Agro-ecosystem Emergy Evolution and Trend in Hunan Province

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Abstract Using the emergy analysis method, we conduct trend analysis of changes in the total emergy, input and output structure, various emergy indicators of agro-ecosystem in Hunan Province during the period 1999 –2008. The results show that during the study period, total emergy input basically remained stable, but the emergy input structure was constantly optimized, of which the input of non-renewable industrial assistant emergy increased by 38.4%, from 4.00E+22 sej to 5.53E+22 sej, and the input of renewable organic emergy declined from 1.32E+23 sej to 1.20E+23 sej; total emergy yield and yield efficiency of this system were promoted dramatically, and in 2008, the total emergy yield reached 1.69E+23 sej, increasing by 23.8% as against that in 1999, the net emergy yield ratio rose from 0.79 to 0.96; since the environmental loading ratio also tended to rise constantly, from 1.12 to 1.79, the sustainability index of this system also experienced the slow downward trend, from 0.71 to 0.54, always less than 1, indicating that the agriculture in Hunan Province is the high consumption-driven ecosystem in general, with obvious features of extensive development.

Key words Agro-ecosystem, Emergy, Evolution and trend, Hunan Province

Agro-ecosystem is the most basic system for human survival and development. Having a clear understanding of its structure and function, assessing and quantifying the value of resources and environment, is conducive to strengthening people's cognition and protection awareness of agricultural resources and environment, making people reflect on their own behavior. It is of great significance to the sustainable development of human society and agro-ecosystem. As a major agricultural province, Hunan has always put agricultural development in a very important position, thus studying the operational status and efficiency of agro-ecosystem in Hunan Province, and revealing its evolution, trend, and the relationship between man and environment in the region, is of great significance to scientific evaluation and rational use of agricultural resources in this region, formulation of the agricultural economic development policy, and implementation of sustainable development strategy. As of today, the emergy theory has been studied carefully in the United States[1–2], Italy[3] and other western countries. China introduced this theory in the early 1990s. At present, the related research areas of the emergy theory have been throughout geo-biological-chemical circulation[4], and various spatial scales of countries[5], provinces[6–8], cities[9–11], counties[12–14] and businesses[15]; have been widely used and highly valued in the analysis and evaluation research of ecosystem of agriculture[16–18] and industry[19–20]. There are a lot of research results on sustainable development of agriculture in Hunan nowadays, but most of the research methods are the research methods of economics and management science, and the reports of using emergy theory to study agricultural sustainable development in Hunan Province are rare. With the help of the emergy analysis method, we analyze the trend of changes in the emergy of agro-ecosystem in Hunan Province during the period 1999 –2008, in order to provide a reference for the formulation of sustainable development policy of agro-ecosystem.

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1 Research methods and data sources

1.1 Emergy theory The emergy theory was developed by the well-known ecologist Odum in the 1980s. Emergy is the available energy (exergy) of one kind that is used up in transformations directly and indirectly to make a product or service.[1] Emergy accounts for, and in effect, measures quality differences between forms of energy. Emergy is an expression of all the energy used in the work processes that generate a product or service in units of one type of energy. The unit of emergy is the emjoule, a unit referring to the available energy of one kind consumed in transformations. Emergy accounts for different forms of energy and resources (*e.g.* sunlight, water, fossil fuels, minerals, *etc.*) Each form is generated by transformation processes in nature and each has different ability to support work in natural and human dominated systems. The emergy theory can quantitatively analyze the structural function characteristics, ecological and economic benefits of the system[22].

Using emergy, sunlight, fuel, electricity, and human service can be put on a common basis by expressing each of them in the emjoules of solar energy that is required to produce them. The basic expression of converting materials or energy into the solar emergy is as follows:

$$M = \tau B$$

where M is the solar emergy (sej); τ is the conversion rate of the solar emergy; B is available energy[23-24].

1.2 Data sources In this paper, the original data are mainly from *Hunan Statistical Yearbook* in the period 2000 - 2009[25], and *China Statistical Yearbook* in the period 2000 - 2009[26]. The energy conversion coefficient and the solar emergy conversion rate in this paper are mainly based on the research results of Yan Maochao and Odum[27], Lan Shengfang[28] and Lu Hongfang[29], and Agricultural Technology Economy Manual[30]. The emergy conversion rate is mainly based on Emergy Analysis of Ecological and Economic System[28]. On the basis of the existing research, the emergy input and output are subdivided in accordance with the characteristics of agro-ecosystem in Hunan Province. The emergy input is subdivided into the emergy input of renewable environmental resources, the emergy input of non-renewable environmental resources, the industrial assistant emergy input and the organic emergy input. The emergy output is subdivided into the emergy output of crop farming, the emergy output of animal husbandry, the emergy output of forestry, and the emergy output of fishery. On the basis of this, we calculate a variety of ecological flow changes in agro-ecosystem in Hunan Province during the period 1999 - 2008, to derive emergy input of agro-ecosystem in Hunan Province in the period 1999 - 2008 (Table 1), the emergy output of agro-ecosystem in Hunan Province in the period 1999 - 2008 (Table 2), and the emergy indicators of agro-ecosystem in Hunan Province in the period 1999 - 2008 (Table 3), respectively.

