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Bamboo vs. crops: An integrated emergy and economic evaluation of using bamboo to replace crops in south Sichuan Province, China

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Abstract

Based on long-term monitoring conducted in Chang-ning county, a pilot site of the 'Grain for Green Program' (GFGP), an integrated emergy and economic method was applied to evaluate the dynamic ecological-economic performance of 3 kinds of bamboo systems planted on sloping farmland. The results confirmed the positive effects of all 3 kinds of bamboo systems on water conservation and soil erosion control. The benefits gained progressively increased during the first 8 years after conversion, going from 4639 to 16127 EMyuan/ha/yr on average. All three bamboo plantations were much more sustainable than common agricultural crops planted on sloping land (CP) on both the short and long-term scales with their Emergy Sustainability Index (ESI) and Emergy Index for Sustainable Development (EISD), respectively, being 14.07–325.71 and 80.35–265.80 times that of CP. However, all 3 bamboo plantations had a Net Economic Benefit (NEB) less than that of CP during the first 8 years after conversion. Even with the government-mandated ecological compensation applied, the annual NEB_{EC}s of the *Bambusa rigida* (BR) and *Phyllostachys pubescense* (PP) plantations were, respectively, 3922.03 and 7422.77 yuan/ha/yr lower than the NEB of CP. Emergy-based evaluation of ecosystem services provides an objective reference for applying ecological compensation in strategy-making, but it cannot wholly solve the economic viability problem faced by all bamboo plantations. Inter-planting annual herbs or edible fungus, such as *Dictyophora echinovolvata*, within bamboo forests, especially in young bamboo plantations, might be a direction for optimizing bamboo cultivation that would improve its economic viability.

1. Introduction

The second Chinese national survey of soil erosion based on remote sensing analysis showed that in the last decade of the 20th century the eroded area was 3.56 million km^2, which occupied about 37.1% of the total land area of China (Liu, 2002). To address this problem, in 1999, China launched the ecological engineering 'Grain for Green Program' (GFGP, also called the sloping land conversion program) and it has become one of the largest ecological restoration programs in the world. The goal of the program is to reduce soil erosion and increase vegetation coverage by replacing sloping farmland with easily planted forests (Li et al., 2016a,b). By the end of 2013, under this program the forest area in China had been increased by approximately 27.67 million ha, at a cost of approximately 35.88 billion US$ (Guo et al., 2014; Wang et al., 2017a,b). The area of bamboo forest in China increased 43% during this period going from 4.21 million ha in 1998 to 6.01 million ha in 2013 (Yuen et al., 2017). The reason behind this quickly extending is the superior adaptability, fast growth, and economic viability of bamboo (Jiang, 2007; Chen et al., 2008; Song et al., 2011).

Considering the large spatial scale and the tremendous number of participants and considerable economic investment made in GFGP, many evaluations of its ecological or economic performance at different scales have been performed over the past ten years.

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However, a suite of different and sometimes conflicting results have been obtained (Weyerhaeuser et al., 2005; Deng et al., 2012; Xu et al., 2007; Wang and Maclaren, 2012; Li et al., 2016a,b). One of the main reasons behind these differences is that the same government-mandated ecological compensation standard (3450 yuan/ha/yr from 2003 to 2010) was applied to a large area with significantly different spatial distributions of environmental resources (Kong, 2007; Wu, 2007), without considering the effects of deflation/inflation on compensation. In addition, in practice, agricultural productivities and the ecological-economic properties of the specific GFGP modes are variable making a single value for ecological compensation impractical (Liang et al., 2006; Wang et al., 2007). Although bamboo forests are rapidly growing alternatives for use in the GFGP, the ecological-economic characteristics of using bamboo to replace crops on sloping land has been rarely studied (Song et al., 2011; Yuen et al., 2017).

Besides, most of the past research has been snapshot comparisons focused on particular processes such as soil erosion control, water provision, soil fertility maintenance, carbon sequestration, afforestation techniques, economic performance, *etc.* (Jia et al., 2004; Liang et al., 2006; Wang et al., 2007; Qi et al., 2013; Cheng et al., 2015). While GFGP is a continuing, long-term project, integrated and comparable evaluations of both short-term economic and long-term ecological performances of these restoration modes is lacking, but urgently needed for mode selection, optimization, and adaptive management (Jia et al., 2014; Wang et al., 2017a,b).

