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An emergy evaluation of the sustainability of Chinese crop production system during 2000–2010

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ABSTRACT

Crop production systems are the basis of human survival and development because they can produce grain and industrial raw materials. As one of the largest agricultural countries in the world, the sustainability of China's crop production system is being concerned widely with its economic development and increasing population. This study adopted emergy analysis to explore the comprehensive performance of this system. A set of emergy based indicator system was used to investigate its economic benefit, environmental pressure and sustainability from 2000 to 2010. The study results show that the purchased nonrenewable input makes the largest contribution to the total input (average value 60.73% of the total input), which mainly derived from agricultural mechanic equipments and chemical fertilizer; on the average, beans has the largest share (20.20%) to the total emergy output, next from rape seed (18.36%), then from peanuts (15.85%), fruits (15.74%), wheat (8.26%), rice (8.07%), corn (7.66%) and cotton (4.60%) accordingly, and the other four categories crops just have a contribution of 1.28%; the production efficiency of China's crop production system has been raised by 11.54% with decrease of the indicator unit emergy value of product (UEVP) from 1.82E09 sej/g to 1.61E09 sej/g, the dependence of this system on economic market has increased by 24.92% with growth of the indicator EIR from 6.22 to 7.77, its economic benefit has been reduced by 0.59% with decline of the indicator EYR from 1.69 to 1.68, and its environmental loading has raised by 57.89% with growth of the indicator ELR from 1.33 to 2.10; the sustainability of China's crop production system is reduced by 37.01% with decrease of the index ESI from 1.27 to 0.80, during this study period. Based on these study results, the following measures should be emphasized in future, including raising the efficiency of purchased non-renewable resources (especially agricultural mechanical equipments and chemical fertilizer), using other methods of cultivation inherently more sustainable (e.g. replacing chemical fertilizer with organic fertilizer, recycling organic wastes, biological control of agricultural pests, use of local renewable energy, and more), strengthening supervision of the related industrial processes and further promoting agricultural environmental protection.

1. Introduction

As the core component of agriculture, a crop production system provide material basis for human survival and economic development. Therefore, it is extraordinarily necessary to study the comprehensive performances of this system for fully understanding of its production status and the factors which influence its sustainable development. A crop production system belongs to a human-controlled ecosystem, which relies on both the environmental inputs (such as sunlight, water, wind and the topsoil, etc.) and the purchased economic inputs (such as mechanical equipments, fertilizers, pesticides, fuels, electricity, etc.), and the latter ones will make more contribution to this system with the progress of agricultural modernization. The various input/output flows of

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crop production systems are usually measured in terms of different units, which make the comparison between them difficult. Among various evaluation methods, emergy analysis (EA), as an ecological evaluation approach presented by the famous ecologist Odum (1988, 1996), can solve this problem. Emergy, creatively combined energetics ecology and systems ecology, is a universal measure of real wealth of the work of nature and society based on a common basis, and can be described as the available energy of one kind previously required to be used up directly and indirectly to make the product or service (Odum, 1996). The unit of emergy is emJoule, a unit referring to the available energy of one kind consumed in transformations. Usually a unit of solar emergy expressed in solar emJoules (abbreviated semj) is used to determine the value of environmental and human work within a system on a common basis. The solar emergy of products and services can be calculated by multiplying the amount of energy by transformity, the amount of mass by specific emergy, and money by emergy per unit money. Therefore, natural contributions formerly missing from evaluations and economic contributions required to produce agricultural yields can be quantified and compared based on a common basis of solar emJoules. This approach has many advantages than other evaluation methods in assessment of human economic systems. It is a noneconomic method for determining relative value (Odum, 1996; Campbell, 2001; Brown, 2003) based on the quality-normalized available energy of all kinds required for the production of a product or service within any system. Compared to embodied energy metrics, EA, which considers the environmental work as input flows to support the ecosystem and human-dominated production system, is a more suitable hermeneutic mode for the cost or ecological footprint analysis, with a scale expansion from local to global, quality promotion from heat value to driving force, core value changing from receiver side to donor side, and world view evolution from anthropocentric to ecocentric. In so doing, ecological cost, which is difficult to be valued in economic market, is unveiled and accounted for, based on which the real sustainability of the whole system can be achieved (Ju and Chen, 2011).

