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Developing grain production policy in terms of multiple cropping systems in China

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ABSTRACT

Multiple cropping is one of the simplest ways to increase grain production, and it has an important role in the food security of China. This paper evaluates the multiple cropping systems of China, and identifies the regional obstacles that limit the use of multiple cropping with the aim to give some implications for developing grain production policy. A time series analysis of remote sensing data coupled with an econometrics model—stochastic frontier analysis (SFA) was used to derive the multiple cropping index (MCI), potential multiple cropping index (PMCI), multiple cropping efficiency (MCE), and potential increment of multiple cropping index (PIMCI) to evaluate the multiple cropping systems. Regional obstacles to the use of multiple cropping were identified by zoning socioeconomic and ecological environmental factors that impact its application. The MCE of China in 2005 was 87.5%, with a gap of 22% between the MCI and the PMCI. The Bohai Rim, the rim of Tianshan Mountain, the Sichuan Basin, and the middle reach of Yangtze River are the main regions that larger PIMCI could be anticipated. The whole country (excluding areas that lacked data) was divided into seven distinct regions in terms of the impact factors and further classified into low-efficiency high-potential regions (LHRs), high-efficiency low-potential regions (HLRs), high-efficiency medium-potential regions (HMRs), and medium-efficiency high-potential regions (MHRs) according to regional multiple cropping performance. Considering about the obstacles and benefits to each region, different strategies should be implemented to different regions for regional grain production increase. Special attention should be paid to the improvement of MCE in north and southwest China with the expectation to increase grain production of China. The results would help implement "The plan to increase grain production capacity by 50 million tons nationwide" launched by the central government of China.

Introduction

China supplies food to 22% of the world population with only 7% of the world's cropland base. Thus, China's food demands seriously conflict with the supply (Yang and Li, 2000), which may affect both domestic and world food security (Wang et al., 1996). The situation is even aggravated in post-reform China because rapid economic growth has triggered industrial and residential land expansion, which has greatly diminished the available croplands (Chen et al., 2013; Hui and Bao, 2013; Tan et al., 2005a). Although a policy of dynamic cropland balance (no net loss) was initiated at the end of the 20th century to halt the decline in cultivated land, the cropland in traditional farming regions with high multiple cropping index and productivity have significantly decreased because of the expansion of industrial and residential construction (Tan et al., 2005a; Yang and Li, 2000; Yu et al., 2009) relative to the increase in croplands with marginal productivity in northwestern China (Liu et al., 2002; Tan et al., 2005b; Deng et al., 2006). This trend threatens China's continued capacity to produce adequate amounts of staple cereals (Brown, 1995).

Land is not the only factor that affects agricultural production (Lichtenberg and Ding, 2008). Grain production increases would come more from intensified use of existing land rather than from increasing the amount of land under cultivation in the future (Ali, 2007; Keys and McConnell, 2005; Lin and Ho, 2003). Thus, the Chinese government has implemented a series of policies for improving the quality and intensity of cropland use since the beginning of the 21st century. The latest and most well known policy is "The plan to increase grain production capacity by 50 million tons nationwide (2009–2020)," which aims to maintain a food self-sufficiency ratio of 95% through six measures for improving cropland use intensity. The simplest and most effective method is increasing the multiple cropping index (MCI) (Hayami and Ruttan, 1985; Turner and Doolittle, 1978; Turner et al., 1977).

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Actually, multiple cropping has a significant role in the food security of China since the country was established. The MCI of China has increased from 131% in 1952 to 158% in 1995. Especially from 1986 to 1995, the MCI of China notably increased by 9.7%, equivalent to an increase of 85,000 km^2 of crop planting area, 75% of which was allocated for planting grains. This improvement increased the annual grain production by 24.1 billion kg, 36.5% of the total grain production increase for the period (Liu, 1997).

Recent research has actively engaged in spatially exploring MCI and potential MCI (PMCI) at various geographic scales using different kinds of data, in order to assess the current situation of multiple cropping systems in China. Verburg et al. (2000) and George and Samuel (2003) estimated the food security of China by employing MCI at the county level, calculated from census data, as one of the major characteristics of crop lands. Fan and Wu (2004a), Yan et al. (2005), and Zuo et al. (2013a) explored the spatial distribution of MCI in China based on remote sensing image data at spatial resolutions of 1 km, 8 km, and 250 m. Fan and Wu (2004b) also calculated the PMCI of China using the linear data envelopment function based on census data-derived MCI, annual accumulated temperature, and precipitation.

Among existing studies, the limiting factors for multiple cropping and the solutions for increasing MCI have not been illustrated sufficiently. This paper proposes strategies for developing grain production policy at the regional and the country level by evaluating the performance of the multiple cropping systems and identifying the socioeconomic and ecological limitations on the use of multiple cropping.

