Ecological Engineering 60 (2013) 354–362

Contents lists available at ScienceDirect

Ecological Engineering

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

Integrated emergy and economic evaluation of tea production chains in Anxi, China

Xianshu Zeng[a,b], Hongfang Lu[a,*], Daniel E. Campbell[c], Hai Ren[a,**]

[a] Key Laboratory of Vegetation Restoration and Management of Degraded Ecosystems, South China Botanical Garden, Chinese Academy of Sciences, Guangzhou 510650, China
[b] University of the Chinese Academy of Sciences, Beijing 100049, China
[c] US EPA, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Atlantic Ecology Division, 27 Tarzwell Drive, Narragansett, RI, USA

A R T I C L E I N F O

Article history:
Received 7 April 2013
Received in revised form 4 August 2013
Accepted 7 September 2013
Available online 10 October 2013

Keywords:
Tea production
Emergy synthesis
Economic analysis
Sustainable development
Statistical analysis

A B S T R A C T

Emergy and economic methods were used to evaluate and compare tea production systems in Anxi, China. Tea production was classified into three phases, *i.e.*, the nursery, the plantation and tea processing, and each phase was evaluated. The results showed that the nursery subsystems were profitable with an economic output/input ratio of 2.86. However, the inclusion of a nursery had no significant influence on the sustainability of the tea plantation system, because it was a small part of the total input to the system. Applying organic fertilizer to replace 66% of the chemical fertilizer decreased the pressure of chemical loading on the environment, and as a result the cultivation phase's emergy sustainability index (ESI) increased 2.10 times. However, due to the relatively high price of organic fertilizer and the labor to spread it, the economic output/input ratio (1.61) of the mixed organic and chemical fertilizer mode was less than that of the chemical fertilizer mode (1.80). If all the tea leaves used in the processing phase were produced on the farm, instead of purchased from outside, about 30% of the economic cost of processing could be saved, and as a result the economic output/input ratio would increase by 41%; the ESI would increase 5.48 times and the emergy index for sustainable development (EISD) would increase 11.05 times. The overuse of chemical fertilizer and low productivity of labor are key problems that need to be solved for further optimization of the Anxi tea plantation systems.

1. Introduction

China is the birthplace of tea cultivation, according to the historical literature, which reveals more than a 4000-year history of tea production in China (Li, 2011). Today China's tea production systems are still in a leading position in the world and a mature and unique production system has developed within the country. According to Chinese government statistics in 2010 the domestic area of tea gardens was 1.95 million ha, and tea production was 1.4 million t, ranking the area in China under tea cultivation and in tea production first and second in the world, respectively. In addition, more than 100 million people were involved in tea production in China in 2010 (Li and Yang, 2011).

Fujian province is the largest producer of tea in China. In 2010, there were 200,000 ha of tea planted in Fujian, which produced 269,000 t of tea (Yu et al., 2012). Many other measures also show Fujian's leading position in tea production, such as its market share of the tea produced, the number of eminent tea tree breeds cultivated, how popular they are, brand awareness, *etc*. Because of its distinctive characteristics, which include "color", "shape", "scent", and "rhyme" or taste, Anxi Tieguanyin oolong tea has become the most prominent among the varieties of tea produced in Fujian province, and it has established a dominant position in the Chinese tea market. Because of the strong market for Anxi tea, raising it has been highly profitable, and in the past local people even cut down the forest to plant tea. In 2010, the total area of tea gardens in Anxi County was 20,000 ha, with an annual production of 70,000 t, and an economic value of 8.1 billion yuan (Yu et al., 2012). The economic importance of tea has generated many published papers from experts in a variety of research fields. Past research has been focused on the following subjects: establishing the brand, marketing methods, tea culture, tea quality, soil fertility, soil and water conservation, tea cultivation, *etc.* (Liao, 2004; Hong, 2005; Yu, 2008; Gao, 2009; Hu, 2010; Yang et al., 2010a). To some extent, these

* Corresponding author at: 723 Xing-ke Road, Tian-he District, Guangzhou, 510650, China. Tel.: +86 20 37084273.
** Co-corresponding author at: 723 Xing-ke Road, Tian-he District, Guangzhou, 510650, China. Tel.: +86 20 37252916; fax: +86 20 37252916.
E-mail addresses: luhf@scbg.ac.cn (H. Lu), renhai@scbg.ac.cn (H. Ren).

0925-8574/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ecoleng.2013.09.004

research results have broadened our understanding of Anxi tea. However, due to the limitations of these disciplines and the analysis methods used for quantitative study, little research has been done to explore the comprehensive ecological economic characteristics of tea production. Without such research, it is hard to meet the current demand to develop sustainable production alternatives that can transform the tea industry; therefore such research is urgently needed.

