysis supplemental energy inputs and food energy outputs, but also environmental energy inputs and human services, and put them in a common emergy basis for measurement of the value of agricultural environment and economy. A comparision in general between emergy analysis and energy analysis on agriculture is listed in Tab. 1.

Tab. 1 Comparision of emergy analysis and energy analysis on agriculture

Characteristic	Energy analysis	Emergy analysis
Measure criterion	Energy	Emergy
Measure units	J	sej
Energy quality	can not express	can express
Energy inputs account	Fossil-energy mainly	Environmental resoutce, fossil-energy and others
Energy flows	A part energy flows	All energy flows
Results	Output/Input energy	A serious emergy indices

2 Overview of agriculture and its energy use in China

China is the most populous country in the world with a tatal poulation of 1.2 billion over. But China has only 100 million hm^2 of arable land for crop production to feed their enormous number of people[1]. On average each person has about only 0.1 hm^2 arable land for food production, which is 1/3 of the world average, 1/6 of the United States average. About 80% of Chinese population live in rural areas, where farmers produce food for their families in villages and for the peoele in cities and towns. During the past decades, agricjlyure in China has changed dramatically. Nowadays the collective organizations of people's communes before 1980s have been replaced by individual peasent families. Most of the traditinal organic-agroecosystems that had been dominant in China disappeared. More and more fossil-energy-based inputs in the form of synthetic fertilizers, pesticides, and machinery are used to increase agriculrural production. But Chinese agriculture is still great defferent from western countries.

3 Concepts and methodology

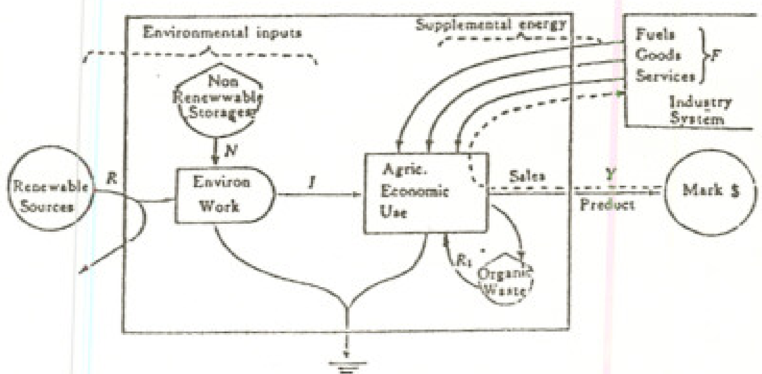
On the basis of general systems principles, Odum has formulated a unifying theory of system eccology and emergy theory[2~4]. In this paper, the energy inputs from environmental sources (sunlight, rain, topsoil), applied energy from industry (fuels, electricity, machinery, fertilize and pestisides) as well as other energy used from within agricultural system (human labor, animal work, manure, seeds) have been put on a common basis by evaluation the solar emergy as done in some previous papers on agriculture[5~8].

The following concepts and definitions are used in the emergy analysis for evaluation of agriculture.

(1) **Avallible emergy.** Potential energy capable of doing work and being degraded in the process.

(2) **Emergy.** Available energy of one kind previously required directly and indirectly to make a product or resoure[3,4]. However, energy of one kind is not equivalent in its abiliable to do work to energy of another kind. Therefor, in adding up the available energies of defferent kinds contributing to a production process, all have to be expressed in units of one kind of energy. For convenience, all forms of energy continenting are supressed in units of solar energy that would be required to generate all the inputs. Thus, wealth is measured by the solar emergy required to accumulate it. Solar emergy is available solar energy required directly and indrectly to make a product or resource, its units is Solar Emjoules (sej).

(3) **Solar transformity.** solar emergy per unit available energy. A list of solar transformity for many types of energy and commodities is derived form previous studies, which is appropriates to analysis of regions or large systems, such as this research. After the energy content of a flow has been estimated, it can be multiplied by its solar transformity to obtain its solar emergy. Several useful emergy indices cal be calculated to illustrate the ecological-economic interface of agriculture (Fig. 1).



