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RESEARCH ARTICLE

Emergy analysis of paddy farming in Hunan Province, China: A new perspective on sustainable development of agriculture

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Abstract

The multi-functionality of paddy farming has become a hot issue recently. Paddy farming provides numerous ecosystem services that are crucial to human well-being. However, evaluation of the contribution of paddy farming to human well-being usually focus on its economic value, while its non-market services are usually ignored. Only evaluating the market profits or market relative benefits cannot reflect comprehensively the contribution of paddy farming to people's well-being. This will affect people's choices for or against paddy farming activities and people's opt for invest or not invest in it. A comprehensive evaluation of paddy farming can provide an important reference for the government and society to conserve the multi-functionality of paddy farming and achieve sustainable development. To this end, this paper reports a case evaluation of paddy farming in Hunan, the largest rice producing as well as rice yield province in China, and uses emergy theory to make a comprehensive evaluation for paddy farming. The emergy evaluation results of the paddy ecosystem in Hunan are as follows: in 2010, the input emergy of the paddy ecosystem in Hunan is 2.51E+22 sej and the output emergy is 6.31E+22 sej. For the input emergy, the part from natural resources is 1.96E+21 sej and the part from human society is 2.32E+22 sej; for the output emergy, the part from products is 2.22E+22 sej, the part from impositive externality is 4.16E+22 sej and the part from negative externality is –7.41E+20 sej. Taking the non-market outputs into consideration, the gains from the human economic society's 1 $ input in paddy farming, emergy sustainability index (ESI) and emergy profit rate are respectively 2.73 $, 3.53 and 151.31%. If the evaluation leave out the non-market output, the three indexes are only 0.96 $, 1.24 and 30.67%. The research results show that non-market services of paddy farming contribute significantly to human well-being. Therefore, in order to protect the multi-functionality of paddy farming and achieve the sustainable management, the government should take reasonable measures and make incentive plans.

Keywords: paddy farming, emergy analysis, ecosystem services, Hunan Province

1. Introduction

In addition to providing food, paddy farming (otherwise known as paddy ecosystem) also provides several ecosystem services which cannot reflect its value through market transactions such as landscape preservation, flood control, gas regulation, water purification, as well as habitation

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provision (Yoshida 2001; Stapleton *et al.* 2004; Sakuyama 2005; Agus *et al.* 2006). People often evaluate the impacts of agricultural activities on human well-being through analyzing its economic cost and (or) economic benefits (He *et al.* 1987; Lin 2007; Lin and Fan 2009; Yang *et al.* 2011).

However, the traditional analysis method does not bring non-market input or output into the production function or the utility function, which inevitably has affected people's overall objective evaluation on agricultural activities. Over the past few years, the rice areas in southern China have reduced continuously, consequently, the sustainable management of paddy farming and national food security are under threat. This phenomenon is closely related to the facts that the input-output analysis of paddy farming which have failed in getting a comprehensive and objective evaluation.

Emergy analysis method developed by Odum (1987) is an analytic approach for ecosystem. This method can not only assess all kinds of materials and energies of ecosystem on the same standards to carry out quantitative analysis but also provide the basis for quantitative study of input and output for national or regional ecosystem (Campbell *et al.* 2005; Pulselli *et al.* 2006; Campbell and Lu 2009; Rugani *et al.* 2011; Su *et al.* 2011; Zhu *et al.* 2012; Hossaini and Hewage 2013; Giannetti *et al.* 2013; Coscieme *et al.* 2014), various subsystems and specific production systems (Brown and McClanahan 1996; Odum 1996; Kang and Park 2002; Gasparatos 2011), assessment of natural resources utilization (Chen *et al.* 2006; Zhu *et al.* 2009; Lv and Ling 2010; Lu *et al.* 2012), economic policymaking (Odum 1996), coordination of international trade relationships (Yu and Wang 2010; Lu and Zhao 2013) and so on (Lan *et al*. 2002).

Even since then, emergy analysis has attracted great interest in the academic field. Emergy analysis on the value of ecosystem services are mainly concentrated in forest ecosystem (Li *et al.* 2005; Campbell and Brown 2012), wetland ecosystem (Cui and Zhao 2004; Li *et al.* 2013; Ding *et al.* 2015), grassland ecosystem (Min *et al.* 2004), as well as emergy analysis for one particular ecosystem service (Liu *et al.* 2015). However, the previous emergy analyses on agro-ecosystem have ignored calculation for non-market outputs. Emergy analyses on agro-ecosystems are mainly concentrated in sustainability issues (Wang *et al.* 2014), including structure and efficiency of agro-ecosystems (Liu *et al.* 2004; Cavalett *et al.* 2006; Wang *et al.* 2015), high yield and efficiency cultivation mode (Xi and Qin 2006; Yang *et al.* 2009) and resource utilization (Hu *et al.* 2010; Chen *et al.* 2014). For emergy analysis on paddy farming, Xi and Qin (2006) have carried out a comparative study on integrated rice-duck organic farming and conventional paddy farming through emergy analysis, and the results show that integrated rice-duck organic farming achieves more ecological and economic benefits. Juan *et al.* (2008) have evaluated the multi-functionality of the paddy field in Taiwan in 2004, and the results show that the market benefits of the paddy field in Taiwan are significantly less than its actual value. Yang *et al.* (2009) have carried out a comparative study for the emergy flows and emergy indices of agricultural resources inputs of glutinous rice-fish agriculture and glutinous rice monocropping, hybrid rice-fish agriculture and hybrid rice monocropping, and the results show that rice-fish ecosystem has more ecological and economic advantages.

Nevertheless, as the existing research is confined to measuring the emergy of the input of natural resources and human society and economic output for paddy farming ecosystem without evaluating its non-market output, the research results fail to reflect the true value of paddy farming.

Hunan is the largest rice-producing province in China in terms of the rice sown area and production. Since the 1980s, with China's rapid economic growth, there have been many problems in Hunan's paddy ecosystem, such as a decline in the comparative benefit of rice production, paddy fields used for other purposes or lied fallow, non-point source pollution of paddy fields deteriorates rapidly, multi-functionality of paddy fields failed to perform its true value. This paper takes Hunan as a case, uses emergy analysis to provide a holistic evaluation of the inputs-outputs of paddy farming. It also provides some implications for policy makers in order to maintain the multi-functionality of paddy farming and encourage its sustainable development.

2. Materials and methods

2.1. Research area

Located in the regions to the south of the middle reaches of the Yangtze River with longitude and latitude ranges of 108°47′–114°15′E and 24°38′–30°08′N, Hunan Province covers an area of 21.18E+6 ha including a cultivated land area of 3.79E+6 ha. With a continental subtropical monsoon humid climate, this region is rich in light, heat and water resources. The annual sunshine duration is 1 300–1 800 h, the amount of solar radiation 86–109 kcal cm^{-2}, the annual average temperature 16–18°C, and the average annual rainfall 1 200–1 700 mm. Owing to the climatic resources suitable for paddy farming and the long history of cultivation, Hunan has become China's leading rice-producing province, with its rice yield accounting for 13% of the total yield nationwide. Since the reform and opening up, the paddy farming area in Hunan decreased from 4.41E+6 ha in 1980 to 4.03E+6 ha in 2010.

2.2. Research methods

Data collection Through literature collection, investigation and calculation, data about natural environment, economic