Table 1 Emergy input of agro-ecosystem in Hunan Province in the period 1999 - 2008

Item		Emergy transformity*	Emergy input (sej)				
			1999	2000	2001	2002	2003
Emergy input of renewable environmental resources	Solar energy energy	1.00E+00	9.75E+20	9.75E+20	9.75E+20	9.75E+20	9.75E+20
	Rainwater potential energy	8.89E+03	1.18E+22	1.23E+22	1.13E+22	1.63E+22	1.02E+22
	Rainwater chemical energy	1.54E+04	2.31E+22	2.38E+22	2.19E+22	3.17E+22	1.98E+22
	Earth rotation energy	2.19E+04	1.91E+20	1.91E+20	1.91E+20	1.91E+20	1.91E+20
	Wind energy	6.63E+02	9.22E+15	9.22E+15	9.22E+15	9.22E+15	9.22E+15
	Subtotal		3.61E+22	3.73E+22	3.43E+22	4.91E+22	3.11E+22
Emergy input of nonrenewable environmental resources	The net loss of emergy in topsoil	6.25E+04	3.15E+20	3.84E+20	3.83E+20	3.81E+20	3.76E+20
Total environmental emergy input	3.64E+22	3.77E+22	3.47E+22	4.95E+22	3.15E+22		
Industrial assistant emergy input	Chemical fertilizer	4.88E+09	3.13E+22	3.14E+22	3.18E+22	3.18E+22	3.25E+22
	Pesticide	1.62E+09	1.37E+20	1.39E+20	1.39E+20	1.41E+20	1.55E+20
	Agricultural diesel oil	6.60E+04	6.73E+20	7.00E+20	7.66E+20	7.92E+20	8.58E+20
	Agricultural machinery	7.50E+07	5.42E+21	5.96E+21	6.37E+21	6.74E+21	7.19E+21
	Plastic film	3.80E+08	7.71E+17	7.98E+17	8.47E+17	9.39E+17	9.99E+17
	Rural electricity consumption	1.59E+05	2.46E+21	2.55E+21	2.67E+21	2.85E+21	3.08E+21
	Subtotal	4.00E+22	4.07E+22	4.17E+22	4.23E+22	4.38E+22	
Organic emergy input	Labor	3.80E+05	1.29E+23	1.29E+23	1.28E+23	1.26E+23	1.24E+23
	Animal power	1.46E+05	1.05E+21	1.06E+21	1.05E+21	1.04E+21	1.07E+21
	Seeds	6.60E+04	1.01E+21	9.87E+20	9.41E+20	9.05E+20	8.80E+20
	Organic fertilizer	2.70E+07	7.67E+20	8.01E+20	8.25E+20	8.58E+20	8.90E+20
	Subtotal	1.32E+23	1.32E+23	1.31E+23	1.29E+23	1.27E+23	
Total assistant emergy input		1.72E+23	1.73E+23	1.73E+23	1.71E+23	1.71E+23	
Total emergy input		2.08E+23	2.10E+23	2.08E+23	2.21E+23	2.03E+23	

Item		Emergy transformity*	Emergy input (sej)				
			2004	2005	2006	2007	2008
Emergy input of renewable environmental resources	Solar energy energy	1.00E+00	9.75E+20	9.75E+20	9.75E+20	9.75E+20	9.75E+20
	Rainwater potential energy	8.89E+03	1.24E+22	1.08E+22	1.12E+22	1.03E+22	1.02E+22
	Rainwater chemical energy	1.54E+04	2.41E+22	2.10E+22	2.18E+22	2.00E+22	1.98E+22
	Earth rotation energy	2.19E+04	1.91E+20	1.91E+20	1.91E+20	1.91E+20	1.91E+20
	Wind energy	6.63E+02	9.22E+15	9.22E+15	9.22E+15	9.22E+15	9.22E+15
	Subtotal		3.77E+22	3.29E+22	3.42E+22	3.15E+22	3.11E+22
Emergy input of nonrenewable environmental resources	The net loss of emergy in topsoil	6.25E+04	3.74E+20	3.74E+20	3.71E+20	3.71E+20	3.71E+20
Total environmental emergy input	3.81E+22	3.33E+22	3.46E+22	3.18E+22	3.15E+22		
Industrial assistant emergy input	Chemical fertilizer	4.88E+09	3.51E+22	3.63E+22	3.66E+22	3.80E+22	3.85E+22
	Pesticide	1.62E+09	1.77E+20	1.83E+20	1.59E+20	1.77E+20	1.83E+20
	Agricultural diesel oil	6.60E+04	9.37E+20	1.02E+21	1.03E+21	1.04E+21	1.11E+21
	Agricultural machinery	7.50E+07	7.88E+21	8.63E+21	9.23E+21	9.98E+21	1.09E+22
	Plastic film	3.80E+08	1.16E+18	1.17E+18	1.30E+18	1.34E+18	1.37E+18
	Rural electricity consumption	1.59E+05	3.29E+21	3.73E+21	4.35E+21	4.37E+21	4.67E+21
	Subtotal	4.74E+22	4.99E+22	5.14E+22	5.36E+22	5.53E+22	
Organic emergy input	Labor	3.80E+05	1.23E+23	1.22E+23	1.21E+23	1.18E+23	1.17E+23
	Animal power	1.46E+05	1.10E+21	1.12E+21	1.11E+21	1.04E+21	7.87E+20
	Seeds	6.60E+04	9.96E+20	1.02E+21	1.04E+21	1.04E+21	1.01E+21
	Organic fertilizer	2.70E+07	9.45E+20	9.88E+20	1.00E+21	9.13E+20	9.09E+20
	Subtotal	1.26E+23	1.25E+23	1.24E+23	1.21E+23	1.20E+23	
Total assistant emergy input		1.74E+23	1.75E+23	1.75E+23	1.74E+23	1.75E+23	
Total emergy input		2.12E+23	2.08E+23	2.10E+23	2.06E+23	2.07E+23	

Note: The emergy transformity * unit of the chemical fertilizer and pesticide is $sej \cdot g^{-1}$; the transformity emergy unit of others is $sej \cdot j^{-1}$. The same below.

