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RESEARCH ARTICLE

Optimized nitrogen application methods to improve nitrogen use efficiency and nodule nitrogen fixation in a maize-soybean relay intercropping system

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Abstract

In China, the abuse of chemical nitrogen (N) fertilizer results in decreasing N use efficiency (NUE), wasting resources and causing serious environmental problems. Cereal-legume intercropping is widely used to enhance crop yield and improve resource use efficiency, especially in Southwest China. To optimize N utilization and increase grain yield, we conducted a two-year field experiment with single-factor randomized block designs of a maize-soybean intercropping system (IMS). Three N rates, NN (no nitrogen application), LN (lower N application: 270 kg N ha^{-1}), and CN (conventional N application: 330 kg N ha^{-1}), and three topdressing distances of LN (LND), e.g., 15 cm (LND1), 30 cm (LND2) and 45 cm (LND3) from maize rows were evaluated. At the beginning seed stage (R5), the leghemoglobin content and nitrogenase activity of LND3 were 1.86 mg plant^{-1} and 0.14 mL h^{-1} plant^{-1}, and those of LND1 and LND2 were increased by 31.4 and 24.5%, 6.4 and 32.9% compared with LND3, respectively. The ureide content and N accumulation of soybean organs in LND1 and LND2 were higher than those of LND3. The N uptake, NUE and N agronomy efficiency (NAE) of IMS under CN were 308.3 kg ha^{-1}, 28.5%, and 5.7 kg grain kg^{-1} N, respectively; however, those of LN were significantly increased by 12.4, 72.5, and 51.6% compared with CN, respectively. The total yield in LND1 and LND2 was increased by 12.3 and 8.3% compared with CN, respectively. Those results suggested that LN with distances of 15–30 cm from the topdressing strip to the maize row was optimal in maize-soybean intercropping. Lower N input with an optimized fertilization location for IMS increased N fixation and N use efficiency without decreasing grain yield.

Keywords: relay intercropping, lower nitrogen, nitrogen use efficiency, nitrogen fixation, nitrogen uptake

1. Introduction

In China, the continuous increase of food production largely depends on chemical nitrogen (N) fertilizer inputs (Zhu and Chen 2002). However, the overuse of N fertilizer and low N use efficiency (NUE) leads to wasted resources and environmental pollution and is contrary to sustainable agricultural production (Kwong *et al*. 2002; Xing and Zhu

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2002; Wang *et al*. 2017). Surplus N fertilization results in substantial soil acidification, with N leaching and emissions as direct triggers of water and air pollution (Guo *et al*. 2010; Zhao *et al*. 2012; Zhang *et al*. 2013), which is contrary to environmental-friendly agricultural production.

As the main food and economic crops in China, maize and soybean are widely cultivated. However, during maize cropping seasons from 1980 to 2010 in China, the NUE declined from 30.2 to 29.9 kg grain kg^{-1} N; in contrast, NUE improved from 39.4 to 53.2 kg grain kg^{-1} N in the USA (Yu *et al*. 2015). To achieve both food security and agricultural sustainable development, optimal N management practices are urgently needed. Suitable N nutrient management and cropping systems can improve nutrient use efficiency and utilization of solar energy while being environmentally friendly.

Efficient N management technology has become one of the most urgent requirements for sustainable agriculture in China. Researchers are trying to reduce N input directly by decreasing chemical N fertilization rates (Liu *et al*. 2011; Ruan *et al*. 2013; Yan *et al*. 2013) and combining chemical N with organic fertilizer or new fertilizer types (slow release or controlled release) to meet crop demand (Shoji *et al*. 2001; Fernández-Escobar *et al*. 2004; Meng *et al*. 2005; Noellsch *et al*. 2009). Previous studies have shown that optimal nutrient management strategies can significantly reduce N fertilization rate and increase crop yield, with multiple benefits for agriculture and the environment (Chen *et al*. 2006; Ju *et al*. 2009; Constantin *et al*. 2010; Ruan *et al*. 2013). In wheat-maize rotation cropping system, the total N fertilizer reduced from 430 to 360 kg N ha^{-1} with improved treatments, resulting in a maize yield increase by 7–14%, and a reduction in wheat yield, N_2O and NO emissions by 1–2, 7 and 29%, respectively (Liu *et al*. 2011). In addition, reduced N with optimal fertilization practices improve NUE, thereby reducing seasonal cumulative N_2O emission (Yan *et al*. 2013).

