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Supplementing chemical fertilizer with an organic component increases soil biological function and quality

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ABSTRACT

The aim of this study was to investigate the impacts of organic-supplementation of a chemical fertilizer for improving soil biological activity, particularly towards disease suppression, in a drip-irrigated cotton system. Over a two-year field-based trial, our study characterized effects of partial substitution of chemical fertilizer with two types and amounts of organic components on the size, activity, carbon utilization potential, and culturable groups of pathogenic and antagonistic microbiota. The total microbial community size increased with application of chemical fertilizer ($P < 0.05$), and more so when chemical fertilizer was supplemented with organic amendments ($P < 0.05$). Alteration of microbial biomass carbon to nitrogen ratio, and the ratio of culturable bacteria and fungi, indicated that increases in the microbial community were underpinned by changes in bacteria. Enzymatic activity was greater in soils receiving fertilizer with organic supplement ($P < 0.05$). Multivariate analysis indicated that there was no influence of fertilizer treatments on carbon utilization profiles (CUPs; $P > 0.05$), but a strong year-effect was evident ($P < 0.05$). The population size of *Verticillium dahliae* and *Fusarium oxysporum* decreased with organic amendments ($P < 0.05$), whilst antagonistic *Trichoderma* spp. and *Bacillus* spp. were inversely correlated to the pathogen populations. Overall, the results of this exploratory study support partial substitution of inorganic fertilizer with organic manure or bio-organic fertilizer to promote suppression of cotton root diseases. Associated benefits on soil biological quality will further increase the sustainability of this agroecosystem.

1. Introduction

Cotton (*Gossypium* spp.) is the main crop grown in Xinjiang province (PR China). Cotton-based agriculture has continued to expand over the past two decades, and now accounts for 42% of the cultivated land area (Zhang and Chen, 2014). In some areas, cotton has been continually cropped for >30 years, and serious soil-borne diseases have emerged that severely restrict production and lower the efficiency of water and nutrient inputs. With the high value (and concomitant expansion) in cotton cultivation across Xinjiang and elsewhere, the effects of diseases are of increasing concern and methods for their sustainable control are being sought.

Diseases caused by the soil-borne pathogens *Verticillium* and *Fusarium* cause significant production loss for cotton and are also major pathogens of many other crops (Singleton et al., 1992). The control of diseases caused by these pathogens is difficult given their broad host range, their ability for saprophytic survival in the absence of a host, and the general difficulty in effective delivery of chemical pesticides for control of soil-borne fungi (Parker et al., 1985).

The natural suppression of soil borne plant diseases offers a sustainable and economically effective means to maintain agricultural production. Suppressive soils are typically characterized as being of general- or specific-suppression to diseases, or having a combination of both properties (Weller et al., 2002). Regardless, the phenomenon is often due to the activities of soil microorganisms that directly or indirectly compete with the pathogenic flora for resources (energy) or space (e.g., root surface).

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Thus, an increase in the disease suppressive capacity of a soil may be due to a number of factors, such as alteration in community composition, increased overall community size, increased activity per unit size, or alteration in a specific function (e.g., antibiotic production).

Many agricultural practices can change the size, structure, and activity of soil microbial communities. In particular, alteration of the nutrient status of soil has been shown to impart large phylogenetic and functional changes in the soil ecosystems (e.g., Wakelin et al., 2013). Where these changes result in increased competition for space or resources, or enrichment in groups of suppressive microorganisms such as antibiotic producing *Actinobacteria* or *Bacillus* bacteria or *Trichoderma* fungi (Weller et al., 2002), increased disease suppression may ensue.

The increase of soil organic matter through using inputs of animal and/or plant material is a primary mechanism to increase the overall size and activity of the soil microbial biomass (Sánchez-Monedero et al., 2008). Although this has been used to increase disease suppression in soils (Bailey and Lazarovitis, 2003), the method will have limited value in broad-acre systems, and particularly those where low net-primary-productivity restricts availability of organic resources, and where organic nutrient costs are high. All these above mentioned are typical of systems such as drip-irrigated cotton in the low rainfall area of Xinjiang province (Wang et al., 2014). Furthermore, in these systems the local farmers depend primarily on chemical (inorganic) fertilizer to increase soil fertility. However the substitution of a component of the chemical with organic fertilizer may allow for increased adoption of this practice as not only improves soil biological fertility, but also minimizes economical risk to growers which caused by low crop yield duo to soil-borne disease occurrence.

A pragmatic way to increase soil microbial biomass, microbial activity, or to drive changes in community composition, may be the partial (e.g., local conventional NPK level reduced 20–40%) of chemical fertilizers displaced by organic or bio-organic fertilizer. This approach has not been widely evaluated for its impact on microbial community composition, nor community function, but may represent a balance whereby soil fertility, and cotton productivity and profitability are maintained. Currently, many other methods of soil-borne disease control include use of fungicidal and bactericidal agents that lead to the economic and environmentally unsustainable outcomes. As such, the aims of this project were to investigate the response of the soil microbial community under drip irrigated cotton to alterations in fertilizer inputs. As it is impractical for farmers to use high inputs of organic matter, the supplementation of mineral fertilizer with two rates of different organic material was investigated. Specifically we determined if organic supplementation affected the size of the soil microbial community, rates of soil processes (enzyme activity), the diversity of community functions (catabolic utilization profiles), and populations of culturable groups including the plant pathogenic fungi *Verticillium* and *Fusarium*, and the antagonistic groups *Trichoderma*, *Actinobacteria*, and *Bacillus*.