Table 2 Emergy output of agro-ecosystem in Hunan Province in the period 1999 – 2008

Item		Emergy transformity*	Emergy output (sej)				
			1999	2000	2001	2002	2003
Crop farming output	Cereals	8.30E+04	3.63E+22	3.60E+22	3.33E+22	3.05E+22	2.99E+22
	Beans	8.30E+04	8.00E+20	8.40E+20	9.41E+20	9.40E+20	8.61E+20
	Potato	8.30E+04	1.52E+21	1.56E+21	1.76E+21	1.85E+21	1.74E+21
	Oil crops	6.90E+05	3.47E+22	3.71E+22	3.66E+22	3.18E+22	3.35E+22
	Cotton	1.90E+06	6.32E+21	6.11E+21	6.79E+21	5.47E+21	5.83E+21
	Hemp	8.30E+04	5.76E+19	9.70E+19	1.36E+20	1.89E+20	1.87E+20
	Sugarcane	8.40E+04	3.79E+20	2.61E+20	3.75E+20	4.06E+20	3.20E+20
	Tobacco	2.70E+04	5.25E+18	6.47E+18	6.28E+18	7.20E+18	7.22E+18
	Vegetables and melons	2.70E+04	1.18E+21	1.18E+21	1.32E+21	1.45E+21	1.72E+21
	Tea	2.00E+05	1.61E+20	1.64E+20	1.67E+20	1.75E+20	1.73E+20
	Fruits	5.30E+05	2.43E+21	2.11E+21	6.97E+21	6.73E+21	7.20E+21
	Subtotal	8.38E+22	8.54E+22	8.83E+22	7.95E+22	8.14E+22	
Animal husbandry output	Pork	1.70E+06	3.13E+22	3.24E+22	3.35E+22	3.47E+22	3.57E+22
	Beef	4.00E+06	2.45E+21	2.55E+21	2.65E+21	2.97E+21	3.27E+21
	Mutton	2.00E+06	6.54E+20	7.33E+20	8.02E+20	9.32E+20	1.03E+21
	Poultry	2.00E+06	5.39E+21	5.47E+21	5.86E+21	6.41E+21	6.82E+21
	Rabbit	4.00E+06	2.20E+19	2.27E+19	2.48E+19	2.92E+19	3.88E+19
	Milk	1.71E+06	6.70E+19	8.30E+19	1.45E+20	2.73E+20	4.13E+20
	Honey	1.71E+06	2.43E+19	2.68E+19	3.86E+19	4.84E+19	4.41E+19
	Egg	1.71E+06	5.48E+21	5.78E+21	6.04E+21	6.49E+21	6.75E+21
	Subtotal	4.54E+22	4.71E+22	4.91E+22	5.19E+22	5.41E+22	
Forestry output	Wood	4.40E+04	1.85E+21	2.03E+21	2.06E+21	1.59E+21	2.14E+21
	Bamboo	4.40E+04	1.18E+20	1.48E+20	1.77E+20	1.97E+20	1.07E+20
	Tung seed	6.90E+05	1.17E+21	1.12E+21	1.08E+21	1.08E+21	1.00E+21
	Camellia Oleifera seed	8.60E+04	1.08E+21	1.12E+21	1.12E+21	1.20E+21	1.13E+21
	Subtotal	4.23E+21	4.42E+21	4.43E+21	4.06E+21	4.37E+21	
Fisheries output	Aquatic products	2.00E+06	3.01E+21	3.22E+21	3.41E+21	3.62E+21	3.79E+21
Total emergy output		1.36E+23	1.40E+23	1.45E+23	1.39E+23	1.44E+23	

Item		Emergy transformity*	Emergy output (sej)				
			2004	2005	2006	2007	2008
Crop farming output	Cereals	8.30E+04	3.49E+22	3.77E+22	3.77E+22	3.77E+22	3.77E+22
	Beans	8.30E+04	8.66E+20	6.22E+20	6.22E+20	6.22E+20	6.22E+20
	Potato	8.30E+04	1.71E+21	1.35E+21	1.35E+21	1.35E+21	1.35E+21
	Oil crops	6.90E+05	3.72E+22	3.82E+22	3.82E+22	3.82E+22	3.82E+22
	Cotton	1.90E+06	7.29E+21	8.64E+21	8.64E+21	8.64E+21	8.64E+21
	Hemp	8.30E+04	1.89E+20	1.48E+20	1.48E+20	1.48E+20	1.48E+20
	Sugarcane	8.40E+04	2.49E+20	1.70E+20	1.70E+20	1.70E+20	1.70E+20
	Tobacco	2.70E+04	7.31E+18	7.46E+18	7.46E+18	7.46E+18	7.46E+18
	Vegetables and melons	2.70E+04	1.70E+21	1.92E+21	1.92E+21	1.92E+21	1.92E+21
	Tea	2.00E+05	1.91E+21	2.63E+20	2.63E+20	2.63E+20	2.63E+20
	Fruits	5.30E+05	7.10E+21	9.39E+21	9.39E+21	9.39E+21	9.39E+21
	Subtotal	9.31E+22	9.23E+22	9.69E+22	9.84E+22	9.84E+22	
Animal husbandry output	Pork	1.70E+06	3.79E+22	4.04E+22	4.04E+22	4.04E+22	4.04E+22
	Beef	4.00E+06	3.58E+21	3.16E+21	3.16E+21	3.16E+21	3.16E+21
	Mutton	2.00E+06	1.11E+21	9.78E+20	9.78E+20	9.78E+20	9.78E+20
	Poultry	2.00E+06	7.08E+21	6.91E+21	6.91E+21	6.91E+21	6.91E+21
	Rabbit	4.00E+06	4.75E+19	6.46E+19	6.46E+19	6.46E+19	6.46E+19
	Milk	1.71E+06	5.23E+20	5.87E+20	5.87E+20	5.87E+20	5.87E+20
	Honey	1.71E+06	5.06E+19	4.95E+19	4.95E+19	4.95E+19	4.95E+19
	Egg	1.71E+06	6.93E+21	7.05E+21	7.05E+21	7.05E+21	7.05E+21
	Subtotal	5.73E+22	6.05E+22	6.26E+22	5.92E+22	5.92E+22	
Forestry output	Wood	4.40E+04	2.40E+21	4.54E+21	4.54E+21	4.54E+21	4.54E+21
	Bamboo	4.40E+04	1.17E+20	1.01E+20	1.01E+20	1.01E+20	1.01E+20
	Tung seed	6.90E+05	1.10E+21	1.02E+21	1.02E+21	1.02E+21	1.02E+21
	Camellia Oleifera seed	8.60E+04	1.27E+21	1.33E+21	1.33E+21	1.33E+21	1.33E+21
	Subtotal	4.89E+21	5.07E+21	4.78E+21	6.99E+21	6.99E+21	
Fisheries output	Aquatic products	2.00E+06	4.04E+21	4.33E+21	4.33E+21	4.33E+21	4.33E+21
Total emergy output	1.59E+23	1.62E+23	1.68E+23	1.65E+23	1.69E+23		

