Emergy Analysis of Agricultural Ecosystem in Shouguang City, Shandong Province

Lin Mu¹, Yan Wang¹, Tianhong Zhao¹* and Jian Ma²

¹Agronomy College, Shenyang Agricultural University, Shenyang, China
²Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang, China

*Corresponding author email: zth@syau.edu.cn

Abstract. By using the method of emergy analysis, this paper analyzed agricultural industrial structure and the emergy input, output and emergy index of agricultural ecosystem in Shouguang City from 2007 to 2016, which reflected the development trend of agricultural ecosystem. The results showed that the total emergy input of agricultural ecosystem in Shouguang City from 2007 to 2016 was in a downward trend, and the change trend of total emergy output was in a downward and then upward trend. From the emergy index, the economic input of agricultural ecosystem in Shouguang City was large, the environmental utilization was not sufficient, but the pressure on the environment was small, and the agricultural ecosystem in Shouguang City was in a sustainable state Continuous development status.

1. Introduction
Emergy is defined as the total amount of effective energy applied directly or indirectly in the process of forming a product or service[1][2]. The emergy theory and analysis method is that Odum chooses solar energy value as a unified measurement standard to measure any kind and level of energy. Through a series of emergy indexes, the system can evaluate its production capacity[3][4]. Emergy analysis was widely used. Internationally, Cavalett took a small farm in Brazil as an example, and used emergy analysis method to study the environmental carrying capacity and sustainability of the integrated production ecosystem compared with the single production ecosystem[5]. In China, Li Shuangcheng put forward the evaluation index of regional sustainable development based on emergy theory, and the results show that China's economic development causes sustained pressure on the environment, and the sustainable development index shows a downward trend[6].

Agriculture is the basic guarantee of human survival and the foundation of national economic development. Shandong Province is a big agricultural province in China. In recent years, agriculture in Shouguang City has developed rapidly. But there was little research on agricultural ecosystem in Shandong Province, so in this paper, the emergy theory and method was used to explore the advantages and disadvantages of agricultural development in Shouguang City, and provide theoretical basis for its development.

2. Data Sources and Research Methods

2.1. Data Sources
The basic data required in this paper are from Shouguang Statistical Yearbook (2007-2016). In this paper, the energy conversion coefficient and emergy conversion rate used in the conversion of energy to emergy are derived from the research of H.T.Odum[7] and Lan Shengfang [8].
2.2. Research Methods

In this paper, H.T.Odum’s emergy analysis theory was used to transform different forms of energy into a unified unit solar Joule (sej). The process of emergy analysis was mainly divided into collecting and sorting data, analyzing energy system, compiling emergy analysis table, establishing emergy index analysis system and analyzing and evaluating system. The indexes used in emergy analysis table include Solar energy value, Net emergy yield ratio (EYR), Emergy investment ratio (EIR), Environment loading ratio (ELR), Emergy-based sustainability index (ESI).

3. Results and Analysis

3.1. Analysis on the Industrial Structure of Shouguang City in Shandong Province

Table 1. Output value of agriculture, forestry, animal husbandry and fishery in Shouguang City from 2007 to 2016

| Year  | Agriculture | Forestry | Animal Husbandry | Fisheries | Service Industry |
|-------|-------------|----------|------------------|-----------|------------------|
|       | 2007        | 2008     | 2009             | 2010      | 2011             |
|       | (RMB×10^4)  | (RMB×10^4)| (RMB×10^4)      | (RMB×10^4)| (RMB×10^4)      |
| 2007  | 50297       | 53697    | 72428            | 89891     |                   |
| 2008  | 47413       | 51066    | 70242            | 87396     |                   |
| 2009  | 49207       | 53957    | 69328            | 85492     |                   |
| 2010  | 51947       | 57697    | 72328            | 90891     |                   |
| 2011  | 54207       | 61097    | 75328            | 95891     |                   |
| 2012  | 56407       | 64397    | 78328            | 100891    |                   |
| 2013  | 58607       | 67697    | 81328            | 105891    |                   |
| 2014  | 60807       | 70997    | 84328            | 110891    |                   |
| 2015  | 63007       | 74297    | 87328            | 115891    |                   |
| 2016  | 65207       | 77597    | 90328            | 120891    |                   |

Table 1 shows that the agricultural output value of Shouguang City from 2007 to 2016 is higher than that of forestry, animal husbandry, fishery and service industry. From the proportion, it can be seen that the proportion of agricultural output value in Shouguang city changed slightly from 2007 to 2009. The proportion of output value is agriculture > animal husbandry > fishery > service industry > forestry. Since 2009, the proportion of fishery output value in Shouguang City has decreased. In conclusion, the industrial structure of agriculture, forestry, animal husbandry and fishery changed little, and the proportion differentiation was obvious, Shouguang City is mainly agricultural development, so this paper took agriculture as the main analysis object.

