Soil & Tillage Research 163 (2016) 21–31

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Original paper

Long-term ditch-buried straw return alters soil water potential, temperature, and microbial communities in a rice-wheat rotation system

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ARTICLE INFO

Article history:
Received 6 January 2016
Received in revised form 27 April 2016
Accepted 4 May 2016
Available online 20 May 2016

Keywords:
Straw incorporation
Soil water
Soil temperature
Microbial community
Rice-wheat rotation system

ABSTRACT

As a novel soil tillage practice, ditch-buried straw return (DB-SR) has exhibited positive effects on soil carbon sequestration, nitrogen retention and rice yield in previous studies. However, little is known about how long-term DB-SR affects soil hydrothermal and microbial processes. Our objective is to test whether DB-SR will alter the soil water potential, temperature and microbial community in a wheat field following rice cultivation. In this study, we found significant alterations in soil water potential, temperature, and microbial communities driven by DB-SR. On average, soil water potential was significantly reduced by 37.33% and 17.56% under DB-SR to a depth of 20 cm (DB-SR-20) and 40 cm (DB-SR-40), respectively. DB-SR-20 increased soil mean daily temperature and daily range of temperature more than DB-SR-40, possibly caused by decreased water content, especially at soil depths of 10 and 15 cm. Both DB-SR-20 and DB-SR-40 led to distinct shifts in soil bacterial and fungal community composition. DB-SR-20 significantly increased the activities of peroxidase, cellobiohydrolase, urease, and acid phosphatase by 3.5%, 75.0%, 81.4% and 41.7%, respectively, but had no effects on β-D-glucosidase activity. DB-SR-40, in contrast, significantly increased the activities of peroxidase and cellobiohydrolase by 2.4% and 36.0%, respectively, but showed no effects on urease and acid phosphatase. It did, however, reduce β-D-glucosidase activity by 15.0%. Overall functional diversity was increased by 29.9% under DB-SR-20 but was not affected by DB-SR-40. Our results suggest that these improvements in soil ecological processes driven by DB-SR will promote wheat yield in a rice-wheat rotation system.

1. Introduction

In recent years, the question of how to effectively manage crop residues has become an important issue for the Chinese government. In order to save time, straw residues are frequently burned in the open field after harvest, causing severe air pollution and increased haze weather. China produces approximately 0.8 billion tons of crop residue per year, of which 16.8% are discarded or burned in open fields and 14.1% are returned to the soil (Bi et al., 2009; Bi, 2010). However, crop straw contains a significant quantity of nutrients and micro-elements, and thus the burning of straw causes some of these renewable resources to be transformed into small particulate matter or volatile gas, which is then lost into the atmosphere (Chen et al., 2012). In addition, straw burning reduces soil organic matter accumulation and microbial diversity (Zhang et al., 2014). Thus, incorporation of straw into soils may be an improvement over burning. However, little is known about the effects of straw incorporation on soil ecological processes in China.

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http://dx.doi.org/10.1016/j.still.2016.05.003
0167-1987/

Straw incorporation into the soil is an important management practice in global organic agriculture (Seufert et al., 2012). Studies have demonstrated the positive effects of straw incorporation on several soil ecological processes. For example, straw incorporation may improve soil structure and promote soil aggregation by increasing the production of fungal hyphae capable of enmeshing microaggregates, thus decreasing soil bulk density (Lenka and Lal, 2013; Peng et al., 2013). Soil hydrothermal processes may also be altered after the addition of straw, leading to changes in water dynamics and soil temperature (Liu, 2010; Lenka and Lal, 2013; Chen et al., 2014; Yuan et al., 2014). Moreover, the organic acids released during straw decomposition can activate organic phosphorus, leading to an increase in soil nutrient availability (Shan et al., 2008). Nitrogen (N) mineralization and N use efficiency are also enhanced after straw incorporation (Said-Pullicino et al., 2014; Pan et al., 2013). The input of a large quantity of straw-derived carbon into the soil stimulates microbial processes and produces a strong response in soil microbial community composition and functioning (Zhao et al., 2014a,b). Thus, we hypothesize that straw incorporation may promote crop growth and yield by improving various soil ecological processes.

A rice-wheat rotation is the main farming practice in the Yangtze River delta agricultural region (Zhu et al., 2014). This agricultural region accounts for 20% of the total farmland and 22% of the total rice/wheat yield in China (Editorial Board of China Agriculture Yearbook, 2012). The rice-wheat agroecosystems are characterized by high chemical N input and high grain yield but also high straw residues. It is difficult for local farmers to effectively manage straw residues in the two weeks between successive crops in the rotation. To save time, straw residues are traditionally burned in open fields. However, straw burning causes severe soil degradation and air pollution (Zhang et al., 2014). Thus, it has now been forbidden by Chinese laws.

