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Analysis

Assessment of net ecosystem services of plastic greenhouse vegetable cultivation in China

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ABSTRACT

Plastic greenhouse vegetable cultivation is rapidly expanding in China and elsewhere worldwide. In order to comprehensively understand the impacts of plastic greenhouse vegetable cultivation on agricultural ecosystem services and dis-services, we developed an assessment framework for the net ecosystem services and used China as a case study. Our results showed that, compared to conventional vegetable cultivation, plastic greenhouse vegetable cultivation has higher fresh vegetable production, greater CO_2 fixation (3.61 t CO_2 ha^{-1} yr^{-1}), better soil retention (23.1 t ha^{-1} yr^{-1}), and requires less irrigation (2132 m^3 water ha^{-1} yr^{-1}), maintains similar soil fertility, but also has higher NO_3^- accumulation and N_2O emissions. In 2004, plastic greenhouse vegetable cultivation in China provided an overall net economic benefit of 67,956 yuan ha^{-1} yr^{-1} (8.28 yuan = 1 USD in 2004), where 68,240 yuan ha^{-1} yr^{-1} represented ecosystem services and 284 yuan ha^{-1} yr^{-1} for dis-services. The transition from conventional vegetable cultivation to plastic greenhouse vegetable cultivation resulted in a net economic benefit of 24,248 yuan ha^{-1} yr^{-1}. A cost-benefit analysis suggests that plastic greenhouse vegetable cultivation in China has the potential to optimize social benefits in addition to increasing annual economic income to farmers directly.

1. Introduction

Although modern agriculture plays an important role in providing goods and services for human welfare (Tilman et al., 2002), it also causes the degradation of some ecosystem services (ES) (MA, 2005). Nonetheless, there is general agreement that many agricultural ecosystems have the potential to support enhanced ES (West and Marland, 2002), such as no tillage and covered agriculture (Sandhu et al., 2008). These alternative cultivation practices mainly focus on maintaining agricultural productivity without further damaging ES and potentially even enhancing ES (West and Marland, 2002).

Greenhouses are an important type of covered agriculture globally and achieve higher crop production by modifying the natural environment, especially prolonging the growing season relative to open field crops (Jensen and Malter, 1995). Greenhouse cultivation benefits people by providing off-season or high quality vegetables to improve health while generating employment opportunities and high incomes relative to conventional vegetable cultivation (CVC) (Jensen and Malter, 1995; Weinberger and Lumpkin, 2007; Ali, 2008). In addition to food provision, greenhouses also protect crops from harmful atmospheric deposition (e.g. acid rain and hazard materials it contains), provide a stable inner environment for crops (Jensen and Malter, 1995), retain more soil and fertility than open agriculture, and use less water than open cultivation (Stanghellini et al., 2003). However, relative to open cultivation, greenhouses can also have environmental consequences, such as soil and groundwater pollution (Song et al., 2009), plastic wates (Stanghellini et al., 2003) and N_2O emission (He et al., 2009).

More than 90% of the greenhouses in China are used for vegetable production (Costa and Heuvelink, 2004) and most of these greenhouses are covered by plastic films. Glass greenhouses, which are common in the industrialized countries, account for <1% of the total greenhouse area of China (Zou, 2002; Costa and Heuvelink, 2004). Plastic greenhouse vegetable cultivation (PGVC), altered from CVC by covering open vegetation field with plastic film, was introduced to China in late 1970s and has since expanded dramatically. The total area covered by PGVC in China increased to 2.5 million ha by 2004

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(85% of the worldwide coverage) (Yang et al., 2007; Ali, 2008; Zhang et al., 2008).

Continued rapid expansion of PGVC in China would amplify the magnitude of both ES (e.g. food provision, water saving, carbon fixation and soil protection) and ecosystem dis-services (EDS) (e.g. N_2O emission and salinization). Some individual research has been conducted in China to investigate vegetable quality improvement, soil carbon and nitrogen pool changes, and nitrogen balance modification resulting from PGVC expansion (e.g., Li et al., 2008; Qiu et al., 2010; Ju et al., 2006). However, studies to date have not comprehensively quantified the benefits and drawbacks of this conversion. Because PGVC expansion may bring environmental benefits as well as risks, both an assessment of the environmental benefits and consequences of PGVC and an economic cost-benefit analysis are urgently needed to better understand this anthropogenic system. Therefore, the objectives of this study were: (1) to estimate the biophysical and economic value of ES and EDS provided by PGVC and compare these to CVC in China; (2) to assess the net economic value of ES provided by PGVC; and (3) to provide sound strategies for local policymakers, as well as other developing countries in order to optimize benefits derived from PGVC.