2 Results and analysis

2.1 The trend of changes in the total emergy of agro-ecosystem in Hunan Province In the period 1999 – 2008, the total emergy input of agro-ecosystem in Hunan Province basically remained stable, declining from 2.08E+23 sej in 1999 to 2.07E+23 sej in 2008, while the total annual emergy yield experienced dramatic growth, increasing from 1.36E+23 sej in 1999 to 1.69E+23 sej in 2008, an increase of 23.8%, indicating that during the study period, the input and output efficiency of agro-ecosystem in Hunan Province was improved greatly. However, total yield is still less than total emergy input, indicating that the input and output efficiency of agro-ecosystem in Hunan Province is still not high, but it has obvious features of extensive development.

2.2 The trend of changes in the emergy input structure of agro-ecosystem in Hunan Province During the study period, there were no great changes in the total emergy input of agro-ecosystem in Hunan Province, but the structural composition experienced great changes. The non-renewable industrial assistant emergy increased significantly, from 4.00E +22 sej to 5.53E +22 sej, an increase of 38.4%, while the renewable organic emergy input declined to some extent, gradually from 1.32E +23 sej to 1.20E +23 sej (Fig. 2). Such structural change in emergy arising from the industrialization of agriculture is the main reason for a substantial increase in efficiency of agricultural production in Hunan Province.

Table 3 Emergy indicators of agro-ecosystem in Hunan Province in the period 1999 –2008

Year	Emergy investment ratio (EIR)	Emergy yield ratio (EYR)	Industrial assistant emergy ratio	Organic assistant emergy ratio	Environmental loading ratio (ELR)	Sustainable development index
1999	4.73	0.79	0.19	0.63	1.12	0.71
2000	4.59	0.81	0.19	0.63	1.10	0.74
2001	4.98	0.84	0.20	0.63	1.23	0.68
2002	3.45	0.81	0.19	0.58	0.87	0.94
2003	5.43	0.84	0.22	0.63	1.42	0.59
2004	4.56	0.92	0.22	0.60	1.27	0.72
2005	5.24	0.93	0.24	0.60	1.53	0.61
2006	5.06	0.96	0.25	0.59	1.51	0.64
2007	5.48	0.95	0.26	0.59	1.71	0.55
2008	5.56	0.96	0.27	0.58	1.79	0.54

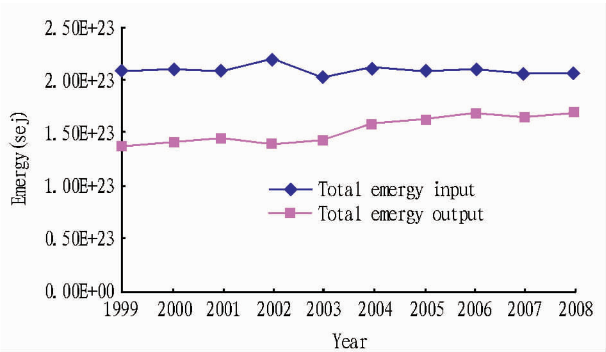


Fig.1 Changes in the total emergy of agro-ecosystem in Hunan Province

During the study period, there were two reasons for decline in the input of renewable organic emergy: (i) The rural labor forces transferred from the agricultural system to work in Guangdong and other southeast coastal areas, and the labor emergy declined from 1.29E +23 sej in 1999 to 1.17E +23 sej in 2008, a drop of 9.5%; (ii) The proportion of animal power in agricultural production declined ceaselessly, from 1.05E +21 sej in 1999 to 7.87E +20 sej in 2008 (Table 1), a drop of 25 %, fully indicating that the level of agricultural mechanization in Hunan Province was increasingly promoted, and the proportion of animal power in agricultural production was becoming less and less. Under the condition of total emergy input changing gently, the emergy input of labor force and animal power decreased incessantly and the non-renewable industrial assistant emergy increased constantly, resulting in continuous improvement in the emergy output of system, showing a good development trend.

In the period 1999 –2008, the share of total environmental emergy input in total emergy input of agro-ecosystem in Hunan Province was small, an average of 17%; the emergy input of renewable environmental resources showed gentle downward trend, declining from 3.61E +22 sej to 3.11E +22 sej, because in recent years, some natural disasters such as ice storm and floods to varying degrees, have occurred in Hunan Province, leading to decline in the area of woodland and grassland to a certain extent; the non-renewable environmental emergy (mainly the topsoil loss), on the whole, increased to a certain extent, from 3.15E +20 sej to 3.71E +20 sej, and after 2000, it showed the stable variation trend with a slight decline (Fig.3), indicating that the policy of returning farmland to forest and grass implemented since 2000, has to some extent curbed the deterioration of the agro-ecological environment.

