Journal of Environmental Management 91 (2010) 2727–2735

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

# Integrated emergy, energy and economic evaluation of rice and vegetable production systems in alluvial paddy fields: Implications for agricultural policy in China

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A R T I C L E I N F O

*Article history:*
Received 11 November 2009
Received in revised form
23 June 2010
Accepted 19 July 2010
Available online 10 August 2010

*Keywords:*
Rice production
Vegetable production
Ecological-economic efficiency
Sustainability
Emergy analysis

A B S T R A C T

China is the largest rice producing and consuming country in the world, but rice production has given way to the production of vegetables during the past twenty years. The government has been trying to stop this land-use conversion and increase the area in rice-vegetable rotation. Important questions that must be answered to determine what strategy is best for society are, "What is the reason behind this conversion?"; "Which system is more productive and which is more sustainable?"; and "How can economic policy be used to adjust the pattern of farmland use to attain sustainable development?" To answer these questions, a combined evaluation of these agricultural production systems was done using emergy, energy and economic methods. An economic analysis clearly showed that the reason for this conversion was simply that the economic output/input ratio and the benefit density of the vegetable production system were greater than that of rice. However, both energy and emergy evaluations showed that long-term rice was the best choice for sustainable development, followed by rotation systems. The current price of rice is lower than the em-value of rice produced from the long-term rice system, but higher than that of rice produced from the rotation system. Scenario analysis showed that if the government increases the price of rice to the em-value of rice produced from the long-term rice system, US$0.4/kg, and takes the value of soil organic matter into account, the economic output/input ratios of both the rice and rotation systems will be higher than that of the vegetable system. The three methods, energy, emergy and economics, are different but complementary, each revealing a different aspect of the same system. Their combined use shows not only the reasons behind a system's current state or condition, but also the way to adjust these systems to move toward more sustainable states.


## 1. Introduction

Rice culture is one of the most successful ancient systems for supporting dense populations (one person per acre) in monsoon climates (Odum, 2007). China produces and consumes more rice than any other country in the world. From 1980 to 2002, rice was the largest crop (46%) produced by the Chinese agriculture system as measured by its exergy (Chen and Chen, 2007). Since 1990 the area of rice production in China has decreased slowly, primarily due to a decrease in rice cultivation in South China. This has occurred despite an increase in rice cultivation in northeast China. During the rapid urbanization of South China from 1990 to 2006, Guangdong Province lost 11.8% of its rice production area, while the area in vegetable production increased 42.8%. A cursory investigation showed that the simple reason for this rapid conversion was the higher economic benefits derived from vegetable growth compared to those gained from rice. The benefits obtained from growing vegetables were higher, because the vegetables were sold on the free market; whereas the price of rice was kept low by the government through monopoly procurement. To meet the government mandated grain quotas, some peasants even prefer to sell the government the rice they purchased from the market, so that their land can be used to produce more profitable vegetables and other cash crops (Chen and Chen, 2007). On one hand, studies have shown that the long-term rotation of vegetables and rice can improve the soil's physical and chemical properties, and reduce the rate of use of energy and nutrients. These rotations also decrease the incidence of crop diseases and pests, and consequently, improve the productivity and economic benefit ratio of farmland (Huang et al., 2006). Thus,

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doi:10.1016/j.jenvman.2010.07.025

rotation systems of vegetables and rice have been advocated by some and are used to some degree. On the other hand, the government set up economic regulations intended to keep a balance among the three production systems to preserve security of the staple food supply and promote regional sustainable development. One method that the government used to accomplish this was an increase in the price of rice and a decrease in the land rent for rice compared with vegetable production. However, the adjustment was not enough, and an objective quantitative ecological-economic evaluation is still needed for guiding further adjustments.

Energy Systems Theory (EST) and emergy evaluation methods first introduced by H.T. Odum and his colleagues during the 1980s, offered a common denominator, emergy, for quantifing both economic and environmental contributions to a system in equivalent units, solar emjoules. Thus, EST has been proposed as a bridge between ecology and the economy by some scientists (Lan et al., 2002). In the past 30 years the theory and methods have been developed and Emergy Synthesis has become a mature ecological-economic evaluation tool, and it has been widely used in the evaluation of agricultural systems on many scales from that of a single farm to the agricultural system supporting a nation (Ulgiati et al., 1993; Odum, 1996, 2004; Lan et al., 1998; Bastianoni et al., 2001; Cavalett et al., 2006; Chen et al., 2006; Lu et al., 2006; Castellini et al., 2006; Pizzigallo et al., 2008; Vassallo et al., 2009; Xi and Qin, 2009; Campbell, 2001). However, arguments about the relationships that exist among emergy synthesis, energy analysis, and economic evaluation are still unsettled (Huang and Odum, 1991; Brown and Herendeen, 1996; Castellini et al., 2006; Maud, 2007; Bastianoni et al., 2007; Franzese et al., 2009), with the latter two methods being applied much more often than the first one (Akbolat et al., 2006; Gündogmus and Bayramoglu, 2006; Shahan et al., 2008; Shalin et al., 2008; Pimentel, 2009). Past studies have shown that the better the environmental performance of the cropping system, the worse its economic performance (de Barros et al., 2009). We asked, "Is this also true for the three systems mentioned above, i.e. rice, vegetables, and the rice-vegetables rotation system?" Emergy theory and methods were used in this paper to evaluate and compare rice, vegetables, and rice-vegetable rotation production systems. Abbreviated economic and energy analyses were included to paint a more complete picture by including more perspectives on this issue.