$I = N + R$

Net emergy yield ratio $= T/F$

Emergy investment ratio $= F/I$

Environmental loading ratio $= (F+N)/R+R_1$

Fig. 1 Emergy diagram illustrating agricultural computation of emergy use and yield ratios

(4) **Net emergy yield ratio.** The ratio of an output yield of emergy divided by the e-

mergy of all the feedbacks from the economy including fuels, fertilizers and services (supplemental emergy).

(5) **Emergy yield ratio.** a measure of its net controbution to the economy beyond its own operation.

(6) **Emergy investment ratio.** The purchased emergy (F) feedback from the economy to the indigenous emergy inputs from environmental resources (I). This index measures the intensity of the economic development and the loading of the environment, it is useful for evaluating the relative contribution of free environmental inputs. For a process to be competitive, it must have as much environmental input as competitors. A high ratio means that the environment supports higher levels of economic inputs than other regions or processes with lower ratios.

(7) **Environmental loading ratio.** The ratio of supplemental emergy and nonrenewable indigenous emerfy to renewable environmental resources emergy. A large ratio suggests a high technological level in emergy use as well as a high level of environmental stress.

Data from various sourecs of geographical or economic information and statistics of the agriculture in China were collected and interpreted: ① to understand its ecological-economic network; ② to calculate emergy folws and understand emergy basis for Chinese agriculture; ③ to calculate principal public emergy indices of the ecological-economic interface, and ④ to assess the national agricultural system and its sustainability.

4 Results and discussion

4.1 Resource emergy basis of Chinese agriculture

An emergy diagram of Chinese agriculture is shown in Fig. 2, which represents an aggregated agroecological-economic systems of China including its main emergy flows and processes. Also, Fig. 2 shows a general agricultural production system of China.

The emergy analysis for resource basis of Chinese agriculture is presented in Tab. 2, which includes the main rernewable and nonrenewable environmental sources (sunlight, rain, topsoil), the nonrenewable inputs purchased from the industrial economy (fuels, electricity, fertilizers, pesticides, machinery), as well as the rernewable organic energy applied from within the self-system of agriculture (human and animal labor, organic fertilizers, seeds).

An emergy analysis of the main agriculrural prodection in China has been performed and the results are schematized in Tab. 3. A summary of the emergy flows is given in Tab. 4, in which the emergy indices were calculated and listed.

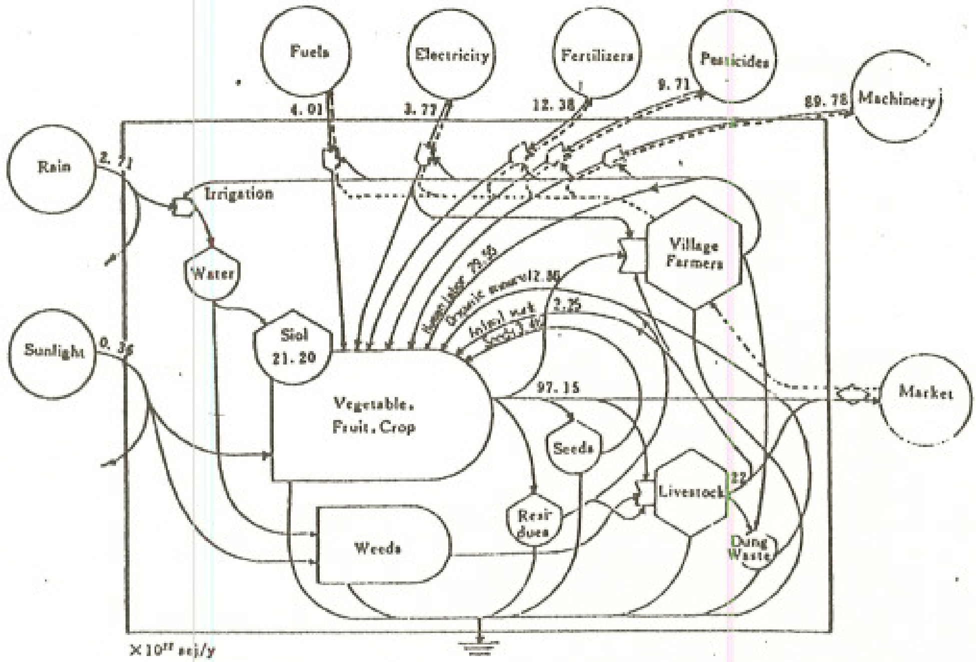


Fig. 2 Emergy diagram for general agricultural production system of China. Dashed lines are flows of money