During the study period, the input of non-renewable industrial assistant emergy exceeded the total environmental emergy input, and the magnitude of the excess was increasingly great. In 2008, the total environmental emergy input was 3.15E +22 sej, and the input of non-renewable industrial assistant emergy was 5.53E +22 sej (the latter is 1.76 times that the former), indicating that the development of agro-ecosystem in Hunan Province is increasingly dependent on the input of industrial assistant emergy; if there is no support of industrial assistant emergy, the sustainable development of agro-ecosystem in Hunan Province can not be maintained.

2.3 The trend of changes in the emergy output structure of agro-ecosystem in Hunan Province In the period 1999 –2008, the emergy output of agro-ecosystem in Hunan Province experienced substantial growth, and the total emergy yield increased from 1.36E +23 sej to 1.69E +23 sej (Fig. 4). The quantity relative ratio of crop farming, animal husbandry, forestry and fishery, changes from 61.4: 33.3: 3.1: 2.2 in 1999 to 58.3: 35: 4.1: 2.6 in 2008.

The quantity ratio relationship between crop farming emergy and animal husbandry emergy has experienced the change " one wanes, the other waxes". The proportion of crop farming emergy declines from 61.4% to 58.3%; the proportion of animal husbandry emergy increases from 33.3% to 35.0% (Table 4). Under the influence of the government’s agricultural policy, this structural change is the result of incessant optimization of agricultural industrial structure in Hunan Province, and also another important reason for the substantial increase in system productivity. Especially increase in the animal husbandry emergy has played a major role in the improvement of system pro-

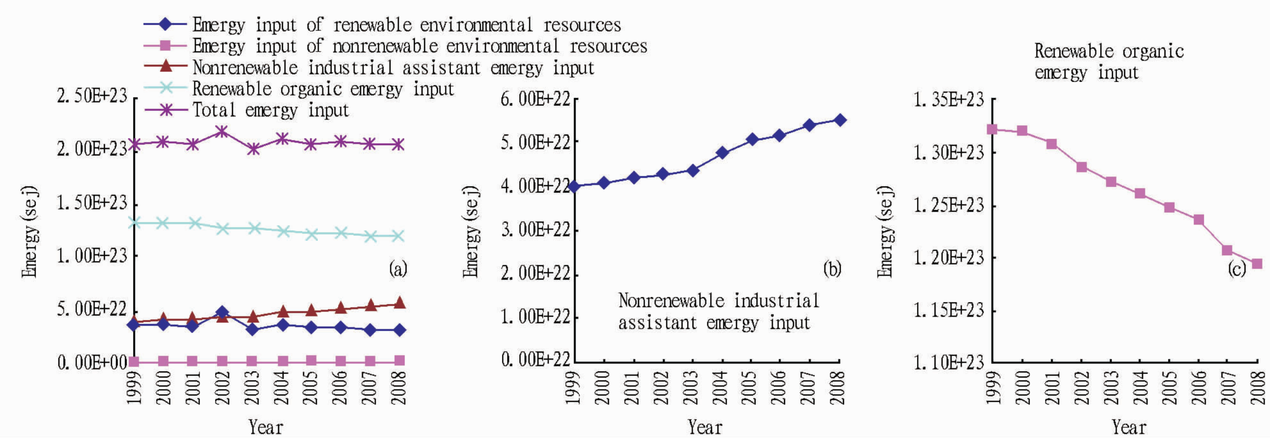


Fig. 2 Changes in the emergy input structure of agro-ecosystem (a), non-renewable industrial assistant emergy (b) and renewable organic emergy (c) in Hunan Province

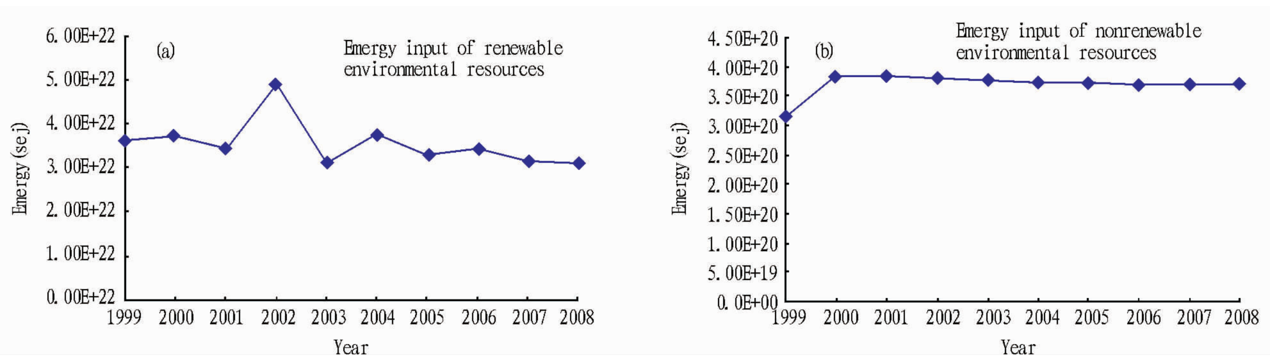


Fig. 3 Changes in emergy input of renewable environmental resources (a) and emergy input of nonrenewable environmental resources (b) in agro-ecosystem of Hunan Province.

ductivity. The reason is that long with economic development and rise in national income, people not only emphasize eating their fill, but also eating well, and there is a growing market demand for livestock products. The livestock products have higher marginal demand tendency than the crop farming products, indicating that the output emergy of animal husbandry over that of crop farming is only a matter of time.