2. Materials and methods

2.1. Site and soil description

Field experiments were carried out at the agricultural experimental station (E84°58′–86°24′, N43°26′–45°20′), Shihezi University, Xinjiang province, PR China. At the site, a long-term (approximately more than 20 years) field site with continuous replanting of cotton under drip-irrigation conditions. The average irrigation rate was 300–350 m^3 during cotton plant growth stage, and rates of NPK were 300–375 kg N/ha, 90–120 kg P_2O_5/ha and 60–90 kg K_2O/ha, respectively. No organic substances had been to the field during the two decades of cultivation history prior to the study. The mean annual temperature is 7.5–8.2 °C, and rainfall and evaporation are between 180 and 270 mm, and 1000–1500 mm, respectively. The soil is a cultivated grey desert soil (Calcaric Fluvisol) with the following physicochemical properties: pH 8.1, soil organic carbon 13.5 g/kg, total N 0.95 g/kg, total P 0.3 g/kg, alkali-hydrolysable N 88.6 mg/kg, available P mg/kg, and available K 136 mg/kg.

2.2. Experimental design

The experimental was setup using a completely randomly design, and carried out during the 2011 and 2012 cotton growing season. The site had a 2-year history of consecutive fertilization. For the experiment, plots were sown to cotton (*Gossypium hirsutum* L.) variety Xinluzao No. 46 (traditional variety). Treatments consisted of: (1) CK: no fertilizer (control); (2) CF: chemical fertilizer (300 kg N/ha, 90 kg P_2O_5/ha, and 60 kg K_2O/ha); (3) 80% CF + OF (80% CF plus cattle manure at 3000 kg/ha); (4) 60% CF + OF (60% CF plus cattle manure at 6000 kg/ha); (5) 80% CF + BF (80% CF plus bio-organic fertilizer at 3000 kg/ha); (6) 60% CF + BF (60% CF plus bio-organic fertilizer 6000 kg/ha). For each treatment (Table 1), three replicate 90 m^2 (20.0 m × 4.5 m) plots were established. Two application rates of bio-organic or cattle manure were broadcasted evenly on the surface of soil in each treated plot, and then organic fertilizers were mixed thoroughly into the top 0–20 cm soil layer in spring using a rotary cultivator (fifteen days prior to cotton sowing). Chemical fertilizers were applied eight times through fertigation and were distributed over the season at cotton growth periods of 10/June, 24/June, 5/June, 14/July, 44/July, 2/August, 12/August, 22/August, respectively. The amount (%) of chemical fertilizer account for total NPK in each time were 7%, 10%, 10%, 20%, 20%, 15%, 10%, and 8%, correspondingly.

A field-based experiment was used to test the influence of addition of organic fertilizers to mineral (hereafter ‘chemical’) fertilizers on soil properties. The chemical fertilizer consisted of a blend of urea (N 46%), potassium ammonium phosphate (N 5%, P_2O_5 24%), and potassium phosphate monobasic (P_2O_5 52%; K_2O 31.8%). Two forms of organic fertilizer were tested: cattle manure (organic matter 24.8%, total N 1.7%, i.e., 3000 kg/ha = 51 kg of N, etc.), and a bio-organic fertilizer (organic matter 29.7%, total N 4.4%, pH 7.6, i.e., 3000 kg/ha = 132 kg of N, etc.) containing approximately 0.5×10^9 CFU/g bacteria along with various small molecular peptides, chicken manure is main medium (developed by Nanjing Agricultural University and supplied by Jiangsu Xintiandi amino acid fertilizers Ltd., China). Hereafter the manure-based fertilizer is referred to as ‘manure’, that developed by Nanjing Agricultural University as ‘bio-fertilizer’.

Table 1
Details of the six fertilizer treatments used in the field experiment.

Treatment	Rate of application
CK[a]	No fertilizer added
CF[b]	300 kg N/ha; 90 kg P_2O_5/ha; 60 kg K_2O/ha
80% CF + OF[c]	80% CF plus common organic fertilizer 3000 kg/ha
60% CF + OF	60% CF plus common organic fertilizer 6000 kg/ha
80% CF + BF[d]	80% CF plus bio-organic fertilizer 3000 kg/ha
60% CF + BF	60% CF plus bio-organic fertilizer 6000 kg/ha

[a] CK = check/control.
[b] CF = chemical fertilizer (mineral or inorganic fertilizer).
[c] OF = organic fertilizer.
[d] BF = biological fertilizer.