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REVIEW

Maize-soybean strip intercropping: Achieved a balance between high productivity and sustainability

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Abstract

Intercropping is one of the most vital practice to improve land utilization rate in China that has limited arable land resource. However, the traditional intercropping systems have many disadvantages including illogical field lay-out of crops, low economic value, and labor deficiency, which cannot balance the crop production and agricultural sustainability. In view of this, we developed a novel soybean strip intercropping model using maize as the partner, the regular maize-soybean strip intercropping mainly popularized in northern China and maize-soybean relay-strip intercropping principally extended in southwestern China. Compared to the traditional maize-soybean intercropping systems, the main innovation of field lay-out style in our present intercropping systems is that the distance of two adjacent maize rows are shrunk as a narrow strip, and a strip called wide strip between two adjacent narrow strips is expanded reserving for the growth of two or three rows of soybean plants. The distance between outer rows of maize and soybean strips are expanded enough for light use efficiency improvement and tractors working in the soybean strips. Importantly, optimal cultivar screening and increase of plant density achieved a high yield of both the two crops in the intercropping systems and increased land equivalent ratio as high as 2.2. Annually alternative rotation of the adjacent maize- and soybean-strips increased the grain yield of next seasonal maize, improved the absorption of nitrogen, phosphorus, and potasium of maize, while prevented the continuous cropping obstacles. Extra soybean production was obtained without affecting maize yield in our strip intercropping systems, which balanced the high crop production and agricultural sustainability.

Keywords: maize, soybean, strip intercropping, high production, agricultural sustainability

1. Introduction

As population expansion, urbanization, environmental pollution, and climate change, the global food crisis is currently aggravated in the world (Godfray *et al*. 2010; Foley *et al*. 2011). To fix the food crisis, the overarching task of the developing countries is to boost grain production on

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the finite cropland especially for those countries with large population and limited arable land. China has the largest population with limited arable land in the world. Drastic burst of human population and natural disasters have led to food crisis in modern Chinese history. Even nowadays, food supply and food safety are a major public health issue in China (Lam *et al*. 2013). Although grain production has been improved after establishment of the new China, the acreage of arable land decreased drastically and people's demands for higher living quality are ever-increasing in recent years. Traditional cropping systems are not able to afford the food demand any more. The limited farmland in China impels people to max the crop yield without expanding the farmland size. Chemical fertilizer use has made a big contribution to increase crop productivity and alleviate the food crisis in the last decades. Increase of food production and crop yield were mainly *via* high input of fertilizer and water irrigation, which finally aggravates environmental deterioration such as serious water and air pollution, soil acidification, and erosion in a unsustainable way (Tilman *et al*. 2002; Feike *et al*. 2012; Liu *et al*. 2013; Zhang *et al*. 2013). These serious problems bring new challenges in food security and sustainability.

Environmental problems caused by overfertilization lead to the rediscovery of intercropping systems in China in recent years. Intercropping is a practice involving growing two or more crops simultaneously in the same field during a growing season to produce more yields (Li *et al*. 2014; Brooker *et al*. 2015). Intercropping has shown potential as a land-use efficient and sustainable agricultural practice (Li *et al*. 2014; Brooker *et al*. 2015), which is as well the main model to increase the land use efficiency in both traditional and modern Chinese agriculture. Intercropping principally contains four subcategories: mixed intercropping, row intercropping, strip intercropping, and relay intercropping, which have been employed about 1 000 years in Chinese agricultural history (Ofori and Stern 1987; Knörzer *et al*. 2009). It is estimated that intercropping has been widely employed between a range of more than 2.8×10^7 ha (Li *et al*. 2007) and 3.4×10^7 ha (Li *et al*. 2001a) of annually sown areas in China. In the long Chinese agricultural history, farmers often grow maize, soybean, peanut, potato, wheat, millet, faba bean, tobacco, cotton, sorghum, sesame, garlic, vegetables, cassava, etc., in intercropping systems (Knörzer *et al*. 2009). Previous studies demonstrated that intercropping systems increased biodiversity, soil quality, soil carbon sequestration, and land-use efficiency, enhanced nutrient-use efficiency and lowered pathogen infection to a greater extent compared with continuous monoculture systems (Zhu *et al*. 2000; Li *et al*. 2007; Wang *et al*. 2014; Cong *et al*. 2015).

2. Chinese traditional soybean intercropping problems

China has a long history for intercropping practice, which can track back to Dong Zhou and Qin dynasties (770–206 BC) initiated from crop rotation. Crop rotation and intercropping were first found to be recorded in an famous ancient encyclopaedia "Important Means of Subsistence for Common People" in China (Knörzer *et al*. 2009). Intercropping practice was initiated from forests with grains or cereals, and then evolved into green plants with soybean, hemp, mung bean, rice, and cotton, etc., in Chinese history. Farmers perform intercropping practice in the history due to their desire to use all available land for more production owing to the rare arable land. In rural areas, farmers always manage intercropping crops in the field with manpower in a inconstant way in Chinese traditional intercropping history, so called unconscious cropping system. However, as a matter of fact, these intercropping systems are not optimal for strong increase of crop yield in a long history. At present, China has about 137.1 million hectares of arable land occupying 16% of total national territorial area, in which 20–25% of arable land were covered by intercropped species, such as maize, soybean, wheat, potato, millet, peanut, cotton, sorghum, sesame, cassava, tobacco, faba bean, garlic and vegetables, etc. (Li *et al*. 2001b, 2007; Knörzer *et al*. 2009). Previous studies demonstrated that traditional intercropping system has its advantage specially when input is low, while this advantage decreased as the inputs increase (Wubs *et al*. 2005). In recent years, chemical fertilizer has been broadly overcommitted in China. Total food yield in China has been raised by more than 5.4 folds (616.24 million tons) in 2016 than that in 1949 (113.18 million tons) largely rely on chemical fertilizer. However, overfertilization and extensive irrigation lead to decrease of crop yield and environmental deterioration in traditional Chinese intercropping practice.

An excellent study revealed that soybean-based cropping can reduce soil carbon and nitrogen losses and thus improve soil fertility and yields, which is important for sustainable agricultural development on a regional and global scale (Drinkwater *et al*. 1998), suggesting that soybean-based intercropping systems are ideal for increasing land-use efficiency and sustainability in modern agriculture. As one of the most important crops worldwide, soybean is capable of providing plant proteins and oil for humans and concentrated feeds for animals. Soybean was first domesticated in China (Lee *et al*. 2011), which is currently the largest soy consumer and one of the major soy producing countries worldwide. In China, farmers traditionally intercrop soybean with maize, wheat, sugarcane, cassava, sweet potato, potato, tobacco, and fruit crops, etc. (Knörzer *et al*. 2009; Li *et al*. 2013; Yang