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Straw return and appropriate tillage method improve grain yield and nitrogen efficiency of winter wheat

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Abstract

Straw return is an important management tool for tackling and promoting soil nutrient conservation and improving crop yield in Huang-Huai-Hai Plain, China. Although the incorporation of maize straw with deep plowing and rotary tillage practices are widespread in the region, only few studies have focused on rotation tillage. To determine the effects of maize straw return on the nitrogen (N) efficiency and grain yield of winter wheat (*Triticum aestivum* L.), we conducted experiments in this region for 3 years. Five treatments were tested: (i) rotary tillage without straw return (RT); (ii) deep plowing tillage without straw return (DT); (iii) rotary tillage with total straw return (RS); (iv) deep plowing tillage with total straw return (DS); (v) rotary tillage of 2 years and deep plowing tillage in the 3rd year with total straw return (TS). Treatments with straw return increased kernels no. ear^{-1}, thousand-kernel weight (TKW), grain yields, ratio of dry matter accumulation post-anthesis, and nitrogen (N) efficiency whereas reduced the ears no. ha^{-1} in the 2011–2012 and 2012–2013 growing seasons. Compared with the rotary tillage, deep plowing tillage significantly increased the grain yield, yield components, total dry matter accumulation, and N efficiency in 2013–2014. RS had significantly higher straw N distribution, soil inorganic nitrogen content, and soil enzymes activities in the 0–10 cm soil layer compared with the DS and TS. However, significantly lower values were observed in the 10–20 and 20–30 cm soil layers. TS obtained approximately equal grain yield as DS, and it also reduced the resource costs. Therefore, we conclude that TS is the most economical method for increasing grain yield and N efficiency of winter wheat in Huang-Huai-Hai Plain.

Keywords: grain yield, N efficiency, straw return, tillage method, winter wheat

1. Introduction

The Huang-Huai-Hai Plain is one of the most important agricultural regions in China. It produces more than 60% of China's winter wheat (Man *et al*. 2015). The average yield of winter wheat is approximately 5 540 kg ha^{-1}, and yields in excess of 9 000 kg ha^{-1} have also been reported in the region (NBSC 2013). However, the output of grain production in this region was based on the higher rate of fertilizer appli-

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cation (Jin *et al*. 2012; Chen *et al*. 2014). Although the use of fertilizer has temporarily increased the yield, its excessive application has brought a series of environmental problems, such as water pollution, field greenhouse gas emission, and soil quality degradation, etc. (Snyder *et al*. 2007; Dai *et al*. 2013; Zhang *et al*. 2013). Therefore, in addition to ensuring a higher production, it is equally important to improve the nitrogen (N) use efficiency and reduce N loss (Zhang *et al*. 2008; Chen *et al*. 2011). Many studies have shown that crop residue is rich in organic materials and soil nutrients, and therefore, it is considered to be an important natural organic fertilizer, that could replace chemical fertilizers (Zhao and Chen 2008; Chen *et al*. 2015).

Conservation agriculture, which consists of straw return, is an important strategy for combating soil degradation (Tian *et al*. 2010; He *et al*. 2015). Compared to conventional agricultural practice, such strategy is useful for improving soil physical characteristics, increasing soil fertility indicators (Powlson *et al*. 2011; Tian *et al*. 2012; Zhu *et al*. 2014; Nie *et al*. 2015), as well as enhancing the crop productivity and nutrient utilization efficiency (Zhao and Chen 2008; Chen *et al*. 2015). However, inappropriate methods of straw incorporation could deteriorate soil structure and unbalance nutrients distribution (Kong 2014; Pang *et al*. 2016). These could limit the action of roots (Guan *et al*. 2014), which is not beneficial for growing winter wheat. Thus, optimizing straw return method is essential for winter wheat production.

Traditional tillage practices in agriculture, including deep plowing tillage and rotary tillage, are common in Huang-Huai-Hai Plain, China (Shi *et al*. 2016). Deep plowing tillage has a higher cost than rotary tillage due to the requirement of expensive farming machinery. In contrast, rotary tillage is increasingly considered by farmers on account of greatly simplified operation, as well as its low cost in field preparation, fuel, equipment, and labor (Wang *et al*. 2006). However, rotary tillage often increases soil bulk density in the top 10–30 cm soil layer in the absence of plowing. This leads to a reduction in air-filled pore space, which is not beneficial for growing winter wheat (Václav *et al*. 2013). Furthermore, the rotary tillage shallows the plough layer, enriches surface nutrient, and emaciates deeper soil, thus resulting soil infertility and impeding the uptake of soil nutrient by crops (Tian *et al*. 2012; Nie *et al*. 2015). As a consequence, agricultural practices that improve soil quality are essential to promote agricultural sustainability and reduce resource consumption (Zhang *et al*. 2016).

Many studies have indicated that straw return show remarkable effects on nitrogen utilization and grain yield (Duan *et al*. 2014). For example, both no-tillage and conventional tillage with residue applied had higher total N uptake and crop yield than methods with no residue applied in middle-lower Yangtze area of China (Xu *et al*. 2010). In Central China, deep-tillage with crop residue application at 30 cm soil depth had distinctly higher crops yield than those without straw application (Zhao *et al*. 2014; Chen *et al*. 2015). However, in Northwest China, there was no significant difference in N uptake between straw return treatments and the treatments without straw return under no-tillage condition (Zhang *et al*. 2009). Apparently, the effects of tillage on crop yield and nitrogen utilization vary with the regional climate, soil condition, residue management practice, and crop rotation (Ponnamperuma 1984). Therefore, the investigation on tillage reform and straw return manner for specific soil, climate, and cropping system is necessary to improve nitrogen utilization and grain yield.

The studies mentioned above focused mainly on the effects of one soil tillage practice, i.e., reduced or no-till tillage, and plowing tillage, on soil structure, grain yield, and N utilization. However, studies on the effects of soil tillage practices, especially rotational tillage with deep plowing tillage (at 2 years interval) on the distribution of straw N, N utilization, and grain yield are limited. Therefore, we undertook this study with the objective of assessing tillage methods to evaluate their impact on (1) the distribution of N released from the applied crop residue, (2) characteristic of dry matter accumulation, and (3) grain yield and N efficiency over 3 years.

2. Materials and methods

2.1. Experimental site

Field experiments were carried out in 2011–2012, 2012–2013, and 2013–2014 at Yangzhuang Village (116°48′E, 35°29′N), Yanzhou County, Shandong Province, China. This experimental field has meadow-cinnamon soil and the cropping pattern is wheat-maize rotation. The information of summer maize of the 3 years is shown in Table 1. Properties of the upper 20 cm soil were 12.3 g kg^{-1} organic C, 1.11 g kg^{-1} total N, 87.2 mg kg^{-1} available N, 8.6 mg kg^{-1} available Olsen-P, and 0.58 mmol kg^{-1} exchangeable K. The precipitation and monthly average temperature in the growing period of winter wheat from 2011 to 2014 are shown in Fig. 1.

2.2. Experimental design

Treatments were a combination of tillage and total aboveground residue returned from the previous crop. Five treatments were applied during the wheat growing season for 3 years, including rotary tillage without straw return (referred to as RT), deep plowing tillage without straw return (DT), rotary tillage with total straw return (RS), deep plowing tillage