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Effects of reduced nitrogen input on productivity and N_2O emissions in a sugarcane/soybean intercropping system

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ABSTRACT

A seven-year (2009–2015) continuous field experiment was established at the South China Agricultural University in order to identify the effects of sugarcane/soybean intercropping and reduced N rate on ecosystem productivity, yield stability, soil fertility, and N_2O emissions. The randomized block experiment was designed with four cropping patterns (sugarcane monocropping (MS), soybean monocropping (MB), sugarcane/soybean (1:1) intercropping (SB1), and sugarcane/soybean (1:2) intercropping (SB2)) and two rates of N fertilization (300 kg hm^{-2} (N1, reduced rate) and 525 kg hm^{-2} (N2, conventional rate)). The results showed that the land equivalent ratio (LER) of all intercropping systems was greater than 1 (between 1.10 and 1.84), and the SB2-N1 optimally improved the land utilization rate among all treatments. The cropping patterns and N applied rates had no significant effect on sugarcane yield. The soybean yield was influenced by different cropping patterns because of different planting densities (4, 8 and 16 rows of soybean were plant under SB1, SB2, and MB, respectively) and was adopted in this experiment. In addition, under the SB2 cropping pattern, the soybean yield at the reduced N application rate was higher than that at the conventional N application rate. Wricke's ecovalence (W_i^2), the sustainable yield index (SYI) and the coefficient of variation (CV) were used to evaluate yield stability. Different treatments had no significant effects on sugarcane yield stability, as demonstrated by three indicators (W_i^2, SYI and CV), which indicated that intercropping with soybean and reduced N rate had no effect on sugarcane yield. For soybeans, the value of W_i^2 demonstrated that the stability of the intercropping system was higher than its counterpart monocropping system, as SYI and CV values indicated that SB2 had higher stability than SB1. During seven years of experiments, there was no significant difference in the soil fertility between MS and SB patterns. The soybean monocropping had a higher available K, pH and lower available P content than sugarcane inter- and mono-cropping. Different cropping patterns had a slight impact on N_2O emissions and the greenhouse gas intensity (GHGI) value. Higher N input promoted N_2O emissions and increased GHGI values. In conclusion, the present study observed that a 40% reduced nitrogen input combined with intercropping soybeans could maintain sugarcane yield and soil sustainable utilization, and that higher N fertilizer additions induced negative impacts on greenhouse gases emissions. Sugarcane intercropping with soybeans can reduce chemical fertilizer input and simultaneously maintain crop productivity; thus, it can be considered to be a reasonable practice for field management.

1. Introduction

Sugarcane is an important crop for sugar and biofuel production (Rios do Amaral and Molin, 2014), and is widely grown in tropical and subtropical regions. Sugarcane contributes approximately 80% of global sugar production and 35% of ethanol production in the world (FAO, 2011). Generally, sugarcane is an exhaustive crop that heavily depletes soil nutrients especially nitrogen in the field. Zende (1990) estimates that sugarcane uptake 0.56–1.20 kg of N

Abbreviations: MS, sugarcane monocropping; MB, soybean monocropping; SB1, sugarcane/soybean (1:1) intercropping; SB2, sugarcane/soybean (1:2) intercropping; N1, N fertilization, 300 kg hm^{-2}; N2, N fertilization, 525 kg hm.

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for every ton of cane that is produced. In order to sustain productivity, usually a large amount of nitrogen is replenished into soil; however, N fertilizer uptake by sugarcane only accounts for approximately 20%–40% of the total N additions (Robinson et al., 2011). Sugarcane is planted with wide row spacing (80–140 cm) and initially slowly growth at the seedling and tillering stage (Li et al., 2013). Hence, wide row spacing and other natural resources (such as water, nutrients and light) are successful for intercropping with legumes in sugarcane fields during the long juvenile period (Manimaran et al., 2009). Some studies have shown that a legume/cereal intercropping system can induce legumes to fix more atmospheric N_2 by trigging the competition with neighboring intercropped crops (Nasielski et al., 2015; Hauggaard-Nielsen et al., 2003). Biological fixed N is then made available nitrogen to neighboring crops via N transfer (Ahmed et al., 2014; Carlsson and Huss-Danell, 2014), which improves the N uptake of the neighboring cereal or gramineous and also enriches nutrients content in soil-plant ecosystems (Amosse et al., 2014). For that reason, sugarcane intercropping with legumes is widely used for the benefit of complementary N use and other resources (Li et al., 2013).

In the last decade, the intercropping system was re-discovered as a sustainable and stable system when compared to its counterpart mono- system (Neamatollahi et al., 2013). Intercropping is a sustainable agricultural practice that enables the effective utilization of water (Xu et al., 2008), nutrients (Zhang and Li, 2003), and light (Mao et al., 2016). In addition to the benefits of resource utilization, intercropping systems can enhance crop health under water stresses as well. According to Nasielski et al. (2015), the soybean yield in tree-based inter-cropping was more stable than that of a mono- system under water stress.

