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The emergy of metabolism in the same ecosystem (maize) under different environmental conditions

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ABSTRACT

Ecosystem sustainability is the basis for life, economic and social sustainability. The energy metabolism of an ecosystem has long been a focus area in the scientific community because it determines the productivity, sustainability and development of ecosystem. This study applied emergy analysis to explore the metabolism of maize ecosystems under different environmental conditions; to investigate its energy input, environmental pressure and sustainability; and to understand the maintenance mechanism of the general ecosystem based on the China statistical data of 2014. Results showed that the sum of renewable natural resources ranged from 0.62×10^{14} seJ/ha in Xinjiang to 6.34×10^{14} seJ/ha in Guangxi; the sum of nonrenewable natural resources ranged from 3.95×10^{14} seJ/ha for Henan to 9.46×10^{14} seJ/ha for Jilin; the sum of purchased renewable resources ranged from 2.97×10^{14} seJ/ha for Heilongjiang to 26.14×10^{14} seJ/ha for Gansu; the sum of purchased nonrenewable resources ranged from 14.89×10^{14} seJ/ha in Sichuan to 33.00×10^{14} seJ/ha in Gansu. In addition, the environmental loading ratio in Xinjiang was the highest, followed by Ningxia (25.92), Gansu (24.77), Inner Mongolia (23.15), the lower values were 4.48, 4.21 and 4.00 for Guizhou, Chongqing and Guangxi, respectively; similarly, the emergy sustainability index in the provinces of southern China were higher than those in northwest of China. Above all, maize ecosystem is developed with a stronger competitive ability than other agricultural ecosystems, especially in the southern region of China, but also has a high environmental loading ratio. Furthermore, the proportion of natural and purchased emergy input ranged from 13.65% vs 86.35% in Xinjiang to 33.70% vs 66.30% in Heilongjiang, which were close to 30% vs 70%, 25% vs75%, 22% vs 78%, 20% vs 80% and 15% vs 85% for Northeast of China, Southwest of China, Loess Plateau, Huang-Huai-Hai Plain and Northwest of China respectively. Our study demonstrates that the natural energy in the maize ecosystem influenced the quantity and proportion of purchased energy. Different combinations of natural and purchased emergy were coupled to maintain the same ecosystem under the different environmental conditions. Its recommendation is to consider changing the crop production systems or artificial energy inputs in different regions based on differences in natural factors in order to make more efficient use of resources, reduce the use of chemical fertilizers, and promote the sustainability of ecosystems.

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1. Introduction

Ecosystem ecology has become the focus field to study life processes and phenomena since Sir Arthur Tansley proposed the concept of ecosystem (Tansley, 1939). Driven by both natural factors and anthropogenic impacts, ecosystems are always in constant change in the real world especially those ecosystems with human disturbance (Andela et al., 2017; Bürgi et al., 2017; Kareiva et al., 2007; Pecl et al., 2017; Steffen et al., 2015). Owing to ever-increasing resource uses, the agricultural ecosystem provides food and clothing for people while at the same time, influencing ecosystem processes such as land use change, freshwater use, and nitrogen and phosphorus loads (Steffen et al., 2015). On the one hand it exemplifies the coexistence of multiple or diversified agricultural ecosystems under local scales because of different energy inputs and compositions (Kremen and Miles, 2012; Zhai et al., 2017;

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Zhang et al., 2012). On the other hand, the same agro-ecosystem can be maintained at larger scales or under different climatic conditions, such as those for maize (He and Zhou, 2016; Lesk et al., 2016; Schlenker and Roberts, 2009; Tao et al., 2016).

In China, maize is cultivated throughout a large region from northeast to southwest China. Its cultivation area and annual yield have both ranked first out of China's cereal crops since 2012 (Zhang et al., 2017), with the climate-suitable planting area for summer maize approaching about 1.6×10^8 hm^2 in the last 10 years (He and Zhou, 2016). China produces more than 20% of global annual maize and is the second consumer of maize in the world (Tao et al., 2016). How can the same maize agro-ecosystem be maintained under different environmental conditions?

Many studies have conducted research on maize production and its relationship with climate change (Schlenker and Roberts, 2009; Tao et al., 2016), extreme weather (Lesk et al., 2016) and phenotypic and genetic change during the domestication process (Piperno, 2017). Nowadays, with the Green Revolution, agricultural or crop intensification has resulted in a dramatic increase in commercial non-renewable energy use (Pimentel, 2009; Rydberg and Haden, 2006). Sustainable agricultural ecosystems face great challenges in the world including those in China (Chen et al., 2014; Tilman et al., 2011; Zhang et al., 2016a). Increasingly scientists have focused on how to produce more grain and how to reduce inputs to lower environmental costs and improve agricultural sustainability (Chen et al., 2014; Jez et al., 2016). For example, the Science and Technology Backyard (STB) platform, which involves agricultural scientists living in villages among farmers, advances participatory innovation and technology transfer, and garners public and private support has been successful in documenting yield and economic gains of maize production in some Chinese provinces (Zhang et al., 2016a).