Table 4 The emergy output structure of agro-ecosystem in Hunan Province in the period 1999 – 2008

Year	Proportion of crop farming	Proportion of animal husbandry	Proportion of forestry	Proportion of fisheries
1999	0.614	0.333	0.031	0.022
2000	0.610	0.336	0.032	0.023
2001	0.608	0.338	0.031	0.023
2002	0.572	0.373	0.029	0.026
2003	0.567	0.376	0.030	0.026
2004	0.584	0.359	0.031	0.025
2005	0.569	0.373	0.031	0.027
2006	0.576	0.372	0.028	0.023
2007	0.608	0.332	0.035	0.025
2008	0.583	0.350	0.041	0.026

During the study period, the relative proportion of crop farming emergy in Hunan Province declined to a certain extent, but the absolute amount of emergy still tended to rise, from 8.38E+22 sej in 1999 to 9.84E+22 sej in 2008, an increase of 17.4% (Fig. 5). The emergy output of crop farming in the study area fluctuated slightly, which may be limited by certain threshold value, such as limited input of natural environment emergy (soil, water, sunlight, etc.) and limited agricultural production technical level. The finiteness of emergy input of the natural environment can not be changed, and if there is no new major breakthrough in agricultural technology (such as a new hybrid rice), then the emergy output of crop farming is difficult to be significantly improved. Therefore, in order to further improve the emergy output of crop farming, there is no other way

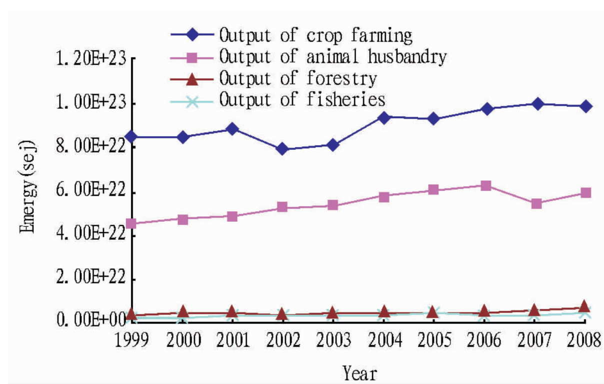
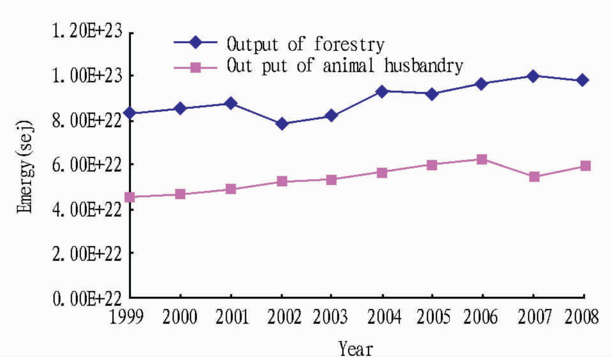


Fig. 4 Changes in the emergy output structure of agro-ecosystem in Hunan Province

but to continue to optimize the emergy input structure, further optimize and adjust the internal structure of crop farming.



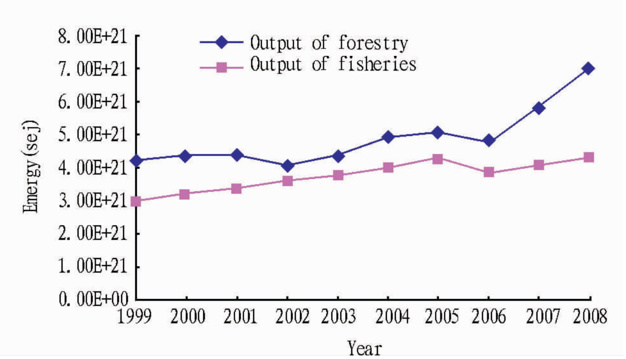


Fig. 5 Changes in agro-ecosystem emergy of crop farming, animal husbandry, forestry and fishery in Hunan Province

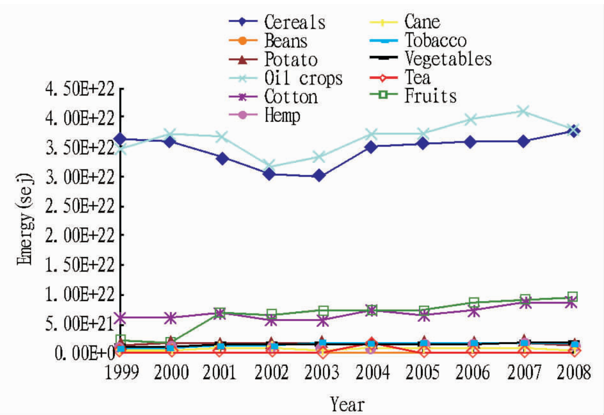


Fig. 6 Changes in the crop farming component emergy of agro-ecosystem in Hunan Province

It can be seen from Fig. 6 that in Hunan's crop farming, grain and oil occupy the greatest share, followed by cotton, fruits, and potatoes; vegetables and melons, beans, sugarcane, tea, hemp and tobacco occupy the smallest share. In contrast with the trend of changes in total emergy yield of crop farming, we see that the emergy output of crop farming fluctuates slightly on the whole, indicating that the adjustment of agricultural industrial structure in Hunan Province is inadequate. The fluctuation in the emergy output of crop farming in Hunan Province is most influenced by the output of cereals and oilseeds.

During the study period, the overall growth rate of crop farming in Hunan Province was 17.4%. The growth rate of fruits was the greatest (286.3%), followed by hemp (156.4%); the growth rate of tea, vegetables and melons, tobacco, cotton, potato, beans, and sugarcane, tended to decline (Table 5).

In the period 1999 – 2008, the emergy output of animal husbandry in Hunan Province was always soaring, from 4.54E+22 sej to 5.92E+22 sej, an increase of 30.4%.

The growth of animal husbandry has led to substantial increase in the emergy output of entire agro-ecosystem. With the expansion of the scale of farming and the continuous improvement of people's living standards, the emergy output of animal husbandry may continue to grow dramatically, and animal husbandry may become the engine and leading industry of agro-ecosystem in Hunan Province.