3.2. Emergy Input and Output Analysis of Agricultural Ecosystem in Shouguang City, Shandong Province

Table 2. Analysis of emergy output of agricultural ecosystem in Shouguang City from 2007 to 2016

| Year  | Planting | Animal Husbandry | Fisheries | Total output |
|-------|----------|------------------|-----------|--------------|
| 2007  | 6.74×10^21| 6.57×10^21      | 4.24×10^21| 1.76×10^22  |
| 2008  | 5.42×10^21| 5.56×10^21      | 4.42×10^21| 1.54×10^22  |
| 2009  | 7.06×10^21| 4.82×10^21      | 2.92×10^21| 1.42×10^22  |
| 2010  | 8.31×10^21| 6.52×10^21      | 1.83×10^21| 1.67×10^22  |
| 2011  | 7.13×10^21| 7.21×10^21      | 1.96×10^21| 1.63×10^22  |
| 2012  | 8.37×10^21| 7.88×10^21      | 2.06×10^21| 1.83×10^22  |
| 2013  | 8.38×10^21| 7.82×10^21      | 2.26×10^21| 1.85×10^22  |
| 2014  | 7.57×10^21| 7.94×10^21      | 2.31×10^21| 1.78×10^22  |
| 2015  | 7.67×10^21| 7.98×10^21      | 2.37×10^21| 1.80×10^22  |
| 2016  | 7.19×10^21| 7.81×10^21      | 2.55×10^21| 1.76×10^22  |
| R | Solar energy \((\times 10^{19})\) | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wind energy \((\times 10^{12})\) | 6.63\times10^2 | 4.69 | 4.46 | 4.43 | 4.40 | 4.40 | 4.40 | 4.40 | 4.40 | 4.40 |
| | Chemical energy of rainwater \((\times 10^{13})\) | 1.54\times10^4 | 6.01 | 10.00 | 9.63 | 7.47 | 12.4 | 7.56 | 8.93 | 7.33 | 7.56 |
| | Rainwater potential energy \((\times 10^{18})\) | 8.89\times10^3 | 3.40 | 5.70 | 5.46 | 4.23 | 7.01 | 4.28 | 5.06 | 4.15 | 4.29 |
| | Rotational energy of the earth \((\times 10^{19})\) | 2.19\times10^4 | 6.92 | 6.57 | 6.53 | 6.33 | 6.33 | 6.33 | 6.33 | 6.33 | 6.33 |
| | Subtotal \((\times 10^{20})\) | 1.44 | 1.83 | 1.78 | 1.53 | 2.05 | 1.54 | 1.68 | 1.51 | 1.54 | 1.52 |
| N | Net topsoil loss energy \((\times 10^{19})\) | 6.25\times10^4 | 1.47 | 1.51 | 1.55 | 1.66 | 1.66 | 1.65 | 1.64 | 1.62 | 1.55 |
| | Subtotal \((\times 10^{19})\) | 1.47 | 1.51 | 1.55 | 1.66 | 1.66 | 1.65 | 1.64 | 1.62 | 1.55 | 1.48 |
| F | Nitrogenous fertilizer \((\times 10^{20})\) | 3.80\times10^9 | 4.45 | 4.52 | 2.93 | 3.38 | 3.06 | 2.99 | 2.89 | 2.69 | 2.73 |
| | Phosphate fertilizer \((\times 10^{20})\) | 3.90\times10^8 | 2.62 | 2.63 | 1.77 | 1.63 | 1.61 | 1.61 | 1.58 | 1.53 | 1.59 |
| | Potash fertilizer \((\times 10^{17})\) | 1.10\times10^8 | 3.99 | 3.51 | 3.27 | 3.97 | 3.80 | 3.71 | 3.69 | 3.84 | 3.89 |
| | Compound fertilizer \((\times 10^{20})\) | 2.80\times10^7 | 2.94 | 3.22 | 2.94 | 3.53 | 3.61 | 3.47 | 3.56 | 3.39 | 3.39 |
| | Pesticides \((\times 10^{15})\) | 1.60\times10^6 | 7.28 | 7.14 | 3.92 | 3.73 | 4.00 | 3.78 | 3.76 | 3.55 | 3.54 |
| | Agricultural film \((\times 10^3)\) | 3.80\times10^3 | 7.64 | 7.60 | 5.40 | 6.57 | 6.61 | 6.84 | 6.73 | 6.46 | 6.69 |
| | Agricultural diesel \((\times 10^{19})\) | 5.40\times10^4 | 10.60 | 11.00 | 9.61 | 9.23 | 9.40 | 9.18 | 8.80 | 8.21 | 7.83 |
| | Agricultural machinery \((\times 10^{20})\) | 7.50\times10^7 | 3.20 | 3.35 | 3.51 | 3.61 | 3.77 | 3.77 | 3.76 | 3.76 | 3.81 |
| | Power \((\times 10^{16})\) | 1.60\times10^6 | 3.06 | 3.31 | 2.48 | 3.26 | 3.20 | 3.23 | 3.28 | 3.22 | 3.20 |
| | Subtotal \((\times 10^{15})\) | 1.47 | 1.53 | 1.25 | 1.35 | 1.34 | 1.32 | 1.31 | 1.26 | 1.27 | 1.20 |
| T | Labour \((\times 10^{20})\) | 3.80\times10^3 | 6.73 | 6.57 | 7.49 | 7.71 | 7.90 | 7.94 | 7.94 | 8.02 | 8.06 |
| | Organic fertilizer \((\times 10^{15})\) | 2.70\times10^4 | 2.78 | 8.51 | 8.72 | 2.78 | 2.81 | 2.81 | 2.78 | 2.73 | 2.68 |
| | Subtotal \((\times 10^{20})\) | 6.73 | 6.57 | 7.49 | 7.71 | 7.90 | 7.94 | 7.94 | 8.02 | 8.06 | 7.90 |
| | Total input \((\times 10^{21})\) | 2.31 | 2.38 | 2.19 | 2.29 | 2.35 | 2.28 | 2.29 | 2.23 | 2.25 | 2.16 |
Notes: R: Renewable environmental resources; N: Non-renewable environmental resources; F: Non-renewable industrial auxiliary energy; T: Renewable organic energy.