A holistic approach coupling human and natural systems is necessary to address complex interconnections and identify effective solutions to sustainability challenges (Fan et al., 2018; Liu et al., 2015). Therefore we ask, "what are the characteristics of energy metabolism in the maize ecosystem of China, and does energy metabolism vary across the ecosystem, and if so, why?". The Maize ecosystem is a complex system that combines natural ecology and social economy, and emergy theory or evaluation has been an important measure for assessing the energy metabolism and sustainability of agricultural systems (Ghaley and Porter, 2013; Houshyar et al., 2018; Odum, 1988; Wang et al., 2015, 2017). In this study, therefore, the emergy of metabolism in the maize ecosystem of China was examined as a case study to find consistencies, differences and characteristics of emergy input, to understand the maintenance mechanism, and to discuss its sustainability under different environmental conditions.

2. Materials and methods

2.1. Data collection and sources

In this study, twenty provinces of China were chosen as research regions having the main corn planting area, and the related land use data were based on the China Statistical Yearbook (CSY, 2015). The corresponding data sources were mainly from the National Agricultural Product Cost Income Data Compilation (NAPCIDC, 2015), China Climate Impact Assessment (CCIA, 2014), Xinjiang Statistical Yearbook (XSY, 2015) and the study by Tao et al. (2013).

Eighteen different input flows distributed into four categories: Renewable natural resources (R), nonrenewable natural resources (N), purchased renewable resources (PR) and purchased nonrenewable resources (PN) emergy (Table 1). Renewable natural energy includes sun, wind, rain and earth cycle, because they were co-products of coupled processes according to emergy theory. The energy input of rain, which constituted the highest emergy flow of the four, was considered to be the entire renewable resource emergy flow to avoid overestimating renewable inputs. Nonrenewable natural energy input was net loss of topsoil. Purchased renewable energy includes irrigating water, human labor, livestock labor, manure and seeds; non-renewable purchased energy includes nitrogen fertilizer, phosphate fertilizer, potash fertilizer, compound fertilizer, pesticides, diesel and capital investment.

2.2. Data statistics and analysis

Emergy synthesis is an accounting tool which takes into account both the environment and the economic inputs into a production system. The maize ecosystem boundary is defined to assess the inputs and outputs according to the emergy synthesis (Fig. 1). Emergy is described as the available energy of one kind previously required directly and indirectly to perform a service or product. It is a solar equivalent joule of available energy that has been used in the past to create a product or service (Odum, 1996). Solar emjoules can be used to quantify all products of the transformations of available energy delivered to the geobiosphere through the planetary baseline (Campbell, 2016). The units given in joules and grams were then multiplied by Unit Emergy Value (UEV) coefficients to convert to units of solar emjoules (seJ). The value of emergy can be obtained using the following equation: Emergy = available energy of an item (Table 2) × UEV (Campbell, 2001; Odum, 1988). Conversion of the different flows into emergy was done with reference to the geobiosphere emergy baseline of 12.1 E+24 seJ/year (Brown et al., 2016; Campbell, 2016); therefore, the UEV data from other studies which were relative to the 9.26E+24 and 15.83E+24 seJ/year baseline were converted to the 12.1 E+24 seJ/year by multiplying by a conversion factor of 1.3 and 0.758 (Table 1).

3. Results

3.1. Energy flows and emergy indicators of maize ecosystem

The energy systems language diagram of the maize production system is presented in Fig. 1 with the main fluxes and components,

Table 1
Unit Emergy Value (UEV) of different inputs for maize ecosystem.

No.	Item	Units	UEV (seJ/unit)	References
Renewable natural resources(R)				
1	Sunlight	J	1.00E+00	Odum (1996)
2	Wind, kinetic energy	J	3.14E+03	Odum (2000)
3	Rain	J	2.33E+04	Odum (1996)
4	Earth cycle	J	7.42E+04	Odum (2000)
Nonrenewable natural resources(N)				
5	Net loss of topsoil	J	9.47E+04	Brown and Bardi (2001)
Purchased nonrenewable resources (PN)				
6	Nitrogen fertilizer	g	4.86E+09	Odum (1996)
7	Phosphate fertilizer	g	4.99E+09	Odum (1996)
8	Potash fertilizer	g	1.41E+09	Odum (1996)
9	Compound fertilizer	g	3.58E+09	Odum (1996)
10	Pesticides	g	2.05E+09	Odum (1996)
11	Diesel	J	8.45E+04	Odum (1996)
12	Capital investment	$	1.92E+12	Brown and Bardi (2001)
Purchased renewable resources (PR)				
13	Irrigating water	J	5.25E+04	Odum and Arding (1991)
14	Human labor	J	4.86E+05	Lan et al. (1998)
15	Livestock labor	J	1.87E+05	Lan et al. (1998)
16	Manure	g	1.62E+08	Bastianoni et al. (2001)
17	Seeds	g	9.14E+08	Coppola et al. (2009)

Note: All these UEVs have been corrected according to the baseline 12.1 E+24 seJ/year (Brown et al., 2016; Campbell, 2016).

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