## 2. Location and methods

### 2.1. Location and sites

The Pearl River Delta is located in South East China in Guangdong province and it is one of the main rice paddy areas in China, because it has a good water supply, fertile soils and subtropical monsoon weather ideal for rice culture. Paddy soil, which is formed through the long-term growth of rice on a plot of land, is widely distributed all over this province. According to the stage of development, and physical and chemical characteristics of the soil, paddy soil in Guangdong province could be classified into seven kinds, among which alluvial paddy soil covers the largest area (Wan et al., 2005).

All of the study sites were chosen on alluvial paddy soil in Huiyang district, which is one of the centers of rice culture in Guangdong Province. This was done so that the environment of natural and study sites would be comparable. Twenty four study sites were chosen for this study to represent the mean management situation of three production modes in Huiyang district, with the help of the Agricultural Bureau of Huiyang (Table 1). Six replicates were chosen for the evaluation of the long-term rice and vegetable production systems with three sites on sandy clay loam soil and the other three sites on clay loam soil. Twelve study sites were chosen to represent the rice-vegetable rotation system in this one year study, with 6 sites for rice and the other 6 sites for vegetables, because one year's vegetable production was followed by another year's rice production in the rice-vegetable rotation mode.

### 2.2. Sampling and measurement

#### 2.2.1. River water

*2.2.1.1. Soil.* Top soil samples (0–15 cm) were collected from the twenty four sites right before the harvest of rice in November 2005. At each site, soil samples were taken at the center and the four corners of the sample plot using an auger, and put together to make a composite sample. Visible roots and stone fragments were removed, and then the sample was air dried and passed through a 1 mm sieve before analysis. The soil organic carbon content was measured using $K_2Cr_2O_7$–$H_2SO_4$ oxidation at 180–185 °C in an oil bath according to the methodology reported by Zhu (2000).

*2.2.1.2. Biomass.* A 1 $m^2$ quadrate was picked randomly and harvested from each site for the measurement of above and below ground biomass. The biomass samples were taken at harvest time from July 20–21(for early rice planted in March), October 29–30 (for late rice planted in August) and November 28–29 (for vegetables). After oven drying the samples for 30 min at 105 °C, they were dried at 80°C to a constant weight. Weight was measured within ±0.02 g using an ALC-1100.2 electronic balance.

### 2.3. Emergy analysis methods

Following the standard emergy analysis methods, the spatial and temporal system boundaries were setup first, and designated as the various sample plot areas examined over one year. Then, emergy analysis tables were set up for each of the three systems under study, following an Energy Systems Language diagram of the growth systems. Five extra columns, which were based on the energy and economic evaluations of the three systems under study, were added to the emergy analysis tables, to show the energy and economic calculations and the variation of the raw data.

Besides inputs of renewable (R) and non-renewable (N) environmental resources, the input of purchased resources was classified into renewable ($F_R$) and non-renewable sections ($F_N$), with the latter being further classified into chemical fertilizer, medicine, machines and tools, fossil fuels, and labor. There is no publication on the renewable fraction of labor in China, and our primary investigation showed that the renewability of labor in this study was almost entirely dependent on people's use of purchased goods and services. Thus, we assumed that 90% of the emergy of labor was supported by non-renewable sources, i.e., included in $F_N$, while the other 10% was considered to be renewable and included in $F_R$ (Ulgiati et al., 1994). Based on the above classification, the analysis of the input composition was performed to discover the differences among the three systems, accompanied by the calculation of a few indices. The transformities and specific emergies of the main products (vegetables, rice and soil organic matter) were calculated and compared with similar products from other systems.

### 2.4. Energy and economic analysis methods

To fill the needs of energy and economic analysis, the economic investigation was combined with the monthly investigation in 2005 for the price of inputs and outputs. Further more, the biomass samples were also used for the measurement of energy content. After being passed through a 0.3 mm sieve, 1 g samples of the biomass of the different crop organs (roots, stems, etc.) were