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Effects of tillage practices and microbial agent applications on dry matter accumulation, yield and the soil microbial index of winter wheat in North China

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ABSTRACT

Using microbial agents combined with chemical fertilizers is a promising approach to maintain the soil microbiota balance in continuous wheat–crop rotation fields. Most previous studies focused on microbial agents applied in the topsoil, with limited studies investigating the effects microbial agents under different tillage practices on soil quality and crops growth. In this study, a field experiment was conducted using a two-factor randomized block design (tillage practices and fertilizer applications) with three replicates, the effects of conventional rotary tillage and deep plowing when applying two different types of microbial agents (ETS and JS) on the dry matter accumulation, yield, soil microbial index and soil respiration of winter wheat (*Triticum aestivum* L.) in north China. The results indicated that wheat grain yield was not decreased after the application of different microbial agents plus 70% of the normal amount of chemical fertilizer and that the straw yield was decreased by 19.1% and 16.4% when ETS and JS, respectively, were individually applied. Additionally, there were no differences in grain and straw yields between the different tillage practices. The aboveground dry matter accumulation increased by 47.5% with ETS application under conventional rotary tillage compared with applications of chemical fertilizer. Under conventional rotary tillage, applications of different microbial agents decreased the microbial biomass C (MBC) concentration by 35.2–42.3% compared with applications of chemical fertilizer, while, the microbial biomass N (MBN) concentration increased by 10.0–18.5% in the 0–20-cm soil layer. With deep plowing, the soil respiration rate was greater than under conventional rotary tillage. In addition, the soil respiration rate after the application of the ETS plus JS combination with deep plowing was greater than after the microbial agents were individually applied during wheat's growth period.

1. Introduction

In the past 30 years, China's grain production has achieved significant growth, and in 2016, China's total grain output reached 616.239 million tons. The increase in grain production is partially due to the large-scale use of chemical fertilizers. According to statistics, the amount of chemical fertilizers used per ha of crops in China was 328.5 kg in 2015, which was much greater than the national average of 120 kg per ha, and was 2.6 times that of the USA and 2.5 times that of the European Union (Zhao and Yin, 2015). The long-term and excessive use of chemical fertilizers causes lower fertilizer efficiencies and increases production costs. Currently, the fertilizer efficiency rate in China is only ∼30% (Zhao et al., 2008), about half those of developed countries, such as the USA and those in the European Union. In addition, chemical fertilizer use creates secondary problems, such as environmental pollution, soil compaction, soil fertility declines, ecological deterioration and crop quality reductions (Guo et al., 2010). The status quo, if continued in China, will reduce the quality of agricultural products and also destroy the balance between the coordinated development of agricultural production and the environment (Chen, 1982; Han et al., 2018).

The application of a chemical fertilizer mixed with a microbial agent is regarded as an efficient way of regulating soil microbial community structure by promoting beneficial bacteria and suppressing

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pathogens (Zhang et al., 2013; Raza et al., 2017). Microbial fertilizers are living organisms undergoing life activities, and their products lead to specific fertilizer effects on crops. Because of the different microorganisms residing in microbial agents, the use of a particular microbial agent will affect the richness of the soil, change the nutrient circle and optimize the structure (including composition and temporal-spatial characteristics) of soil ecosystems, thereby affecting soil health (Wu, 2017). As early as the beginning of the 20th century, organic fertilizers containing azotobacter have been studied (Bowen and Rovira, 1999; Amarger, 2001). At present, microbial agents have been shown to improve soil structures, alter soil microflora, and control soil-borne diseases and agricultural nonpoint pollution (Yao et al., 2010; Tao et al., 2015; Xiong et al., 2017; Yilmaz and Sönmez, 2017). He et al. (2015) isolated plant growth-promoting bacteria from saline soil in a cotton field, and develop efficient slow-release biofertilizer formulations with this special bacteria. Pishchik et al. (2015) investigated the effects of a fertilizer having *Bacillus subtilis* as the main component on the physiological status of wheat. Wheat had an enhanced resistance to the adverse impacts of high rates of nitrogen (N) fertilizer owing to the rearrangement of bacteria in the rhizosphere's ecological niches by the applied microbial agent. Andreev et al. (2016) applied microbial fertilizer based on a Lacto-fermented mix of feces on maize planting experiment. The height of corn plants after the application of microbial fertilizer significantly increased, but there was no significant difference in the corn yield. Applying a microbial fertilizer (seed inoculation with *Azotobacter chroococcum* and *Peudomoance fluorescence*) plus half the normal amount of chemical fertilizer was successfully used for fenugreek, a legume, production, minimizing the consumption of chemical fertilizers and improving fenugreek yield, especially under deficit irrigation regimes (Dadrasan et al., 2015).

