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Research Paper

Rhizosphere soil properties and banana *Fusarium* wilt suppression influenced by combined chemical and organic fertilizations

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ABSTRACT

Combining chemical fertilizer with organic fertilizer is an important management strategy for maintaining soil fertility and disease suppression. Banana is an important cash crop in tropical regions and is severely threatened by *Fusarium* wilt disease. Little is known about the effects of combined fertilization on rhizosphere soil properties and disease suppression in tropical regions in China. In this study, the effects of combined fertilization on rhizosphere soil properties and the development of banana *Fusarium* wilt disease were assessed based on key components of soil chemical and biological properties. With chemical fertilization (CF) only, the soil urease, SOC and available nutrients contents were increased continuously, while the soil bacterial diversity, pH, and acid phosphatase activities were initially increased, and then decreased with increasing NPK application rate. Under low NPK application rate (25% CF), the OM addition was more effective in increasing soil bacterial diversity, pH, available nutrients, urease and acid phosphatase activities than NPK fertilization only. However, excessive OM addition had negative effect on soil available P and K content under high NPK application rate (100% CF). The T6 treatment of 50% CF + 500 organic matter (OM) had the highest integrated score among the treatments. Path coefficient analysis revealed that soil bacterial diversity plays the most important role in improving soil integrated score. The disease index was significantly and negatively linear correlated with the integrated score ($r = -0.92$, $P < 0.01$). These results demonstrate that an appropriate combination of organic and inorganic fertilizer application is effective at improving soil fertility and reduced disease incidence of banana.

1. Introduction

Chemical fertilizers can provide nutrients rapidly and effectively for plant growth and have been widely applied into fields over the past few decades in order to obtain higher crop yields worldwide (Blatt, 1991). However, excessive applications of chemical fertilizers have led to the degradation of soil fertility such as nutrient leaching, soil compaction, soil erosion and loss of organic matter (Calleja-Cervantes et al., 2015; Bogunovic et al., 2017a; Bogunovic et al., 2017b). Therefore, new strategies are urgently required to develop sustainable approaches for increasing soil fertility. The application of organic fertilizer improves soil fertility by providing a balanced and sustainable nutrient supply, increasing soil organic matter and biodiversity (Debosz et al., 2002; Sradnick et al., 2013; Xia et al., 2017). Previous studies revealed that the combined application of chemical and organic fertilizers is an efficient practice for maintaining soil fertility and productivity (Bhattacharyya et al., 2008; Bandyopadhyay et al., 2010).

Fertilization practices can lead to changes in soil biological and chemical properties. These changes have been associated with soil health and fertility (Garbeva et al., 2004; Janvier et al., 2007; Mazzola and Manici, 2012), which in turn influence the soil disease development (Senechkin et al., 2014; van Bruggen et al., 2015). A healthy soil is characterized by high microbial diversity and disease suppression (Keesstra et al., 2012; Khaledian et al., 2017). There are biotic and abiotic forms involved in soil suppression. The mechanisms include unfavourable living environment which direct inhibition of pathogens, competition for nutrients and space with pathogens, production of toxic metabolites, and induction of systemic resistance (Chen et al., 2012; Hadar and Papadopoulou, 2012).

The effects of fertilization practice on soil properties and disease suppression are complex and depend on variations in fertilizer types, soil properties, climate conditions and management practices (Keesstra et al., 2016; Parras-Alcántara et al., 2016; Yazdanpanah et al., 2016). For example, it is believed that N fertilization may affect soil microbial community structure (Shen et al., 2008). However, previous study has demonstrated that microbial community structure was not shifted after N fertilization when compared with unfertilized treatment (Ge et al., 2008). Although the impacts of fertilization on soil organic carbon

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(SOC) have been well documented, there are conflicting results in these studies. Previous study has reported that application of chemical fertilizer enhances soil SOC content (Yang et al., 2015). However, results in these work were not consistent with other studies (Mancinelli et al., 2010; Ayuke et al., 2011), which revealed that chemical fertilizer have no positive effects on SOC content. In addition, different soil management practices such as vegetation cover, seasonal and spatial variations can lead to changes in soil quality (Rodrigo Comino et al., 2016; García-Díaz et al., 2017).

Some soil chemical and biological properties can provide unique integrative assessment of soil function, and are considered as indicators of soil quality and fertility (Anderson, 2003; Schloter et al., 2003). These soil properties are affected by fertilization practices. For example, soil microorganisms are involved in many important soil biological processes, such as nutrient mineralization and cycling, soil organic matter transformation and residue decomposition (Bever, 2003). Soil microbial diversity is an important factor that determines soil fertility and can be influenced by fertilization management (Lupwayi et al., 2012). Urease, phosphatase and invertase play key roles in soil N, P and C cycles and are important indicators of soil quality (Zhao et al., 2009). An understanding of the impact of fertilization practice on these soil properties is particularly important in sustainability of agricultural management systems.

Plant diseases are responsible for major economic losses in the agricultural industry worldwide (Martinelli et al., 2015). Due to poor knowledge of fertilizer management, the accumulation of mineral fertilizer and nutrient deficiency in soil by fertilization practices are still widespread in tropical region in China (Yang et al., 2015; Hu et al., 2016). In this region, continuous cultivation of banana and excessive applications of chemical fertilizers leads to soil compaction, destruction of soil structure and organic matter deficiency (Qiao et al., 2012; Yan et al., 2013). In addition, the use of machinery increased the bulk density and penetration resistance, and the reducing use intensity of machinery could be effective in improving C, N sequestration and crop yield (Al-Kaisi et al., 2005; Bartimote et al., 2017). These soil management practices results in yield and quality of banana decline and serious occurrence of banana *Fusarium* wilt. Although the effects of combined fertilization practice on soil properties and disease development have been widely investigated, there is little information about the effects in this region. Assessing the impact will help to determine the relationship between soil fertility and fertilization management practices in tropical region in China.