2. Methods and Data Collection

2.1. Characteristics and Distribution of PGVC in China

We examined two basic types of PGVC in China. In Northern China (temperate zone), the main type of PGVC was solar greenhouses (Appendix A Fig. S1a in Supplementary Data) that combine solar radiation with the brick/soil walls and plastic films and straw roof covers to keep the internal temperature >10 °C. Less than 5% of these solar greenhouses, mainly distributed in Heilongjiang and Xinjiang Province (46~50ºN), needed extra coal-fired heating (Costa et al., 2003). The roof was mainly composed of bamboo canes, metal frame and wood to support the plastic cover (Costa et al., 2004). Greenhouses covered areas ranging from 150 to 800 m^2 (width: 5–10 m, length: 30–80 m) and are managed easily by a small family (Costa et al., 2003). In Southern China (subtropical zone), the main type was the round-arched plastic greenhouse (Appendix A Fig. S1b in Supplementary Data) with the architecture from local materials such as bamboo and steel. The widths and lengths most commonly used were 8–12 m and 40–60 m, respectively.

The primary vegetables produced by PGVC in the north and south were cucumbers (*Cucumis sativus* L.), tomatoes (*Lycopersicon esculentum* Mill.), eggplant (*Solanum melongena* L.), and peppers (*Capsicum frutescens* L. var. *grossum* Bailey) (Zou, 2002; Costa et al., 2004; Jiang and Yu, 2006). The land where the PGVC are currently located was previously used for conventional vegetable cultivation. Organic fertilizers (e.g., manure) and compost fertilizers (e.g., organic mixtures of rice husks and manure) were the chief types of fertilizers used. Most greenhouses were flood irrigated using polyethylene pipes. Therefore, the environmental effects of the two vegetable cultivation systems were comparable.

PGVC has been implemented in all 32 Chinese provinces. Based upon climatic conditions (primarily temperature, precipitation and total solar radiation) (Appendix A Table S1 in Supplementary Data), PGVC in all of China's provinces was categorized into nine regions according to climatic factors such as accumulated temperature, solar radiation and maximum snow depth (Zhang and Chen, 2005) (Fig. 1).

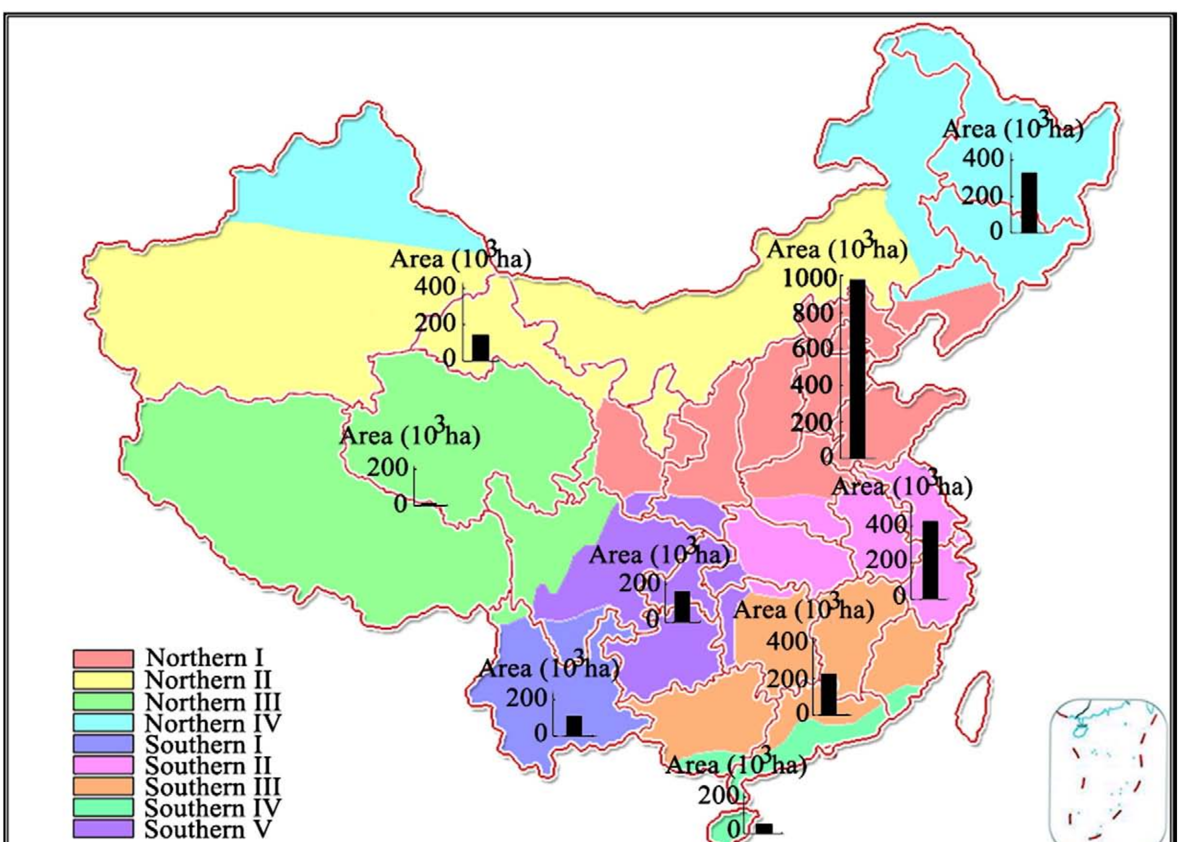

Fig. 1. Distribution of PGVC in China. Black bars indicate the total area of PGVC in each region.