Currently, microbial agents are generally used in traditional methods of fertilization by combining with organic fertilizers and straw return. Some antibiotic microbial agents have been used in seed dressing. These traditional methods place microbial agents only on the soil surface and do not show distinct effects on deeper soil. Long-term traditional tillage compacts soil, which maintains the stability of soil structures to some extent but increases the bulk density of deep soils and hinders root growth (Zhang et al., 2011). Deep plowing could take advantage of the nutrient subsoil and improve the adaptability of crops by destroying the surface soil structure (Schneider et al., 2017). Different tillage practices may have relatively high impacts on the use efficiencies of different fertilizers and on crop growth (Wang et al., 2015; Seddaiu et al., 2016). However, there are limited reports on the effects of using microbial agents in different tillage practices on soil quality and crops growth.

At present, most microbial agents are applied to the topsoil and produce excellent results, but limited effects focused on the subsoil. In this study, a field experiment was conducted using a two-factor randomized block design – fertilization and the tillage practice. The aim of this study was, (1) to investigate the effects of the microbial agents on the dry matter accumulation (DMA), yield and soil respiration of winter wheat; (2) to compare the effects of microbial agents under conventional rotary tillage and deep plowing practices; (3) to discuss the feasibility of partially replacing chemical fertilizers with microbial agents under different tillage practices on the production of an efficient and dependable winter wheat crop in northern China

2. Material and methods

2.1. Study site

The field experiment was conducted from October 2016 to June 2017 at the Yucheng Comprehensive Experiment Station of the Chinese Academy of Sciences (116°36′E, 36°57′N, 21.2 m above sea level), Dezhou, Shandong Province, northern China. This site is representative of agriculturally intensive areas of the North China Plain that have an annual mean temperature of approximately 13.1 °C and precipitation of 593.2 mm. The soil type is fluvo-aquic, and the soil texture is silt loam (sand, 12%; silt, 66%; clay, 22%). Detailed soil characteristics at the experimental site are shown in Table 1.

Table 1
Soil characteristics at the experimental site.

Parameter	Values
Bulk density ($g{\cdot}cm^{-3}$)	1.46
$EC_{1:5}$($ds{\cdot}m^{-1}$)	0.17
Ph^{water}(1:2.5)	8.00
Total organic matter (%)	1.50
Total N ($g{\cdot}kg^{-1}$)	0.64
Total P ($g{\cdot}kg^{-1}$)	0.84
Total K ($g{\cdot}kg^{-1}$)	19.99

Values are means (n ≥ 3) with standard deviations.

2.2. Experimental design

Winter wheat was used in our experiment. A field experiment was conducted using a two-factor randomized block design with three replicates. The main factors were the tillage practices of conventional rotary tillage and deep plowing (DT). The secondary factors were the fertilizer applications, which consisted of the normal amount of chemical fertilizer and a reduced chemical fertilizer level plus two types of microbial agents (used individually). The microbial agents were provided by ETS Biotechnology Development Company, Ltd. (Tianjin, China). The two tested microbial mixtures were a microbial organic fertilizer agent (ETS; Fertilizer registration certificate No. 2011-0801 according to the Chinese Ministry of Agriculture) and a microbial decomposition agent (JS). Seven treatments were designed for winter wheat planting, TF (rotary tillage with chemical fertilizer), TE (rotary tillage with ETS plus 70% the normal amount of chemical fertilizer), TJ (rotary tillage with JS plus 70% the normal amount of chemical fertilizer), TEJ (rotary tillage with the combination of ETS and JS, plus 70% the normal amount of chemical fertilizer), DTE (deep plowing with ETS plus 70% the normal amount of chemical fertilizer), DTJ (deep plowing with JS plus 70% the normal amount of chemical fertilizer), DTEJ (deep plowing with the combination of ETS and JS, plus 70% the normal amount of chemical fertilizer). Details of the application rates of the chemical fertilizer and microbial agents per treatment are presented in Table 2.

Winter wheat (*Triticum aestivum* L.) 'Jimai 22' was planted on October 18, 2016 and harvested on June 16, 2017. A combined chemical fertilizer (N 26%, P 12% and K 10%, respectively) was used at a normal amount of 865 $kg{\cdot}ha^{-1}$ (225 kg $N{\cdot}ha^{-1}$). This was divided into two equal parts, one was applied as the base fertilizer and the other was applied at the jointing stages. Tillage was carried out before winter wheat sowing, and the experimental area (5 m × 5 m, 25 m^2) was fixed with a cell spacing of 50 cm A rotocultivator was used for conventional

Table 2
Details of the seven tillage and microbial agent application treatments used in the field experiment.

Treatment	Tillage practices	Straw returning depth	Chemical fertilizer	ETS($kg\ ha^{-1}$)	JS($t\ ha^{-1}$)
TF	Conventional rotary tillage	Uniformly distributed	225 kg $N\ ha^{-1}$		
TE	(working	in 0-15 cm	70% TF	3000	
TJ	depth of 10-		70% TF		30
TEJ	15 cm)		70% TF	3000	30
DTE	Deep plowing	Uniformly	70% TF	3000	
DTJ	(over 35 cm)	distributed	70% TF		30
DTEJ		in 0-35cm	70% TF	3000	30