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Analysis of the spatial mismatch of grain production and farmland resources in China based on the potential crop rotation system

Tingting Li[a,b], Hualou Long[b,c,*], Yingnan Zhang[b,c], Shuangshuang Tu[b,c], Dazhuan Ge[b,c], Yurui Li[b,c], Baoqing Hu[d]

[a] Rural Development Institute, Chinese Academy of Social Sciences, Beijing 100732, China
[b] Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[c] University of Chinese Academy of Sciences, Beijing 100049, China
[d] Key Laboratory of Environment Change and Resources Use in Beibu Gulf, Guangxi Teachers Education University, the Ministry of Education, Nanning 530001, China

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ABSTRACT

At present, China's grain production pattern runs counter to the distribution patterns of farmland resources and water-heat conditions. It is urgently important to conduct research on the spatial matching of grain production and farmland resources. Based on the Potential Crop Rotation data, with regards to the situations of irrigation and rain feeding, this paper builds a measuring model of potential farmland, and separately measures the spatial matching index of grain yield with actual and potential farmland resources, thus revealing China's grain production pattern. The results indicate that serious spatial mismatch exists between grain production and farmland resources in China. Take the potential crop rotation system into consideration, the spatial mismatch of grain yield and potential farmland resources has been aggravated by the grain production barycenter's shift to the north China, with low Crop Rotation Index. The function-promoting regions of grain production in China are going through two evolution patterns of "northward and southward expansion" and "westward movement and northward expansion," respectively. Inefficient use of farmland mainly occurs in the fragile ecological environments, such as the farming-pastoral ecotone of Northern China, the northwest area of Xinjiang and the southwest karst landform areas. The inefficient use of and the decreasing amount of available farmland have become the main causes of the decline in grain production. The problems facing Chinese agriculture caused by the spatial mismatch include the imbalance in regional structures, ecological risks, agricultural production risks, and the risk of food price. In order to cope with these problems, this paper provides some advices on protecting farmland acreage, expanding farmland potential, ensuring the safety of water resources, and extending the industrial grain chain. Our paper additionally proposes policy reforms and innovations designed to ensure the implementation of the above measures, so as to commonly defuse China's food security crisis.

1. Introduction

Food security is a fundamental problem related to the sustainable development of a country's social economy and national security. The food security situation in China is being confronted with many challenges (Anderson and Strutt, 2014; Enenkel et al., 2015; Fan and Brzeska, 2014). Since the 1990s, the urbanization and industrialization of China has entered the acceleration stage, which features the disordered expansion of urban construction land and the occupation of a large amount of high-quality farmland (Ding, 2007), as well as the over-use of agricultural water resources (Brown et al., 2005; Thompson and Prokopy, 2009; Yue et al., 2013). A large number of people from rural areas now swarm into cities. This migration of huge numbers of people gradually intensifies the decreased use of farmlands for agricultural purposes, while increasing its non-agricultural use (Gu et al., 2007; Li et al., 2014; Long et al., 2012, 2016; Su et al., 2015; Seto et al., 2000). Soil pollution, land degradation and water pollution all intensify the food security problem (Liu et al., 2015; Lu et al., 2015; Qing et al., 2015; Xu et al., 2014). Continuous population growth and changes in residents' consumption patterns lead to a greatly increasing demand

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* Corresponding author at: Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, 100101, China.
E-mail address: longhl@igsnrr.ac.cn (H. Long).

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for food (Dorward, 2013; Unnevehr and Hoffmann, 2015; Mitchell, 2008). Food security has in fact been a cause of great concern for a very long time (Ferranti, 2016; Pinstrup-Andersen, 2009; Smyth et al., 2015; Zhou and Turvey, 2014).

With the continuous development of regional economies, obvious changes have occurred in terms of the grain production and supply-demand patterns in China (Lu, 1997; Deng et al., 2013). Some research has shown that the barycenter of grain production presents a trend of “northward and middle-part forward movement” (Liu and Zhai, 2009). Statistics also indicate grain circulation pattern changes, from the traditional pattern of “grain in the south being transported to the north” to the present pattern of “grain in the north being transported to the south” (Xu et al., 2013a; Liu et al., 2009). Driven by factors such as per capita farmland acreage, grain yield per unit area, and economic benefits (Xu et al., 2013b), grain production will in the future be concentrated in the northern and western regions. These areas boast a low proportion of non-agricultural income, great potential for improving grain yield per unit area and high economic benefits (Deng et al., 2013). The spatial pattern of per capita grain growth also indicate a new prospect of “low growth in the middle region and high growth in the western region” (National Bureau of Statistics of China, 2010). The imbalanced spatial distribution of grain production is causing year-by-year increases in grain trade volume between the main producing areas and the main selling areas. This imbalance will have a profound impact on regional grain policy and interprovincial grain trade (Wu, 2000).