In this study, the soil samples were collected from the rhizosphere soil of banana on tropical red loam in Southern China. The objectives of this study were (1) to evaluate the effects of different rates of combined fertilization on soil chemical, biological properties and soil fertility, and (2) to explore the correlations between soil fertility and disease suppressiveness to the *Fusarium* wilt of banana under different fertilizer management practices.

2. Materials and methods

2.1. Site description and experimental design

The fertilization experiment was located at the experimental farm of Chinese Academy of Tropical Agricultural Sciences, Haikou (20°05′N, 110°10′E), China (Fig. 1). The region has a typically subtropical monsoon climate with an annual mean temperature of 24 °C, and annual average precipitation of 1632 mm. The minimum monthly mean temperature is 15.4 °C in January and a maximum monthly mean temperature is 33.1 °C in July. The dominant parent material of soil is granite. The main soil type is montane lateritic soil. In the study area, the vegetation is dominated by banana, mango, and pineapple. The soils are classified as Udic Ferralsol in the World Reference Base for Soil Resources (FAO, 2014).

The soil had a sandy loam texture (clay 80 g kg^{-1}; sand 672 g kg^{-1}). The basic soil chemical properties at the start of the experiment were as follows: organic matter 12.7 g kg^{-1}, available nitrogen (N) 98.2 mg kg^{-1}, available phosphorus (P) 13.4 mg kg^{-1}, available potassium (K) 65.5 mg kg^{-1} and pH 5.9.

The experiment was initiated in April 2013. A continuous cropping of banana (*Musa acuminata Colla*, Cavendish subgroup cv. Brazil) was set up. After each cropping season, residue removal and tillage treatments were implemented, and next cropping season was continued. In the last cropping season, the banana was transplanted on 3 April 2015 and harvested on 27 November 2015. Treatments were arranged in a randomized block design with three replications. Each plot was 30 m^2 (5 m × 6 m) and with a density of 2500 plants ha^{-1}.

The rate of local farmers' chemical fertilization (CF) was: N, 400 g; P_2O_5, 200 g; K_2O, 800 g per plant in growing period and was named 100% CF in this study. This is equivalent to 1000 kg of N, 500 kg of P_2O_5 and 2000 kg of K_2O per hectare, respectively. Chemical N, P, and K fertilizers were applied as urea, calcium superphosphate and potassium sulfate, respectively. The nutrient ratio of the chemical fertilizer was 2:1:4 for N: P: K. The organic fertilizer contained 74% organic matter, 3% total amino acids and small molecular peptides, 1.2% N, 1.1% P_2O_5, and 0.7% K_2O. The organic fertilizer was produced by Beijing Eco-start Agriculture and Technology Co. Ltd., China, and is made up of well-rotted composting mixture of chicken manure and sheep dung (1:1 v:v), and the high-temperature drying method was adopted to storage. Trichoderma in the organic fertilizer were identified using dilution plate method and morphological characteristics, and the result showed that there were no Trichoderma in it. In this study, the fertilization rate was applied according to each banana tree. The rate of organic matter in this paper was calculated with dry matter. The treatments consisted of: control (CK): no fertilizer; T1: 25% CF; T2: 25% CF + 250 g OM (equivalent to 625 kg of OM per hectare); T3: 25% CF + 500 g OM (equivalent to 1250 kg of OM per hectare); T4: 25% CF + 750 g OM (equivalent to 1875 kg of OM per hectare); T5: 50% CF; T6: 50% CF + 250 g OM; T7: 50% CF + 500 g OM; T8: 50% CF + 750 g OM; T9: 100% CF; T10: 100% CF + 250 g OM; T11: 100% CF + 500 g OM and T12: 100% CF + 750 g OM.

As the treatments with the NPK fertilization only (T1, T5, and T9), after plantlet was transplanted, chemical fertilizers were applied six times onto the soil surface of the banana rhizosphere and plowed into the soil (0–20 cm depth) by tillage during the growing season of 20/April, 8/May, 1/June, 10/July, 4/September, and 2/November, respectively. The amount (%) of total chemical fertilizers in each time were 5%, 10%, 15%, 20%, 25%, and 25%, correspondingly. As the treatments with the combination of NPK and organic fertilization (T2, T3, T4, T6, T7, T8, T10, T11, and T12), before plantlet was transplanted, the 40% of the organic fertilizer (100 to 300 g organic matter per hole) was applied as basal fertilizer, and the remaining organic fertilizer was divided into six equal applications (25–75 g organic matter per plant) at the time when chemical fertilizers were applied. Chemical fertilizers and organic fertilizer were evenly spread onto the soil surface and immediately incorporated into the plowed soil. After fertilization, irrigation was performed immediately. During the growing season, no pesticides were applied. Other management practices such as field tillage and irrigation were the same as those of the local farmers and weeds were controlled manually.

2.2. Fusarium infection and disease assessment

In the last cropping of banana, the soils in each planting hole were inoculated with a 20 mL suspension of strain *Foc* 4 (isolated from banana plants in this region) with a concentration of 5 × 10^5 CFU mL^{-1}. Banana plantlets with eight leaves were transplanted into planting holes. This experiment was carried out from April to November in 2015. In late November 2015, the wilt disease incidence (DI) and severity were assessed according to the disease index on a scale of 0–5 (Saravanan et al., 2003). The disease index = [Σ(number of plants in