Global food demand is increasing with economic development and population growth. Especially, China feeds approximately 20% of the world's population with 7% of the world's farm land (Godfray *et al*. 2010; Tilman *et al*. 2011; Larson 2013). In China, the average unit grain yield increases from 1.09 tonne ha^{-1} in 1949 to 6.51 tonne ha^{-1} in 2014 (Zhou 2017). However, large amounts of soybeans are imported annually to meet the grain and soybean oil consumption in China. Relay intercropping and intercropping systems can be high-yielding, land-use efficient, and resource-efficient, and can efficiently control weeds, diseases and pests (Li *et al*. 2006; Corre-Hellou *et al*. 2011; Rodríguez-Navarro *et al*. 2011; Zuo *et al*. 2015; Wang *et al*. 2017; Yang *et al*. 2017). In particular, those systems including soybean crops can increase soybean yield with limited arable land. On one hand, legume-based cropping system can reduce N leaching by 50% compared with conventional systems (Drinkwater *et al*. 1998). Soybeans reduce N input requirements by biological nitrogen fixation, which meets 50–60% of N demand (Salvagiotti *et al*. 2008). On the other hand, fertilization methods have a significant impact on intercropped crops, with better performance when heterogeneous N was supplied at interspecific rather than intraspecific rows (Wu *et al*. 2014). Interspecific facilitation can increase resource use efficiency and land productivity without negative impacts on the environment (Oljaca *et al*. 2000; Li *et al*. 2001, 2003; Hochman *et al*. 2011). Therefore, soybean-based relay intercropping and intercropping systems, with improved fertilization methods can increase soybean yield and decrease environment costs. However, environmental factors, e.g., light, heat, and rainfall, can limit cropping systems. Intercropping systems are employed in areas with two (or three) crops a year, such as the Huang-Huai-Hai region in China (Liu *et al*. 2017), whereas relay intercropping systems are used in areas with one crop a year (or three crops in two years), such as in Southwest China (Yang *et al*. 2017).

Maize-soybean relay intercropping system can increase NUE, light use efficiency, and land productivity, which has become a major planting pattern in Southwest China (Gao *et al*. 2010; Yan *et al*. 2010; Xiang *et al*. 2012; Yang *et al*. 2014, 2017; Yong *et al*. 2015; Wang *et al*. 2017). Despite these benefits, few studies are focused on the lower N application rate and its application methods to maize-soybean relay intercropping system. The early study showed that crops performed better at lower N application rate (270 kg N ha^{-1}), and the fertilizer placement can increase grain yield (Dong *et al*. 2014). However, the lower N applied rate and fertilization methods on NUE and soybean biological nitrogen fixation are still unclear in the maize-soybean relay intercropping system. Therefore, this study was performed to test the optimized N management strategy for maize-soybean relay intercropping system in Southwest China. It was hypothesized that lower N input with optimized fertilization locations for maize-soybean relay intercropping system would increase NUE, N agronomy efficiency (NAE), and total yield compared with conventional N application rate and location. The objectives of this study were to: (1) investigate NUE, NAE and yield responses of crops to lower N and fertilization locations and to (2) determine ureide, leghemoglobin content, and nitrogenase activity responses of soybean to lower N and fertilization locations.

2. Materials and methods

2.1. Experimental site

The experiment was performed in Renshou County (29°40´–