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RESEARCH ARTICLE

Effects of Long-Term Winter Planted Green Manure on Distribution and Storage of Organic Carbon and Nitrogen in Water-Stable Aggregates of Reddish Paddy Soil Under a Double-Rice Cropping System

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Abstract

In agricultural systems, maintenance of soil organic matter has long been recognized as a strategy to reduce soil degradation. Manure amendments and green manures are management practices that can increase some nutrient contents and improve soil aggregation. We investigated the effects of 28 yr of winter planted green manure on soil aggregate-size distribution and aggregate-associated carbon (C) and nitrogen (N). The study was a randomized completed block design with three replicates. The treatments included rice-rice-fallow, rice-rice-rape, rice-rice-Chinese milk vetch and rice-rice-ryegrass. The experiment was established in 1982 on a silty light clayey paddy soil derived from Quaternary red clay (classified as Fe-Accumuli-Stagnic Anthrosols) with continuous early and late rice. In 2009, soil samples were collected (0-15 cm depth) from the field treatment plots and separated into water-stable aggregates of different sizes (i.e., >5, 2-5, 1-2, 0.5-1, 0.25-0.5 and <0.25 mm) by wet sieving. The long-term winter planted green manure significantly increased total C and N, and the formation of the 2-5-mm water-stable aggregate fraction. Compared with rice-rice-rape, rice-rice-Chinese milk vetch and rice-rice-ryegrass, the rice-rice-fallow significantly reduced 2-5-mm water-stable aggregates, with a significant redistribution of aggregates into micro-aggregates. Long-term winter planted green manure obviously improved C/N ratio and macro-aggregate-associated C and N. The highest contribution to soil fertility was from macro-aggregates of 2-5 mm in most cases.

Key words: green manure, organic carbon, reddish paddy soil, total nitrogen, water-stable aggregates

INTRODUCTION

Green manure is a traditional organic manure in China and has been used since ancient times. The planting area using green manures in China is the largest in the world. Production and application of green manure have played an important role in food production and improving soil fertility. Despite the long history of green manure in China, farmers have had little enthusiasm to improve soil fertility since the 1980s. This has been mainly due to the low economic benefit of green manure in rice production and the large labor force required for winter planting of green manure. Meanwhile, the obvious benefits of artificial fertilizers have been greatly promoted. The yield increase from incorporating green manure in the year of application is not as obvious with the same investment in artificial fertilizer. Since the mid-twentieth century, the area devoted to producing green manure has

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gradually reduced. With the development of market economy and people's increased demand for green food (i.e., safe, nutritious and non-polluting), a higher quality of agricultural products is also needed. Therefore, green manure planting had again received widespread interest. Since 2006, the planting area of green manure in China has increased to 2.7 million ha. In 2008, the seeded area utilizing green manure was 437 million ha. The total weight of green manure produced was 9 339 million t and the amount incorporated into soil was 4 558 million t. The green manure in the southern region of Yangtze River is mainly used to improve soil fertility by being returned to the field. Green manure is one of the cleanest organic manure resources, with no heavy metals, antibiotics, hormones and other residual hazards. The large amount organic matter in green manure helps improve soil microbial properties and quality of arable land. Additionally, the nutrients contained can substitute for artificial fertilizers to some extent. Green manure not only improves crop yields and soil fertility but can also improves the quality of agricultural products (Yang *et al*. 2010; Xu 2011).

Application of organic manures can help in forming soil aggregates and improving their stability. Li *et al*. (1999) showed that application of green manure could increase the content of >0.25-mm water-stable aggregates. Jiang *et al*. (2010) found that application of green manure could help transform smaller water-stable aggregates into larger ones, and increased the content of those >0.25 mm. Long-term winter planting of green manure, especially of Chinese milk vetch (*Astragalus sinicus* L.), can increase the content of 0.25-5-mm water-stable aggregates in soil (Yang *et al*. 2012). Chen *et al*. (2009) showed that long-term application of Chinese milk vetch green manure increased the content of >2-mm but decreased that of <1-mm water-stable aggregates in the plowed soil layer, and increased the content of organic carbon in all sizes except the 0.25-0.5 mm and the content of total nitrogen of all aggregate sizes. In the plowed soil layer, organic carbon (C) was preferentially enriched in >1-mm aggregates. Application of inorganic fertilizer and organic manure both have a large impact on the distribution of organic C and nitrogen (N) in soil aggregates; and the larger the aggregates, the more organic C and N will be contained.

Paddy soil is one of the most important agricultural lands in China and research on this soil has been long considered of great importance. Reddish paddy soil at the Key Field Monitoring Experimental Station for Red Soil Eco-Environment of the Ministry of Agriculture, Qiyang County, Hunan, China, was used in the present study. In recent years, researchers have studied the effects of winter planting of green manure on rice yield (Gao *et al*. 2013), weed species diversity (Xie *et al*. 2011), microbial properties, enzyme activities (Yang *et al*. 2011a), quality (Yang *et al*. 2011b) and physical properties (Yang *et al*. 2012) of reddish paddy soil. However, there have been few studies of the distribution and storage of organic C and N in water-stable aggregates in reddish paddy soil with long-term winter planted green manure under double-rice cropping system in the Yangtze River. This study will provide a better understanding of how long-term (28 yr) winter planting of rape (*Brassica napus* L.), Chinese milk vetch and ryegrass (*Lolium perenne* L.) affect the content, distribution and storage of organic C and N in water-stable aggregates in the plowed layer of a reddish paddy soil under a double-rice cropping system.

RESULTS

Effect of long-term winter planted green manure on the content and distribution of organic C and total N in different sizes of water-stable aggregates in the plowed soil layer

Effect on the content and distribution of organic C After 28 yr of continuous cultivation of rice, the effects of winter planting of different green manures on the size of water stable aggregates of the plow layer soil were inconsistent (Table 1, Yang *et al*. 2012). The content of organic C of the plowed soil layer (0-15 cm depth) of long-term winter planted green manure (hereafter termed winter green manure) and of long-term winter fallow treated plots (hereafter termed winter fallow plots) differed significantly ($P<0.05$). The soil organic C (SOC) content was significantly higher in plots receiving winter green manure than winter fallow ($P<0.05$). Specifically, the SOC contents of the rice-rice-rape (R-R-RP), rice-rice-Chinese milk vetch (R-R-MV) and rice-rice-ryegrass (R-R-RG) plots were 8.0, 4.8 and 6.7% higher than those of rice-rice-fallow (R-R-WF), respectively. The