Tab. 2 Emergy analysis of resoutces basis for agriculture of China

Item	Actual energy[1] (J/y)	Transformity (sej/J)	Solar emergy ($\times 10^{22}$ sej/y)
Renewable resources			
Sunlight	3.85×10^{21}	1	0.36
Rainchemical energy	1.49×10^{18}	18 199	2.71
Total			3.07
Nonrenewable sources from within the system			
Net loss of topsoil	3.39×10^{18}	62 500	21.20
Nonrenewable industrial subsidiary energy			
Machinery	1.20×10^{16}	7.50×10^{7}	89.78
Fossil oil	6.07×10^{17}	6.60×10^{4}	4.01
Electricity	2.37×10^{17}	1.59×10^{5}	3.77
Nitrogen fertilizer	4.08×10^{16}	1.69×10^{6}	6.90
Phosphae fertilizer	1.26×10^{15}	4.14×10^{7}	5.21
Potassium fertilizer	1.04×10^{15}	2.63×10^{6}	0.27
Pesticides	4.93×10^{15}	1.97×10^{7}	9.71
Total	8.92×10^{17}		119.65
Renewable organic subsidiary energy			
Human labor	7.78×10^{17}	3.80×10^{5}	29.55
Animal work	1.54×10^{17}	1.46×10^{5}	2.25
Organic manure	4.76×10^{18}	2.70×10^{4}	12.86
Seeds	1.37×10^{17}	2.00×10^{5}	3.46
Total	5.86×10^{18}		48.15

1) All data is in 1988

Tab. 3　Emergy output of main crops, livestock and fishing production in China[1)]

Item	Energy (J/y)	Transformity (sej/J)	Solar emergy ($\times 10^{22}$ sej/y)
Selected crops production			
Rice	2.88×10^{18}	3.59×10^{4}	10.10
Wheat	1.59×10^{18}	6.80×10^{4}	10.20
Corn	1.32×10^{18}	2.70×10^{4}	3.56
Other grains	1.05×10^{18}	2.70×10^{4}	2.83
Cotton	7.03×10^{16}	1.90×10^{6}	13.40
Vegetable oil	2.46×10^{17}	6.90×10^{5}	17.00
Sugar	1.04×10^{18}	8.40×10^{4}	8.87
Fruits	2.79×10^{17}	5.30×10^{5}	14.76
Vegetable	1.75×10^{18}	2.70×10^{4}	4.72
Other crops	4.38×10^{18}	2.70×10^{4}	11.80
Total			97.15
Liverstock production			
Meat	8.06×10^{16}	1.71×10^{6}	13.80
Other products	3.55×10^{16}	1.73×10^{6}	6.15
Wool	6.17×10^{15}	3.84×10^{6}	2.37
Total			22.32
Fishing production			
Fish products	3.84×10^{16}	2.00×10^{6}	7.70

1) All data is in 1988

Tab. 4　Summary of emergy flows and indices for Chinese agrivulture system

Kind of emergy flows	Express	Quantity ($\times 10^{22}$ sej)	Indices	Ratios
Renewzble environmental sources	R	3.07	$I/(U+I)$	0.13
Nonrenewable environmental sources	N	21.20	$F/(U+I)$	0.62
Total free environmental sources	$I=R+N$	224.27	$R_1/(U+I)$	0.25
Renewable organic energy	R_1	48.15	F/U	0.71
Fossil-energy use	F	119.65	R_1/U	0.29
Total supplemental energy use	$U=F+R_1$	167.80	F/I	4.93
Total inputs	$U+I$	192.07	Y/U	0.27
Crops yield	Y_1	97.15	$(F+N)/(R+R_1)$	2.80
Liverstock yield	Y_2	22.32		
Fishing yield	Y_3	7.70		
Total yield	$Y=Y_1+Y_2+Y_3$	127.17		

4.2　The emergy flows of Chinses agriculture

The total emergy used for Chinese agrivulture is estimated at 192×10^{22} sej in 1988 (Tab. 2, 4). Free environmental resource emergy accounts for 13% of the total emergy use driving Chinese agrivultural system, applied fossil fuel emergy from industries accounts for 62%, and applied organic fertilizers (green manure, dung, straw) emergy accounts for 25%.