N fertilizer in agricultural fields can be lost through many pathways, such as ammonia volatilization, nitrate leaching, and nitrous oxide (N_2O) emissions, which lead to ecosystem degradation and environmental pollution (Robinson et al., 2011; Franco et al., 2010). Many researchers have demonstrated that approximately 80% of anthropogenic N_2O emissions come from agriculture fields at a global scale (Reay et al., 2012; Smith et al., 2008). N_2O emissions from agricultural fields have increased by nearly 17% from 1990 to 2005 primarily due to increased synthetic N fertilizer consumptions (Ma et al., 2013). Applying a reasonable amount of N fertilizer and adopting diversified cropping patterns can remarkably reduce N_2O emissions from agricultural fields (Ashworth et al., 2015). An intercropping system is considered to be an effective measurement for reducing N_2O emissions in the field because it can reduce nitrogen input (Beaudette et al., 2010; Mutuo et al., 2005) through the benefit of complementary N use (Li et al., 2013). In addition, many studies have shown that intercropping systems could reduce the need for farm chemical compound input and that this approach is potentially resilient to environmental change, such as reduce disease, pests, and weeds. This consequently results in a higher yield and more stability than that of a mono- system (Uzokwe et al., 2016; Qin et al., 2013; Dyer et al., 2012).

However, most studies have focused on yield advantage and nutrient acquisition in intercropping systems (Wang et al., 2015; Li et al., 2011; Bedoussac and Justes, 2010), but few studies have focused on yield stability, soil fertility and N_2O emissions in intercropping over a long period. The hypothesis of the present study is that the intercropping system and reduced N input rate can maintain yield stability and mitigate N_2O emissions in sugarcane fields. In order to assess whether intercropping can maintain yield stability, soil fertility and mitigate N_2O emissions by using reduced N fertilizer level over a long period, the experiments were continuously carried out in the field for 7 years. The objectives of the present study were: 1) to test the advantage of land use efficiency and yield of sugarcane intercropped with soybean; 2) to assess the stability of crop yield and soil fertility of intercropping combined with reduced N input; 3) to measure N_2O emissions in the intercropping system with reduced N input.

2. Materials and methods

2.1. Field sites

The long-term experiment was conducted at a farm at the South China Agricultural University, Guangzhou, China (23°8′N, 113°15′E) from 2009 to 2015. Annual sunshine duration is 1289–1780 h, annual average precipitation was 1348–2278 mm, and annual average temperature was 21.9–22.8 °C(Fig. 1). The soil is a latosolic red soil, in the upper 30 cm, consisted of organic matter, available N, Olsen P, and K were 21.08 mg kg^{-1}, 75.38 mg kg^{-1}, 75.04 mg kg^{-1}, and 61.71 mg kg^{-1}, respectively.

2.2. Experiment design

The experimental design of this study was the same as Yang et al. (2013), described previously. A two factor design (4 cropping patterns and 2N rates) and 3 replicate plots were arranged randomly in the experiment. The cropping patterns included sugarcane monocropping (MS), soybean monocropping (MB), sugarcane/soybean (1:1) intercropping (SB1), and sugarcane/soybean (1:2) intercropping (SB2). The N rates were 300 kg hm^{-2} (N1, reduced rate) and 525 kg hm^{-2} (N2, conventional rate used by local farmers).

Each treatment was repeated three times with a plot area of 26.4 m^2 (5.5 m × 4.8 m). The row spacing of sugarcane was 1.2 m and soybean was 0.3 m in all treatments. Four rows of sugarcane in each treatment and 38 double bud seedlings were sown in each row. Three different planting densities with 4 (MS1), 8 (MS2), and 16 (MB) rows of soybeans in each plot and 25 holes were planted in each row.

Sugarcane was planted every year in February or March, depending on the weather conditions. Soybean was sown 7 days later after sugarcane planted. The cultivar of sugarcane was “Yuetang00-236” provided by the farm of the South China Agricultural University. The main characteristic of this cultivar was precocial, high yielding, high sugar content, with a high germination rate and strong tillering ability. The soybean cultivar was “Maodou No. 3.” provided by the Guangdong sub-center of the National Center for Soybean Improvement, which was precocial and high yielding. These varieties were representative and have been widely used in the South China area. Basal fertilizer for sugarcane monocropping and intercropping were applied before the sugarcane planted, including KCl at 150 kg hm^{-2}, Ca superphosphate at 1050 kg hm^{-2}, and compound fertilizer (N:P:K = 15:15:15) at 750 kg hm^{-2}. The first topdressing fertilizer was applied at the tillering stage of the sugarcane, including KCl at 150 kg hm^{-2}, and urea at 113 kg hm^{-2} or 225 kg hm^{-2} under N1 or N2, respectively. The second topdressing fertilizer was applied at the jointing stage of sugarcane and 295 kg hm^{-2} or 672 kg hm^{-2} of urea was applied under N1 or N2, respectively. No fertilizer was applied into the soil of soybean monocropping.

2.3. Sample collection and analytical methods

2.3.1. Sample collection

Plant samples were collected when the soybean or sugarcane at maturity stage from three biological replicates in the field. The soybean yield was measured by collecting all soybean pods in the middle row per the repetition of each plot in both of mono- and inter-cropping systems. The sugarcane yield was measured by collecting all stalks in the third row per the repetition of each plot in both systems. Soil samples were collected from three biological