The American ecologist, H.T. Odum (1924–2002), first put forward Energy Systems Theory (Odum, 1971, 1983), and later developed the methods of emergy evaluation, which provides a self-consistent, energy-based method to evaluate different energy, material, monetary flows in terms of a single energy type, *e.g.*, solar joules. Emergy refers to the amount of available energy of one type previously used up directly and indirectly to make a product or service (Odum, 1996). Emergy is usually expressed as solar emjoules (sej). The unit emergy values (UEV), *i.e.*, transformity (sej/J), specific emergy (sej/g), and emergy/money ratio (sej/money unit), are used to convert energy, material, and monetary flows of all kinds to solar emjoules allowing direct comparison based on their equivalent ability to do work in the system, as well as addition and subtraction among them. Thus, a gap in ecological-economic valuation caused by the difficulty in assigning value to the environmental contributions to the economy was filled (Odum, 1988, 1996, 2007; Lan et al., 2002). After nearly 30 years development and application, Energy Systems Theory and the emergy methods derived from it has become a mature ecological economic evaluation tool, which can accompany current economic analysis methods. Also, it has been widely applied 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; Bastianoni et al., 2001; Odum, 2004; Cavalett et al., 2006; Agostinho et al., 2008; Cavalett and Ortega, 2009; Lu et al., 2002, 2006, 2009, 2011; Lu and Campbell, 2009; Li et al., 2011a; Zhang et al., 2011). However, most past studies have laid the stress on single system performance, and system evaluations (samples) have seldom been repeated to allow statistical analysis. As a result, it is hard to obtain a deeper insight into the variability of that type of system and the reliability of the data and results (Li et al., 2011b). The goal of this study is to provide scientific evidence for the development of more sustainable modes of tea production, and furthermore to investigate strategies for the sustainable development of the tea production system in Anxi, China. To achieve this goal, we employed an integrated evaluation method that combines emergy evaluation with statistics and economic analysis.

2. Location and study site

Located in south-central Fujian province (117°34′–118°18′ E, 24°51′–25°26′ N), South East China, Anxi county is controlled by subtropical monsoon weather with an annual average sunshine of 2069 h (5.02E+09 J/m^2), an annual average temperature of 16–18 °C, an annual average rainfall of 1.8 m; and an annual frost free period of 349 days. These ideal climate conditions create the unique quality of Anxi Tieguanyin tea.

The regional tea production system is mainly composed by individual tea gardens. Most of the tea garden area was found in holdings of 0.33–0.67 ha, but some holdings can be more than 2 ha. Following the program of tea production, the Anxi tea production processes can be classified into three stages, *i.e.*, the seedling, plantation and processing stages. Processing turns green tea leaves into dry tea leaves. Farmers must cultivate or purchase seedlings to replace old/unhealthy tea trees which account for about 10% of the total tea trees every year. A specific government-approved, technological standard for tea garden management is lacking; therefore, the application of chemical fertilizers and pesticides was based on the experiences of farmers, and generally more was applied than was actually needed (Zhang, 2012). In recent years, the local governments have attached importance to the construction of ecological tea gardens, *i.e.*, they strongly advocate a mode of production with (1) some high deciduous trees planted in and around tea gardens to block part of the strong sunlight from reaching the tea trees in summer; (2) some leguminous grass or cover crops planted under/between the tea trees for erosion control and soil improvement and (3) restricting the use of high risk pesticides. Some farmers realized sustainable practices should be a priority, and they began using more organic fertilizers and applied less chemical pesticide on their plantations. All other required input items into the tea cultivation systems were similar, except for the seedlings and fertilizers. In the past, most farmers used to process only the tea leaves yielded by their own farm, but today more and more farmers choose to sell their tea leaves to other farmers who are more skillful tea processers, as well as, to some professional tea processing mills/factories with different production scales.

3. Methods

To explore optimization strategies on the farm scale, the tea production process was classified into 3 stages and 9 production modes: (1) the nursery or seedlings stage; (2) the plantation stage, which was classified into 4 modes considering the source of seedlings and the type of fertilizer used, *i.e.*, (a) cultivated seedlings-mixed organic and chemical fertilizer (CS-OCF); (b) purchased seedlings-mixed organic and chemical fertilizer (PS-OCF); (c) cultivated seedlings-chemical fertilizer (CS-CF), and (d) purchased seedlings-chemical fertilizer (PS-CF); (3) the tea processing stage, which was also classified into 4 modes considering the production scale and the source of tea leaves, *i.e.*, (a) small scale-purchased tea leaves (S-P); (b) small scale-farm raised tea leaves (S-R); (c) large scale-purchased tea leaves (L-P); and (d) large scale-farm raised tea leaves (L-R). Both emergy evaluation and economic analysis methods were applied to perform a quantitative evaluation and comparison of the ecological-economic advantages and disadvantages of the different production modes in each stage.

3.1. Sampling methodology

To collect the input and output data for tea production in both monetary and biophysical units, we randomly interviewed 30 local tea farmers from July to August 2009. Among the 30 farmers interviewed, 22 were able to provide complete information and 15 of them were selected to participate in the analysis, *i.e.*, they provided 3, 6 and 6 samples for the tea seedling, plantation and processing subsystems, respectively. The meteorological hydrologic data needed, such as incident solar radiation, precipitation and soil erosion, were found in publications (Wu and Lin, 2006; Yang et al., 2010a).

3.2. Data processing

Data collection and analysis were organized according to stages, *i.e.*, the seedling, plantation, and processing stages. Three repeated samples were taken for the nursery stage from farms that used their own seedlings and the market price data were obtained from farmers during the investigation. Then, the average emergy and market price value of tea seedlings was combined with the 3 CF and 3 OCF samples to make 3 repetitions for each of the 4 plantation modes, *i.e.*, CS-CF, CS-OCF, PS-CF, and PS-OCF, to allow statistical evaluation and comparison among the treatments. Six samples for the