Table 2 shows that the total output energy of agricultural ecosystem in Shouguang City decreased from 2007-2009, increased from 2009-2013, and changed slightly from 2014-2016. The total output value of agricultural ecosystem in Shouguang City in 2010 and 2007 was the same, and the total output value in 2013 was the largest.

From 2007 to 2016, the agricultural ecosystem in Shouguang City was dominated by planting and animal husbandry, and from 2007 and 2010-2013, the planting industry was more than the animal husbandry, and the animal husbandry was more than the planting industry in 2008-2009 and 2013-2016, while the fishery was gradually reduced. The emergy output of planting industry tends to increase from 2007 to 2010, but decreases from 2011 to 2016. The emergy output of animal husbandry is on the rise from 2007 to 2016, and the emergy output of fishery is on the decline.

Table 3 shows that the total emergy input of agricultural ecosystem in Shouguang City was in a downward trend from 2011 to 2016. In general, the input energy of nonrenewable industrial auxiliary energy was the largest, the second was renewable organic energy, the third was renewable environmental resources, the last was nonrenewable environmental resources. The inputs of nitrogen fertilizer, phosphate fertilizer, compound fertilizer and agricultural machinery were more in the nonrenewable industrial auxiliary energy input. In the renewable organic energy input, the labor input was the largest, while the input of organic fertilizer was far less than that of labor force. It can be further seen that Shouguang City is mainly engaged in agricultural development and has more agricultural labor. The investment of renewable and nonrenewable environmental resources in Shouguang City was very little and fluctuated little, which indicated that Shouguang City used less environmental resources and lacked favorable environmental resources protection when developing agricultural ecosystem. Meanwhile, the net topsoil loss in agricultural ecosystem of Shouguang City was less, which greatly reduced the damage of crops to soil.

### 3.3. Emergy Index System Analysis of Agricultural Ecosystem in Shouguang City, Shandong Province

1. **Net emergy yield ratio**
   - Fig. 1 shows that the EYR of agricultural ecosystem was on the rise, indicating that the output of agricultural ecosystem in Shouguang City increased under the market condition of reducing the total emergy input in agricultural ecosystem. Table 4 shows that the EYR of agricultural ecosystem in Shouguang City is higher than that in other cities except Yancheng City, indicating that its agricultural ecosystem has strong competitiveness.

2. **Emergy investment ratio**
   - Fig. 1 shows that the EIR of agricultural ecosystem in Shouguang City was relatively stable from 2012 to 2016, indicating that the utilization status of environmental resources in agricultural ecosystem of Shouguang city changed little and did not reach the optimal state, while the production input was more economic input. Table 4 shows that the emergy investment rate of agricultural ecosystem in Shouguang City is too high compared with other cities, and the economic input is too large.