Based on long-term monitoring conducted in Chang-ning County, a pilot site of the GFGP, we applied an integrated emergy and economic evaluation to explore the ecological-economic dynamics of three kinds of bamboo forest plantation systems compared to a common crop system found in the region. A suite of questions was of particular interest, *i.e.,* whether these bamboo systems can reduce soil erosion from sloping agricultural systems? If yes, does this environmental benefit lead to better ecological economic performance of the bamboo plantation systems compared with a common crop system planted on sloping land? What is the difference among the three bamboo systems and the common crop system, and are there any sensitive points that are worth paying attention to for further optimization of these systems? Is the ecological compensation scheme implemented well-matched with the actual ecological economic properties of these modes? If not, what kinds of adjustments should be made?

2. Study sites and methods

2.1. Location and study sites

The experimental area was located in Chang-ning County (104°44′-105°03′E, 28°25′-28°48′N) (see Fig. 1), Sichuan Province, and it is controlled by mid-subtropical monsoon weather, with annual average sunshine of 1212 h, an annual average temperature of 18.3 °C, with the maximum temperature going up to 40.7 °C and the minimum temperature down to −4.2 °C. This area has an annual average rainfall of 1104 mm and rainfall is concentrated in the rainy season from April to September. The annual frost free period is 358 days. As a pilot site of the GFGP to replace crops on sloping ground with bamboo forests, the area of bamboo forest plantations increased from 21,402 ha in 2000 to 48,713 ha in 2016, which accounts for 82.6% of the total forest area in Chang-ning County. In 2016, over 84% of the bamboo plantations were dominated by 3 species, *i.e. Bambusa rigida* (40.39%), *Phyllostachys pubescens* (33.00%), and *Pleioblastus amarus* (10.81%).

The bamboo forest plantations examined are representative of all three major types of bamboo forests, *i.e.*, monopodial (runner rhizomes), sympodial (clumping rhizomes), and mixpodial (characteristics of both clumping and runner rhizomes) bamboo forests. Also, an important factor in the evaluation is that the economic utilities of the three dominant species planted are different, i.e., the culm of *Bambusa rigida* (BR) is widely used as the raw material for paper-making; *Pleioblastus amarus* (PA) is mainly planted for its edible bamboo shoot, while both the bamboo shoots and culms of *Phyllostachys pubescense* (PP) are generally used as a vegetable, decorative material, farm tools *etc.*

Both 3 and 8 year-old plantations were investigated to explore the dynamic ecological-economic performance of the three types of bamboo forest plantations, considering that the economic investment cycles are 3 years for *Bambusa rigida and Pleioblastus amarus,* and 8 years for *Phyllostachys pubscense.* Perhaps not coincidentally, 8 years is also the period of ecological compensation for the GFGP, after which the ecological economic characteristics of these forests

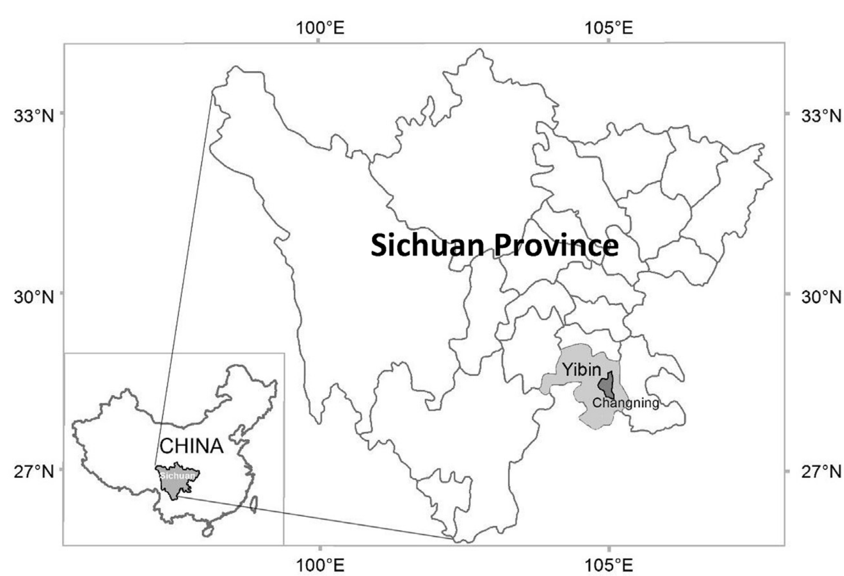

Fig. 1. The geographical context and location of Chang-ning County.