Data and methodologies

Data preparations

Five nation-wide datasets (Table 1), including remote sensing data, land use data, meteorological data, socioeconomic data, and ecological–environmental data, are used to develop grain production policy.

The remote sensing, land use, meteorological datasets were used to evaluate the multiple cropping systems. For the remote sensing data, we used 16-day composite MODerate-resolution Imaging Spectroradiometer (MODIS) Enhanced Vegetation Index (EVI) time series data at a spatial resolution of 250 m to obtain the MCI of China. The dataset was obtained through the Earth Observing System Data and Information System of the National Aeronautics and Space Administration. Land use data, scaled in 1:100,000, based on visual interpretation by experts using Landsat Thematic Mapper (TM) and China–Brazil Earth Resource Satellite (CBERS) images (Zuo et al., 2013b), was used to define the range of China's cropland, which was converted into raster format at 250 m spatial resolution to fit the remote sensing data. The meteorological data was used to develop the spatial explicit maps of the annual average temperature, annual average precipitation, and sunshine percentage at a spatial resolution of 1 km using Kriging interpolation. The MCI map and meteorological variables were then both generated into maps at the county level through mean value calculation, and then used to evaluate the multiple cropping systems.

The socioeconomic data and the ecological–environmental data, which provide two types of factors that may affect the implementation of multiple cropping, were utilized to define the regional barriers to MCI increment. Theoretically, labor and equipment, funds and markets, and prices and agricultural policy are the three most important aspects of the socioeconomic factors that influence multiple cropping (Liu, 1982). Therefore, rural labor, gross agricultural machinery, area of irrigation, agricultural income, and farming income were chosen as essential socioeconomic factors. All variables used in this study were county-level statistical data obtained from Thematic Database for Human-earth System of China, which was established by Chinese Academy of Sciences (CAS). However, statistical data are still lacking for provinces such as Tibet and Qinghai, which accounts for 35.20% of the country's total land area. Fortunately, most of the land area in these counties is mainly used for pasture rather than cultivation. Thus, eliminating these areas would not significantly affect the analysis.

Soil erosion and DEM were employed to indicate the ecological and environmental conditions. The soil erosion map of China, scaled in 1:100,000, was produced based on Landsat TM images by CAS (Zhao et al., 2002). Both the soil erosion data and DEM data were converted into maps at the county level through mean value calculation.

Evaluating multiple cropping systems

Four indicators were used to comprehensively evaluate the multiple cropping systems: (1) multiple cropping index (MCI), the number of crops planted per year in the same piece of land, representing the actual situation of the multiple cropping systems; (2) potential multiple cropping index (PMCI), the maximum number of crops planted per year in the same piece of land, representing the potential capacity for the implementation of multiple cropping; (3) multiple cropping efficiency (MCE), the ratio between MCI and PMCI, which indicates the efficiency of the multiple cropping systems; and (4) potential increment of multiple cropping index (PIMCI), the gap between MCI and PMCI, which indicates the capacity for increasing MCI.

Considering the vegetation index (VI) time-series profile curve clearly reflects crop phenology (Jonsson and Eklundh, 2002; Sakamoto et al., 2005; Zhang et al., 2003), we determined the MCI by counting the peaks of the annual time-series profile curve of the MODIS EVI data or by comparing the difference between the values of VI in certain crucial phases (Zuo et al., 2013a). The result was in raster format at a spatial resolution of 250 m. We calculated the average MCI in each county using the following function so as to combine it with the climate data at county level for calculating the PMCI, MCE and PIMCI:

$$\mathrm{MCI}_{\alpha} = \frac{\mathrm{MCI}_i \times n_i}{\sum_i n_i} \tag{1}$$

where MCI_{α} indicates the average MCI in a certain area; MCI_i indicates the value of MCI for each pixel, $i = 1, 2, 3, \ldots$; and n_i indicates the number of pixels that MCI equals to i within that area.

Using the MCI as the output and the climate variables (including annual average temperature, annual average precipitation, and sunshine percentage) as the inputs of the multiple cropping systems, PMCI was calculated using stochastic frontier analysis (Verburg et al., 2000), which is based on the economics theory that efficiency corresponds to the ability to increase the outputs with a certain number of inputs, or the ability to reduce inputs for a certain number of outputs (Kumbhakar and Lovell, 2003). The details of this method and its validation are clearly described in an article by Zuo et al. (2013a).

Finally, MCE and PIMCE were calculated using the following functions:

$$\mathrm{MCE}_i = \frac{\mathrm{MCI}_i}{\mathrm{PMCI}_i} \tag{2}$$

$$\mathrm{PIMCE}_i = \mathrm{PMCI}_i - \mathrm{MCI}_i \tag{3}$$

where, MCI_i, PMCI_i, MCE_i, and PIMCE_i correspond to the MCI, PMCI, MCE, and PIMCI of county i, $i = 1, 2, 3, \ldots$. The average MCI, PMCI, MCE, and PIMCI for each province and each region were also