Since emergy approach was introduced by Odum, several emergy-based studies on agriculture have been published, aimed at ascertaining the environmental support provided for free by nature to the agricultural process as well as to the upstream processes delivering needed goods and materials. In so doing, free energy of sun, chemical energy of rain, environmental services by the wind, nutrients in topsoil, ground-water, time embodied in resource generation, societal support to labor and services, were also accounted for, so as to point out the large role played by the biosphere work in support of the economic value of agricultural production. Odum (1984) explored the environmental role of agriculture, and the basic concepts of biosphere work in support of agriculture as well as optimization concepts versus maximization concepts were dealt with as basic sustainability aspects to be addressed. Since 1990s, this method has been widely adopted to assess agricultural systems with different scales and management patterns to investigate their resource use, productivity, environmental impact, and overall sustainability (Tilley and Martin, 2009), including national agricultural systems (Ulgiati et al., 1994; Lan et al., 1998; Haden, 2003; Chen et al., 2006; Rydberg and Haden, 2006; Burgess, 2011; Viglia et al., 2011; Zucaro et al., 2011; Gasparatos, 2011; Ghisellini et al., 2014), regional agricultural systems (An et al., 1998; Liu et al., 1999; Zhang et al., 1999; Rodrigues et al., 2003; Ferreyra, 2006; Wang et al., 2009, 2014; Lee and Huang, 2011; Agostinho et al., 2011.), specific cropping systems (Lagerberg and Brown, 1999; Panzieri et al., 2000; Bastianoni et al., 2001; Rigby and Caceres, 2001; Ortega et al., 2003; Lefroy and Rydberg, 2003; Guillén Trujillo, 2003; Lefroy and Rydberg, 2003; Cuadra and Rydberg, 2006; Martin et al., 2006; Cohen et al., 2006; Cavalett et al., 2006; De Barros et al., 2009; Cavalett and Ortega, 2009a,b; Francescatto et al., 2009; Barros et al., 2009; Lu et al., 2009, 2010; Wei et al., 2009; Goncalves Pereira and Ortega, 2009; Hu et al., 2010; Giannetti et al., 2011a,b; Zhang et al., 2012; Ghaley and Porter, 2013; Pelliciardi et al., 2014; Ferraro and Benzi, 2015.). In recent years, integrated systems consisted of one crop production and other production systems, have been also researched by some scholars, such as agro-ecological projects (Lu et al., 2006; Xi and Qin, 2009; Wu et al., 2013; Yang and Chen, 2014; Buller et al., 2014), biomass energy production systems connected to crop production systems (Bastianoni and Marchettini, 1996; Jiang et al., 2007; Dong et al., 2008; Coppola et al., 2009; Zhang and Long, 2010; Cavalett and Ortega, 2010; Ju and Chen, 2011), agro-pastoral systems (Dong and Gao, 2005; Dong et al., 2005, 2006; Zhang et al., 2007). Finally, some scholars have also carried out methodological studies about the use of emergy for the assessment of ecosystem services, implementation of systems approach in the agricultural analysis, and emergy-based decision support (Doherty and Rydberg, 2002; Rydberg and Jansen, 2002; Brandt-Williams and Pillet, 2003; Martin et al., 2006; Rydberg et al., 2007; Beerman, 2007; Pulselli et al., 2011). Meanwhile, EA, accompanied by other methods or tools, has been used to investigate a crop production system from different angles, such as an integrated emergy evaluation with GIS (Lin et al., 2013), embodied energy analysis (SAEE), ecological footprint (SAEF), renewable empower density (SAR), and emergy net primary productivity (SANPP) (Agostinho and Pereira, 2013), economic cost and return estimation (CAR), ecological footprint (EF) and EA (Cuadra and Björklund, 2007). In addition, some scholars have explored uncertainty in emergy evaluations using different methods in recent years (Hudson and Tilley, 2014; Li et al., 2011; Ingwersen, 2010, 2011).

All these studies make a good base for the standardization of the emergy method in the evaluation of agricultural systems, providing a set of benchmark values of flows and indicators to guide future studies in other parts of the world and emphasize the important role of environmental services and natural capital stocks in agricultural functions, which are most often disregarded in conventional energy and economic studies.

However, most of the above emergy studies do not offer sufficient time-series perspective and is just limited to comparison of systems and individual performance of specific farms, sectors or regions. Recently Ghisellini et al. (2014) explored the trends of the sustainability of Italian agricultural system based on an emergy decomposition analysis, and pointed out the main driving forces affecting the sustainability of the two agricultural systems in Italy. In China, Tao et al. (2013) adopted a multi-objective indicator system to assess the performance of crop production system in the 31 provinces of mainland China based on emergy method. However, this study only focuses on one year (2010), and cannot give the trends of China's crop production system in the past years. Chen et al. (2006) revealed the overall panorama of the Chinese agriculture during 1980–2000 using emergy evaluation, but this work needs to be updated so as to reflect the recent trends after 2000. Meanwhile, there are still lacking on the research of the whole Chinese crop production system in successive years using EA.

Nowadays, with the accelerating economic development, Chinese crop production system is faced with enormous challenges, including the decreasing and degrading of arable land, increasing food requirements derived from the ascending population, and non-point sources pollution from fertilizer and pesticides uses. Meanwhile, some indirect impacts derived from this system, have also been concerned, such as energy consumption and emissions embodied in the production of all agricultural supplies (Zhang et al., 2015). Under these conditions, it is urgent for decision-makers to understand the input–output status of this crop production system for improving policy-making in future. In order to understand the past driving forces and learn from past lessons for future policy