The present pattern of grain production in China commonly results from multiple factors. Grain production is not only affected by certain specific natural factors, such as the location of farmland (He et al., 2013; Song et al., 2015; Xu and Zhu, 2015), crop rotation systems (Cornish et al., 2015a,b; Rigolot et al., 2016), climate change (Bandara and Cai, 2014; Cheeseman, 2016; Rutten et al., 2014; Ye et al., 2014), and the condition of available water resources (Chen et al., 2013a; Jiang, 2015; Xu et al., 2005), but also affected by a number of external factors, including chemical fertilizer use (Smith and Siciliano, 2015; Zhao et al., 2016) and modernized agricultural conditions (Wang and Zhou, 2013; Su et al., 2014a). The farmland resources in China are confronted with the dual challenges of quantity and quality. As such, the sharp decrease of available farmland (Chien, 2015) and intensified land degradation (Jiang et al., 2015) directly threaten China’s grain yield. Global climate change is also leading to a northward shifting of the crop rotation system boundary, to an increase in the Multiple Cropping Index (Ye et al., 2015) and to more frequent occurrences of climate-related damage (Marvin et al., 2013). Combined, these factors bring new opportunities and challenges to grain production in China. The spatial imbalance of water resources causes the water resource occupation per farmland acre in South China to be eight times greater than that in North China. The implementation of a “South-to-North Water Diversion” Project, at least to a certain extent, relieves the pressure caused by the shortage of water resources in northern regions. However, the spatial mismatch of water resources and grain production cannot be neglected forever (Dong et al., 2011; Li et al., 2015). Water pollution (Lu et al., 2015) and the massive increase in non-agricultural water usage (Davijani et al., 2016) further restrict any potential improvement in overall grain production capabilities. The progress of agricultural technology is a “double-edged sword”, because while the use of chemical fertilizers and pesticides increases the grain yield, meanwhile, those same fertilizers and pesticides also cause problems such as agricultural non-point source pollution (Smith and Siciliano, 2015), soil crust (Shahgholi and Abuali, 2015) and other issues. Without doubt, the spatial shifting of both grain production and farmland resource barycenters is magnifying the crisis that grain production faces in terms of water, soil, and ecology.

Therefore, the need to conduct research on the spatial matching degree of grain production and farmland resources is urgent. Previous studies have mostly focused on analyzing the correlation between grain production and actual farmland areas (Long and Zou, 2010; Robinson and Carson, 2015; Liu et al., 2014, 2009). These studies neglected the changes in grain sowing areas caused by the different crop rotation systems. The hydrothermal resources in the southern region are very rich, and the production potential per unit area of farmland is far greater than that of the northern area. The spatial mismatch of the grain production and farmland resources caused by the northward shifting of the grain production barycenter is causing a serious waste of resources. Based on the Potential Crop Rotation data which examines the situations of irrigation and rain feeding, this paper builds a model of measuring potential farmland. Separately, we measure the spatial matching index of grain yield against actual and potential farmland resources. Through analyzing and comparing the two index-measuring results, we can reveal the main grain-producing areas, as well as the most inefficient farmland utilization areas, and we further analyze the function degradation areas and potential areas of grain production. We also use this data to judge whether or not the spatial pattern of grain production is in accord with the distribution rules of potential farmland, and provide corresponding suggestions to ensure China’s food security.

2. Materials and methods

2.1. Data source and processing

The data relating to grain yield, irrigated areas (*IA*) and total cultivated area (*TCA*) of 2,347 counties in China, in 1990, 2000 and 2010, was mainly extracted from “*China Statistical Yearbook for Regional Economy*” and “*China County Statistical Yearbook*”. The data pertaining to 100 m gridded farmland in 1990, 2000 and 2010, was provided by National Data Sharing Infrastructure of Earth System Science (www2.geodata.cn). The data pertaining to 10 × 10-kilometer grids of Potential Crop Rotation Index (PCRI) for the irrigated and rain-fed scenarios in 1990, 2000 and 2010, was provided by Global Change Research Data Publisher & Repository (www.geodoi.ac.cn). It was estimated with GAEZ-model developed by FAO and IIASA, based on DEM data, soil data, meteorological data and arable land. The PCRI includes single, 1.5 times, double and triple crop rotation systems.

The PCRI was resized from 10 kilometer to 100 m grids, in order to calculate the potential farmland combined with actual farmland. Eventually, the actual farmland and potential farmland were calculated at county level.

2.2. Methods

Potential farmland area denotes the natural potential area of physical farmland. For example, the potential farmland was two times the actual farmland in a double crop system. Therefore, potential farmland is given as (Liu et al., 2014):

$$y_p = y \times PCRI_i \times i + y \times PCRI_r \times (1 - i) \tag{1}$$

$$i = \frac{IA}{TCA} \tag{2}$$

where, y_p is the area of potential farmland, y is the area of actual farmland, $PCRI_i$ and $PCRI_r$ is the PCRI under irrigated and rain-fed scenarios, respectively; i is the ratio of irrigated area (IA) to the total cultivated area (TCA).