Table 5 Growth rate of various farming industries in the period 1999 – 2008 Unit: %

Item	Growth rate	Item	Growth rate	Item	Growth rate	Item	Growth rate
Cereals	3.8	Potato	10.7	Cotton	36.6	Sugarcane	55.2
Beans	–22.2	Oil crops	10.1	Hemp	156.4	Tobacco	42.2
Vegetables and melons	62.5	Tea	63.3	Fruits	286.3	Crop farming	17.4

The emergy output of forestry in Hunan Province occupies small share. In the period 1999 – 2008, the emergy output of forestry in Hunan Province showed a rising trend, and especially from 2006, the output emergy of forestry experienced rapid growth, indicating that the smooth implementation of national policy of returning farmland to forest makes the emergy output of forestry in Hunan Province have more extensive room for growth.

The proportion of fishery emergy output in Hunan Province is the smallest, but it grew rapidly, from 3.01E+21 sej in 1999 to 4.33E+21 sej in 2008, an increase of 43.9%. Hunan Province is known as " land flowing with milk and honey", having the natural advantages and abundant rainfall for aquaculture and; fishery makes great contribution to the total emergy output of system. Therefore, the output potential of this part is very large.

2.4 The trend of changes in the emergy indicators of agro-ecosystem in Hunan Province

2.4.1 Emergy investment ratio. The emergy investment ratio is the ratio of total assistant emergy input to the emergy input of environmental resources. In the period 1999 – 2008, the emergy investment ratio of agro-ecosystem in Hunan Province rose from 4.73 to 5.56 (Fig. 7), showing an overall rising trend, but the growth rate was not very obvious, a far cry from the international standards (the emergy investment ratio of agro-ecosystem in Italy in 1989 was 7.55)[26]. At present, the agricultural resources of agro-ecosystem in Hunan Province have not yet been used efficiently, restricting the development of agricultural production, but the total assistant emergy input still has large room for growth.

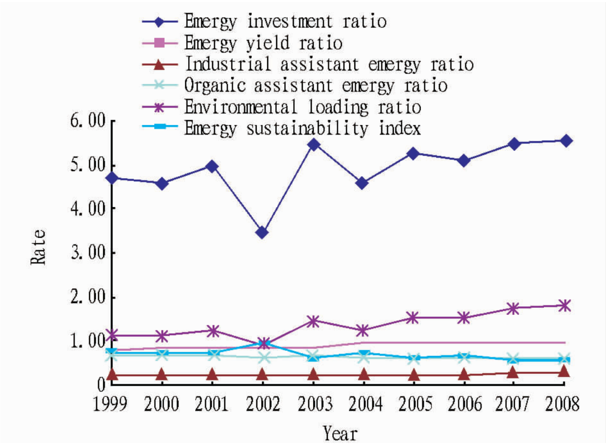


Fig. 7 Changes in emergy investment ratio, emergy yield ratio, industrial assistant emergy ratio, organic assistant emergy ratio and environmental loading ratio of agro-ecosystem in Hunan Province

2.4.2 Emergy yield ratio. The emergy yield ratio is the ratio of the total emergy yield to total assistant emergy input. During the study period, the net emergy yield ratio of agro-ecosystem in Hunan Province showed an increasing trend, rising from 0.79 in 1999 to 0.96 in 2008, indicating that with constant optimization of the emergy input and output structure of agro-ecosystem in Hunan Province, the efficiency of system emergy yield is increasingly promoted, with a good development trend.

Emergy yield ratio is often used to judge whether the system has advantage in terms of obtaining economic input emergy, which reflects the sustainable development of the system to a certain extent. Odum[4] believes that this value should be 1 to 6, and if this value is less than 1, it indicates that the system's input exceeds the system's output. The agro-ecosystem in Hunan Province shows the extensive economic characteristics of high input, low output. Therefore, improving the emergy input and output structure of system, and promoting the function and efficiency of the system, is the main task for agriculture in Hunan Province.

2.4.3 Industrial assistant emergy ratio and organic assistant emergy ratio. The industrial assistant emergy ratio is the ratio of non-renewable industrial assistant emergy to the total emergy input. During the study period, the industrial assistant emergy input ratio of agro-ecosystem in Hunan Province showed an overall rapid upward trend, increasing from 19% in 1999 to 27 % in 2008, but the total amount is less than the level of organic assistant emergy input in the same period (Fig. 7).

The reasons include the following two aspects: (i) Agriculture is regarded as a weak industry, and the overall return rate of it is lower than that of the secondary and tertiary industries. The characteristic of agricultural investment project is that it is greatly affected by the natural resources and environment, with long investment cycle and many risk factors. Farmers themselves and the non-farm investors do not want to invest much in agricultural production. (ii) In recent 10 years, the state attaches great importance to the foundation role of agriculture, and issues concerning agriculture, countryside and farmers; the state implements the protection price for the price of agricultural products. To a certain extent, it has improved farmers' enthusiasm for production and investment.

The organic assistant emergy ratio is the ratio of renewable organic emergy input to total emergy input. During the study period, the organic assistant emergy ratio of agro-ecosystem in Hunan Province showed a downward trend on the whole, declining from 63% in 1999 to 58% in 2008 (Fig. 7). The trend of changes in the organic assistant emergy ratio is contrary to that of industrial assistant emergy ratio, which is an inevitable result of agricultural mechanization.

During the period 2006 – 2008, the organic assistant emergy ratio of agro-ecosystem in Hunan Province was maintained at a high level of 58%, indicating that the agricultural mechanization and modernization in Hunan Province still has a long way to go. In the organic emergy input, the labor emergy gains prominence, and the proportion of organic fertilizer is very small. In 2008, the proportion of organic fertilizer to chemical fertilizer in industrial assistant energy is 1: 181. Therefore, in the process of Hunan's agricultural industrialization and rise in the industrial assistant emergy ratio, it is necessary to properly control the increase in the proportion of chemical fertilizer in the industrial assistant energy, and encourage the use of organic fertilizer in organic assistant emergy input, which is also the requirement of building ecological agriculture and protecting the agricultural ecological environment in Hunan Province.