Straw incorporation has been advocated in the rice-wheat rotation system. However, there are drawbacks to conventional rotary tillage with straw return (RT-SR), in which straw is crushed during harvesting and then incorporated into the soil by rotary tillage. RT-SR is not able to incorporate all of the straw produced, especially after the rice season (Chang et al., 2014). Increased emission of trace gases is also frequently reported under RT-SR practice (Ma et al., 2009; Zou et al., 2005). Moreover, RT-SR mixes fragmented straw with soil in the plough horizons, which may negatively affect tillage, inhibit seed emergence and seedling establishment, and cause N competition between crop seedlings and soil microbes (Zha et al., 2013; Zhang, 2014; Yang et al., 2015).

In order to overcome the shortcomings of the conventional straw incorporation method, we have developed a novel soil tillage practice that combines straw incorporation and deep ploughing: ditch-buried straw return (DB-SR) (Zhu and Bian, 2010). DB-SR is currently under evaluation, and methodological details are described in previous studies (Wang et al., 2015; Yang et al., 2015, 2016). In these studies, we found that not only is DB-SR able to achieve complete straw incorporation, but it also improves soil C and N processes by increasing C sequestration and N retention and reducing N leaching. Despite these advantages, little is known about how DB-SR regulates soil hydrothermal processes, which in turn affect microbial communities and their functioning. Thus, in this study, we assessed the role of DB-SR on soil hydrothermal and microbial processes. We hypothesized that DB-SR would produce positive effects on soil hydrothermal properties and microbial community structure and functioning in the wheat field following rice cultivation.

2. Materials and methods

2.1. Experimental site description

This study was conducted at the experimental fields of the Academy of Agricultural Sciences of Nantong City (32°13′N, 120°63′W). The farming system was a winter wheat (*Triticum aestivum* L.) – summer rice (*Oryza sativa* L.) rotation. This region has a humid, mid-subtropical monsoon climate with an average annual temperature of 14.4 °C, mean annual radiation of 2078.4 h, and mean annual precipitation of 1057.1 mm. The soil is classified as gleyi-stagnic anthrosol with sandy loam texture and contains 20.45 g/kg organic matter, 1.62 g/kg total N, 12.75 mg/kg available phosphorus (P), and 44.41 mg/kg available potassium (K) in the 0–20 cm soil layer.

2.2. Experimental design and farm management

The field experiment was a randomized complete block design with three treatments: control (straw removal after harvest), DB-SR to a depth of 20 cm (DB-SR-20), and DB-SR to a depth of 40 cm (DB-SR-40). Each treatment was replicated three times for a total of nine plots. Each experimental plot was 18 m^2 (3 m × 6 m). Three ditches (20 cm wide and 2 m apart) per plot were hand-dug and their positions were rotated after each crop season. After harvesting, the straw was sun-dried, bundled, weighed, and transferred to the field ridge for further treatment. Ditches were then hand-dug in the fields at specific locations and depths. The straw bundles were arranged, placed into the ditches, repressed, covered with soil, and overburdened. Afterwards, the entire field was shallow-rotary tilled to a depth of 3–5 cm. All of the straw produced was incorporated in the two DB-SR treatments, a total of 10,000 kg ha^{-1} for rice and 5000 kg ha^{-1} for wheat. The thickness of the newly buried straw layer was approximately 7 cm and was located 14–20 cm from the field surface; thus, the soil layer was above the straw layer and was approximately 13 cm thick (0–13 cm from field surface). Once this was completed, conventional management practices were performed, including fertilization, soil preparation, and sowing for wheat or rice transplanting.

The experiment was initiated after the rice season in November 2008. Winter wheat (var. Yangmai 13) and summer rice (var. Nanjing 44) were used in the field experiment. Winter wheat was manually planted in early November with a seed quantity of 150 kg ha^{-1} or ~375 seeds m^{-2}. Rice seedlings were raised in mid-May and transplanted manually in mid-June with 25 cm × 15 cm between hills and rows.

Compound fertilizer (N: P_2O_5: K_2O = 15:15:15) and urea [$CO(NH_2)_2$, N = 46.4%) were utilized for both crop seasons. The total amount of nitrogen applied during rice season was 300 kg ha^{-1}, with 60% applied initially, 30% applied at tillering, and 10% applied at the grain-filling stage. Because of the sandy loam texture, the soil exhibited weak N maintenance. A relatively high amount of N fertilization is therefore commonly utilized in local rice production systems to meet the high yield standard. The total nitrogen application over the wheat season was 180 kg ha^{-1}, with 70%, 10%, and 20% applied at the initial, tillering, and grain-filling stages, respectively. Both phosphate (P_2O_5) and potassium (K_2O) fertilizers were used as basal fertilizers. The total amount of P was 130 kg ha^{-1} for rice and 80 kg ha^{-1} for wheat. The total amount of K was 250 kg ha^{-1} for rice and 150 kg ha^{-1} for wheat. Water, weed, and pest management practices were similar to local conventional production for rice and wheat.