3. **Sustainability index**
   - Fig. 1 shows that the ESI of agricultural ecosystem in Shouguang City from 2007 to 2016 is in an increasing trend. Table 4 shows that the ESI of agricultural ecosystem in Shouguang City is higher than that of other cities, slightly lower than that of Zhangzhou City, indicating that the agricultural ecosystem of Shouguang City is full of vitality and the system is in a state of sustainable development.

4. **Environment loading ratio**
   - Fig. 1 shows that the ELR of Shouguang City is on the decline trend from 2007 to 2016. Meanwhile, Table 4 shows that ELR of agricultural ecosystem in Shouguang city is lower than that of other cities. It shows that the pressure on the environment of Shouguang City is weakened, which has certain advantages for the development of green agriculture, but it also means that Shouguang City does not make full use of environmental resources.
Table 4. Comparison of energy index of agricultural ecosystem in Shouguang City with other regions

|                  | EYR | EIR | ELR | ESI |
|------------------|-----|-----|-----|-----|
| Zhangzhou 2011   | 6.88| 1.14| 2.07| 8.29|
| Yancheng 2010    | 11.12| 4.78| 4.92| 0.97|
| Shijiazhuang 2010| 6.93| 10.05| 4.75| 2.11|
| Yonghe County 2014| 1.87| 1.39| 1.49| 1.25|

Note: The table data was compared with the corresponding data of Shouguang City in the same year; Data from Kang Hong, 2014[9]; Yang Zhiping, 2013[10]; Li Shuangjiang, 2013[11]; Li Xing, 2018[12]

Figure 1. Dynamic changes of energy value indexes of vegetable production system in Shouguang City from 2007 to 2016

4. Conclusion
In this paper, emergy analysis theory was used to study the development status of agricultural ecosystem in Shouguang City from 2007 to 2016, and revealed that Shouguang City in 2007 - 2016, the agricultural production system had a large amount of economic input in the development process, and the economic development status was good. The utilization efficiency of energy input in the system was high, the pressure on the environment was small when producing crops, and the damage to the environment was not high. The system was in the state of sustainable development, but the utilization degree of the environment was low, the environmental resources were not fully utilized. At present, China strongly advocates that we should protect the ecological environment and live in harmony with nature while making full use of environmental resources. Therefore, Shouguang City should make full use of environmental resources, reduce economic costs, reduce industrial auxiliary energy input and increase the use of green organic fertilizer on the premise of developing green ecological agriculture to achieve better benefits.

Acknowledgements
This study was supported by the Program of Shouguang Facility Agriculture Center in Chinese Academy of Sciences (2018SGB01). Lin Mu and Yan Wang contributed equally to this work and should be considered co-first authors.

Reference
[1] Sha S and Hurme M. 2012. Emergy evaluation of combined heat and power plant processes[J]. Applied Thermal Engineering, 43: 67-74.
[2] Lee S M and Odum H. T. 1994. Emergy analysis overview of Korea [J]. Journal of Korea
Environment Science and Society, 3(2): 165-175.

[3] Odum H. T. and Odum E. C. 2006. The prosperous way down [J]. Energy, 31(1) :21-32.

[4] Ulgiati S., Odum H.T., Bastianoni S. 1994. Emergy use, environmental loading and sustainability an emegry analysis of Italy [J]. Ecological Modelling, 73(3-4).

[5] Otávio C, Júlio F Q and Enrique O. 2005. Emergy assessment of integrated production systems of grains, pig and fish in small farms in the South Brazil [J]. Ecological Modelling, 193(3).

[6] Li S C, Fu X F and Zheng D. 2001. Emergy analysis for evaluating sustainability of Chinese economy [J]. Journal of natural resources, (04): 297-304.

[7] Odum H. T. 2000. Eco-economic evolution, emegry evaluation and policy options for the sustainable development of Tibet [J]. The Journal of Chinese Geography, (01): 1-27.

[8] Lan S F and Qin P. 2001. Emergy analysis of ecosystems[J]. Chinese Journal of applied ecology, (01): 129-131.

[9] Kang H and Lin H H. 2014. Study on sustainable development of characteristic agricultural ecosystem in Zhangzhou city based on emergy analysis[J]. Guangdong Agricultural Sciences, 41(23): 188-194+200.

[10] Yang Z P. 2013. Dynamic analysis on Agri-ecological system of Yangcheng city based on emegy theory [J]. Research of soil and water conservation, 20(06): 311-315+332.

[11] Li S J and Hu Y N. 2013. Evolution Trend Analysis of Agro-Ecosystem in Shijiazhuang City Area [J]. Hubei Agricultural Sciences, 52(06): 1469-1473.

[12] Li X. 2018. Research on sustainable development of agricultural ecosystem in Yonghe County based on emegy theory [D]. Shanxi Agricultural University.