During the past few decades there have been remarkble increase in Chinese agriculture fossil-fuel energy for machinery, fertilizers, and pesticides. However, the organic energy has long been an important source for agriculture production in China. For the organic energy, the major inputs were from manure, crop residues, human labour and animal work, as well as seeds from within the system of agriculture. The organic emergy use in 1988 is estimated at 48.15×10^{22} sej, accounting for 94% of the total renewable emergy inputs, which plays an important role in Chinese agriculture for its sustainability. However, nonrenewable fossil energy used in Chinese agriculture is now much more than organic energy(Tab. 2,4), especially including inputs of commercial fertilizers and pesticides.

The total emergy yield of the national agriculrure in China is estimated at 127.17×10^{22} sej, of which crops accounts for 76%, livestock and fishing are low-level (less intensive) in contrast with crops production. Perhaps livestock and fishing can be developed futher for improving food supply in China. Meat consumption per person in China was only 14 kg, one-eighth of that in the United Stated[9].

4.3 Emergy indices and discussion

The general emergy investment ratio of the Chinese agricultural system is estimated at 4.93 (Tab. 4), which is similar to that in some developed countries (Ulgiati, 1992). The higher purchased emergy inputs is , the higher is the cost of production and the higher is emergy investment ratio. High investment ratio causes more use of enveronmental energy to match purchased inputs. It may diminish natural capital and thus reduce agricultural production. Thus the production have much lower competition (Odum, 1992). So China should match its free renewable environmental resources and renewable organic energy, and decrease the agriculrural production cost. The net emergy yield ratio of Chinese agricultural system is only 0.75, lower than that in many developed countries (for example 1.37 in Italy). It shows that Chinese agricultural technology and yield are low. Finally, the environmental loading ratio of Chinese agricultural system is estimated at 2.8, which is close to that in middle-level developed countries. The higher is the environmental loading ratio, the higher is the level of technology-development. From the figure it can be seen that the total development-level and environmental pressure of Chinese agriculture is average in the world.

In Chinese agriculture, fossil-energy use derectly and indirectly for machinery, fertilizers, and pesticides has increased. Draft animal power input and organic fertilizer use has declined. However, the inputs of human labor remains high. Clearly, with abundant human labor in rural areas, it may not be desirable to adopt a highly mechanized agriculrural system like the USA. Ever though in 1990s agriculture production in China is becoming more fossil-energy intensive, it is still highly intensive in labor and animal power. Perhaps the best approach would be to increase the machenization energy 5%~10% to reduce or eliminate some of the less desirable hand operations, such as planting and weeding (Wen Dazhong et al, 1984).

The rapidly growing human population needs more nutrition food. Our ability to produce more food through agricultural production depends on arable land, and various forms of energy (Wen D, et al, 1984). With the increasing demand for these limited resources, Chinese agriculture is facing serious problems of resource shortage and environmental degradation. There is a need to develop a productive and sustainable agriculture to meet the increasing human demand. A more effective use of renewable organic fertilizers and nonrenewable fossil-energy is most important aspects in developing a productive and sustainable agriculture in China.

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中国农业生态系统的能流能值分析

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摘　要　应用最新能值 (emergy) 分析理论和方法，以能值为共同尺度，定量分析中国农业生态系统的能物流，包括自然环境资源、石化补助能和可更新有机能的能值投入，以及农牧渔业的产出能值；计算得出一系列反映生态与经济的能值综合指标体系，绘制了中国农业总体生产系统能流能值模型图；评估了国家农业环境资源基础、能投结构和能值产出，并与一些发达国家比较分析，评价了中国农业的生态经济效益，分析了农业总体结构、能投结构，为农业生产的持续、稳定发展提供科学依据.

关键词　能值分析，能流，农业生态系统，中国