2.4.4 Environmental loading ratio. The environmental loading ratio refers to the ratio of sum of non-renewable environmental resources emergy input and non-renewable industrial assistant emergy input to renewable environmental resources emergy input. During the study period, the environmental loading ratio of agro-ecosystem in Hunan Province showed a slow upward trend, rising from 1.12 in 1999 to 1.79 in 2008.

The main reasons for constant rise in the environmental loading ratio of agro-ecosystem in Hunan Province mainly include the following three aspects: (i) The environmental resources emergy input continued to decline, decreasing from 3.61E+22 sej in 1999 to 3.11 E+22 sej in 2008. The impact of industrialization and urbanization made the area of agricultural land (especially the area of woodland and grassland) decrease to a certain extent. (ii) The non-renewable environmental resources increased from 3.15 E+20 sej in 1999 to 3.71 E+20 sej in 2008. (iii) With the acceleration of agricultural industrialization, the non-renewable industrial assistant emergy input was constantly increased. In comparison with the national average (2.80) in 1998, Japan's level (14.49) in 1990, and Italy's level (10.03) in 1989[28], it is low, indicating that in the process of agricultural modernization in Hunan Province, there is certain environmental loading space.

2.4.5 Emergy sustainability index (ESI). The emergy sustainability index (ESI) refers to the ratio of emergy yield ratio to environmental loading ratio. This index can objectively show the regional capacity for sustainable development. If 1 < ESI < 10, it indicates that the agro-ecosystem in this region is full of vitality and development potential; ESI > 10 is the symbol of underdevelopment of the agricultural economy, indicating that that development and utilization of resources is not enough; if ESI < 1, it indicates that the agro-ecosystem in this region is the high consumption-driven ecosystem, and the local non-renewable resources are used greatly.

In the period 1999 – 2008, the emergy sustainability index of agro-ecosystem in Hunan Province declined from 0.71 to 0.54, always at the level less than 1, indicating that on the whole, the agriculture in Hunan Province is the high consumption-driven ecosystem, still not the ecosystem full of vitality and development potential. During the study period, ESI of agro-ecosystem in Hunan Province showed a declining trend (Fig. 7). Since 2002, the emergy yield ratio of this system has been increasing incessantly, but the corresponding environmental loading ratio has been also rising more rapidly. Relative to the higher environmental loading ratio, the emergy yield ratio of agro-ecosystem in Hunan Province is not high, which is closely related to the characteristics of agricultural resources in Hunan Province. In Hunan Province, the area of mountains and hills is large, with high level of land fragmentation, and the per capita arable land area is small, not conducive to the launching of agricultural mechanization. In addition to large rural population and many surplus labor forces, there was once a particular phenomenon that the contracted land was mainly borne by women and the elderly, playing a role in crowding out agricultural mechanization and modernization. Due to low labor productivity, considerable human emergy input did not lead to substantial increase in the emergy yield. Under the conditions of high environmental loading ratio, low emergy yield ratio will lead to relatively low emergy sustainability index.

3 Conclusions

On the basis of collection, sorting and analysis of considerable data, using the emergy analysis method, we conduct trend analysis of changes in the total emergy, input and output structure, various emergy indicators of agro-ecosystem in Hunan Province during the period 1999 – 2008. We draw the following conclusions: During the study period, total emergy input basically remained stable, but the emergy input structure was constantly optimized, total emergy yield and yield efficiency of this system were promoted dramatically; since the environmental loading ratio also tended to rise constantly, the sustainability index of this system also experienced the slow downward trend, but always less than 1, indicating that the agriculture in Hunan Province is the high consumption-driven ecosystem in general, with obvious features of extensive development.

It is worthy of noting that the energy conversion coefficient and emergy conversion rate are mainly based on the research results of Odum and other scholars. The energy conversion coefficient and emergy conversion rate can meet a wide range of analyses, but because of regional differences in some factors in various countries and regions, such as production level and efficiency, some errors may arise, which need to be corrected by us through further research.

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existing research results, there are at least two upsurges of the Ginkgo culture: one in Song Dynasty, when Ginkgoes became a tribute for Chinese emperors, and Ginkgo tress become a common emotional media; the other is those election activities for national, provincial and municipal trees as well its scientific research. In recent years, Ginkgoes are rather widely planted throughout China, and even become a fashion. However, it also have raised some problems. It is of great significance to study the development history of the Ginkgo culture and explore the spiritual core of the Ginkgo culture and its future trend, for the exploration and construction of today's Ginkgo spirit and even the Ginkgo culture.

Each age has its own demands, mission and limitation. Based on the above review of history of the Ginkgo culture, we can find that the Ginkgo culture has been deepening and developing continuously, and each age has its own orientation for the development of the Ginkgo culture. The Ginkgo culture doesn't spring up out of nowhere; instead, it is built upon the foundation of comprehensive in-depth scientific knowledge and powerful Ginkgo economic industry, and is consistent with the ideological trend. Only through integration with the needs of the current age and national characteristic, can we make the Ginkgo culture have its own foundation and specialty, and not let it become isolated. Though currently the Ginkgo culture has great vitality, the promotion and research on Ginkgo and the Ginkgo culture is far from sufficient. The strong call for the spiritual connotation of the Ginkgo culture at present has made the construction of the Ginkgo culture urgent. To develop the Ginkgo culture, we should inherit legacy of history, further develop each aspect of the Ginkgo culture to realize coordinated development. Facing with the reality, we will further deepening the Ginkgo culture at this new age, insist on sustainable scientific development, and create an open flexible system of the Ginkgo culture. In the future the Ginkgo culture will enter a new age of harmonious development of human and the nature, technology and culture.

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