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REVIEW

Towards sustainable intensification of apple production in China—Yield gaps and nutrient use efficiency in apple farming systems

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Abstract

China is in a dominant position in apple production globally with both the largest apple growing area and the largest export of fresh apple fruits. However, the annual productivity of China's apple is significantly lower than that of other dominant apple producing countries. In addition, apple production is based on excessive application of chemical fertilizers and the nutrient use efficiency (especially nitrogen) is therefore low and the nutrient emissions to the environment are high. Apple production in China is considerably contributes to farmers' incomes and is important as export product. There is an urgent need to enhance apple productivity and improve nutrient use efficiencies in intensive apple production systems in the country. These can be attained by improved understanding of production potential, yield gaps, nutrient use and best management in apple orchards. To the end, priorities in research on apple production systems and required political support are described which may lead to more sustainable and environmental-friendly intensification of apple production in China.

Keywords: apple production, China, environmental problems, nutrient use efficiency, potential yield, sustainable intensification, yield gaps

1. Introduction

Agricultural productivity in China has been rapidly improved over the past decades. However, this development has resulted in severe ecological and environmental problems (Ju *et al.* 2004, 2009; Fan *et al.* 2011; Zhang *et al.* 2011). Fertilizer applications in cash crops appear to be very high and much higher than the applications in cereal crops (Fan *et al.* 2011). Besides, the nitrogen use efficiency of cash crops in China is very low compared to that in developed countries. Such excessive applications of chemical fertilizers in combination with low nutrient use efficiencies lead to serious environmental problems due to the strong emissions of nutrients and biocides to the atmosphere, soil, ground and surface waters (Ju *et al.* 2009).

Negative influences of agriculture on the environment and ecosystems have been recognized worldwide. Sustainable intensification of crop production should lead to maximization of crop productivity with simultaneously proper management and protection of ecosystems (FAO 2014). A more practical definition of sustainable intensification is the use of the available natural resources as efficiently as possible, while minimizing the unfavorable impacts on soils, water, air and biota as much as possible (Eckert *et al.* 2000). Considering the continual increases in human pop-

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ulation and land use pressure in a country as China, there is little scope to expand the land area used for agricultural production. Hence, intensification of agricultural production systems is needed in China during the coming decades. To achieve a more sustainable and environmental-friendly type of agriculture and to protect natural ecosystems against emissions of nutrients and biocides from agriculture, the Chinese government has recently launched a number of actions to change the current agricultural developmental model which is at the cost of environment. The main objective is to improve yields and productivity of different farming systems with the same input level of agricultural chemicals.

Apple is one of the most important cash crops in China. This study gives an overview of the main problems of current apple production systems and management practices in China. These problems have to do with the low productivity of apple orchards, the poor nutrient use efficiency, and the large nutrient and other emissions to the environment. We first identified the major factors that cause these problems, and next identified the best possibilities for enhancing apple productivity and improving nutrient use efficiencies. To successfully achieve sustainable intensification of apple production systems across the country, relevant research on apple production systems and supportive agricultural policies are to be initiated. The study indicates the best possibilities for achieving sustainable apple production systems in the coming decades through closure of both the apple productivity gap and the nutrient use efficiency gap.

2. Apple production in China

Apple (*Malus domestica* Borkh.) is one of the most popular tree fruit in the world. Being the first ranking country in total growing area and export of fresh apple fruits, China has taken the predominant position in world apple industry (FAO 2016). Till 2013, the annual production of fresh apple fruits is approximately 39.7 million t and the cultivated area is 2.41 million ha, which represent 49 and 46%, respectively, of the world apple production and planting area (FAO 2016). The European Union (EU) and the United States were the 2nd and 3rd largest world producers, respectively (FAO 2016). After entry into the World Trade Organization in 2001, China's apple products have become one of the most competitive agricultural products in foreign trade (Zhai *et al.* 2008). China has been the largest apple exporter worldwide (USITC 2010). The export value and export volume of apple were approximately 0.1 billion USD and 0.86 million t, respectively in 2014 (NBSC 2016). In addition to production and export, China is one of the largest countries of apple consumption. China has a large domestic market with an annual consumption of approximately 11.28 kg per capita, which is significantly higher than the world average apple consumption (2.1 kg person^{-1} yr^{-1}) (MOA 2008).

Apple production ranks the first in fruit industry in China in terms of growing area. Shandong, Liaoning, Hebei, and Henan provinces in the Bohai Bay area and Shaanxi, Shanxi, and Gansu provinces in the Loess Plateau area are the major apple growing provinces in China. The total production in 2014 in the above provinces were 9.29, 2.47, 3.45, 4.41, 9.88, 4.17, and 2.97 million t, respectively (NBSC 2016). Fuji (*Malue domestica Borkh*., *cv.* Fuji) is the dominant commercial cultivar produced which constitutes approximately 60% of total apple cultivated in the country (FAO 1999). Other important cultivars include Starkrimson (*Malue domestica Borkh*., *cv.* Starkrimson), Jonagold (*Malue domestica Borkh*., *cv.* Jonagold), Golden Delicious (*Malue domestica Borkh*., *cv.* Golden Delicious) and Gala (*Malue domestica Borkh*., *cv.* Gala).

Apples are produced in widely varying locations across the country, but are mostly concentrated in the Bohai Bay area and the Loess Plateau area (Liu and Fan *et al.* 2012) (Fig. 1). The two areas account for 80% of growing area and 90% of production in the country. In the Loess Plateau and Bohai Bay regions, most apples orchards are operated by smallholders (e.g., more than 75% farmers owned small piece of land less than 0.3 ha in the Loess Plateau region and more than 40% of apple orchards were below 7 ha in the Bohai region) and are cultivated with low levels of mechanization and standardization (Liu *et al.* 2002; Zhai *et al.* 2008). For smallholder farmers, apple is the major income source. The development of the apple production and industry in the region has contributed considerably to the local economy and employment (Fan and Hu 2005; Zhang *et al.* 2012). There is an urgent need to increase production and export revenues and to improve farmers' livelihoods. Instead of expansion of the apple production area, more focus should be given on improving the productivity and

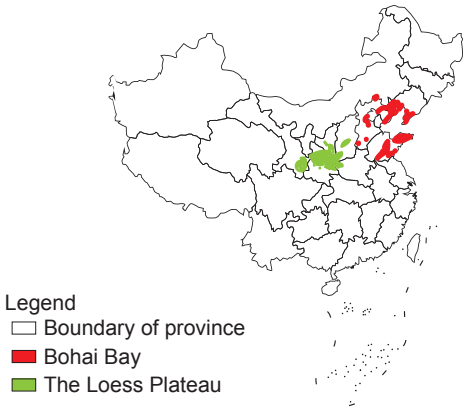

Fig. 1 Major apple production regions in China (the central area indicates the Loess Plateau region and the northeast area indicates Bohai Bay region, MOA 2008).