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REVIEW

The transformation of agriculture in China: Looking back and looking forward

JIAO Xiao-qiang[1], Nyamdavaa Mongol[2], ZHANG Fu-suo[1]

[1] *Center for Resources, Environment and Food Security, Department of Plant Nutrition/Key Laboratory of Plant-Soil Interactions, Ministry of Education, China Agricultural University, Beijing 100193, P.R.China*

[2] *Lancaster Environment Centre, Lancaster University, Lancaster LA1 4YQ, UK*

Abstract

China's grain yield increased from 1 t ha^{-1} in 1961 to 6 t ha^{-1} in 2015, while successfully feeding not only its large population but also supplying agricultural products all over the world. These achievements were greatly supported by modern technology and distinct governmental policy. However, China's grain production has been causing a number of problems mainly related to declining natural resources and a lack of environmental protection. Due to the growing population and changing dietary requirements, increasing food production must be achieved by increasing resource use efficiency while minimizing environmental costs. We propose two novel development pathways that can potentially sustain agricultural crop production in the next few decades: (i) enhancing nutrient use efficiency with zero increase in chemical fertilizer input until 2020 and (ii) concurrently increasing grain yield and nutrient use efficiency for sustainable intensification with integrated nutrient management after 2020. This paper provides a perspective on further agricultural developments and challenges, and useful knowledge of our valuable experiences for other developing countries.

Keywords: food security, sustainable development, agriculture, grain production

1. Introduction

Due to Borlaug's Green Revolution, China has successfully produced enough grain for its large population while using only 9% of the global arable land during the past half century (Zhang 2011). Without this revolution, it is very likely that this comparably small amount of land would not have sustained China's growing population and would have led to many serious problems as a result of starvation (Brown 1995). Currently, grain per capita is more than 400 kg in China. In addition, China has become one of the largest agricultural producers. The high food production helped reduce a number of social problems resulting from hunger and food shortages in China. For example, the public now has greater access to grain at reasonable and stable prices (Khush 2001; Pingali 2012). In addition, China was the first developing country to achieve the target of reducing poverty in the population by half in 2015 (Huang and Yang 2017). Overall, the agricultural industry has made significant contributions to the economic development of China since the establishment of the People's Republic of China in 1949.

Farmers in the agricultural sector still have challenges to

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JIAO Xiao-qiang, E-mail: xqjiao526@126.com; Correspondence ZHANG Fu-suo, Tel: +86-10-62733499, Fax: +86-10-62731016, E-mail: zhangfs@cau.edu.cn

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face in the next few decades, such as continuing to improve grain production while reducing chemical fertilizer application and improving protection of the environment (Tso 2004; Fan *et al.* 2012; Shen *et al.* 2013). Average grain yield in China was only half the size of that in the EU and USA in 2005. Furthermore, grain production stagnated or declined in a large proportion of the arable land in China during the last few decades, due to inappropriate agronomy practices, climate change and so on (Ray *et al.* 2012). Compared with other developed economies, grain production in China utilized more resources, such as chemical fertilizer, to achieve high yields (Vitousek *et al.* 2009; Jiao *et al.* 2016). Indeed, China produced 19% of the world's food supply while using an amount of chemical fertilizer equivalent to 30% of the world's annual food consumption during the last decade (West *et al.* 2014; Jiao *et al.* 2016). Excessive use of chemical fertilizers causes many negative environmental impacts, such as water pollution, eutrophication, high NO_3^- concentration in underground water and air pollution (Carpenter 2008; Liu *et al.* 2013; Norse and Ju 2015; Zhou *et al.* 2016).

Sustainable agriculture has become the new focus of research in China. In fact, food security has become a high priority to the Chinese government and is thus, closely regulated by policy, particularly in economic and social fields. In 1980, China's government introduced the Household Responsibility System to replace the People's Commune System, which stimulated farmers' enthusiasm to farm. Moreover, until 2015, the Chinese government has released 14 "No. 1 Documents" focusing on agriculture (Tong *et al.* 2003; Yang 2006; Jiao *et al.* 2016). This declaration has objectives for promoting grain production and reducing the use of natural resources by facilitating more technological advances in this area. However, it is difficult to develop feasible strategies that will achieve sustainable grain production while overcoming so many challenges. This begs the question: can China produce a sufficient food supply to feed its growing population while protecting the environment and preserving its limited natural resources?

In this study, we examined the trends of grain yield in China during the past half-century, and then identified the factors that contributed to grain yield increase, such as technological advances and policy support. Next, we focused on the challenges and problems of grain production in China during the last decade. Finally, we addressed potential pathways for sustainable intensification in agriculture for China's future.

2. Historical dynamic trajectory of grain production in China over the past half-century

During the phenomenon nationally known as the "Miracle", China's agricultural producers were feeding 22% of the world's population despite using only 9% of the world's arable land (Fan *et al.* 2012). Grain production per capita in China increased dramatically from less than 250 kg in the 1960s to more than 400 kg in the 2010s (Zhang 2011). In the past half-century, grain yield increased steadily from 1 t ha^{-1} in 1961 to 6 t ha^{-1} in 2015 (Fig. 1). In comparison with other countries, China's grain yield, at its lowest in 1961, was equivalent to Africa's grain yield in 2005. China's grain yield then increased to 3 t ha^{-1} by 1980, when it achieved the same level as Latin America and South-East Asia in 2005 (Sanchez 2015). In 2015, grain yield in China peaked at 6.0 t ha^{-1}. The likely cause of China's "Miracle" is the use of technological innovations such as chemical fertilizers, semi-dwarf and heterotic crops, and pesticides, in conjunction with the introduction of better policies and regulations by the Chinese government (Zhang 2011; Huang and Zhang 2017).

Today, agriculture is an industry of food, fiber and energy production based on the growth and development of plants to sustain and enhance human life (Oenema *et al.* 2009). It is like a converter that combines the inputs of solar radiation, CO_2, water and soil nutrients and transforms them into food for human and other animal consumption. The four inputs are the key elements of the agricultural converter. China's "Miracle" of feeding 22% of the world population with 9% of the world's arable land was due to China's effective integration of all these elements based on increasing scientific knowledge of the intricacies of plant-soil interactions for grain production during the past half century (Yang 2006; Fan *et al.* 2012).

Generally, agricultural soil in China was considered not fertile enough to improve grain production (Yang 2006). However, many approaches have been used to improve soil quality such as application of manure, chemical fertilizer and crop straw return (Yang 2006). Yang (2006) estimated that about 90 kg ha^{-1} of manure and 40 kg ha^{-1} of chemical fertilizer were applied into croplands in China in the 1970s. Farmers in rural areas call manure "organic treasures". Manure is typically collected from domestic animals, such as pig, cattle, and poultry. The animals feed on crop residuals, weeds, and grasses and their feces are then recycled as fertilizer to improve soil fertility (Li *et al.* 1988). Most importantly, manure applied to soil can stimulate plant growth, and in turn, result in more root carbon (root biomass carbon and rhizo-deposition carbon) return to the soil for maintaining fertility. This positive feedback loop with manure to sustainably maintain soil fertility has been integrated with other agronomic practices as a basic strategy to increase grain production (Barrett and Bevis 2015; Vanlauwe *et al.* 2015).

Chemical fertilizers, especially N-enriched fertilizers, were widely used by farmers to boost crop yield in the 1980s