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Short communication

Return rate of straw residue affects soil organic C sequestration by chemical fertilization

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ABSTRACT

A 12-year field experiment was used to examine effects of return rates of crop straw residue on organic C sequestration by chemical fertilization in surface (0–20 cm) soil. The tested soil was a Hapli-Ustic Cambosol (FAO taxonomy) and the used crop was maize (*Zea mays* L.). The four main treatments were consisted of a gradient of return rate of straw residue, namely 0%, 25%, 50% and 100% of shattered straw residue (referred to as 0%S, 25%S, 50%S and 100%S, respectively). The three sub-treatments contained unfertilized control (CK), unbalanced N fertilization (N) and balanced NPK fertilization (NPK). Along the gradient of straw return rate, topsoil C storage significantly increased. The balanced NPK fertilization was more effective in sequestrating topsoil C than the unbalanced N fertilization. Responses of topsoil C storage to the straw return and fertilization significantly increased with the experimental duration. With increasing straw return rates, C-sequestration effects of the N, and NPK treatments in topsoil changed from not significant to significant or from significant to more significant in statistics. Our findings demonstrate that C-sequestration effects of chemical fertilization in topsoil strongly depend on return regime of straw residue.

1. Introduction

Because of its importance to soil fertility and sustaining the productivity of agroecosystems (Johnston, 1986), maintaining a satisfactory soil organic carbon (SOC) content is an integral component of soil management strategy (Gong et al., 2009a). SOC sequestration is generally influenced by many factors, such as soil use, agricultural managements, root biomass, sampling depth, and climatic and soil conditions. SOC balance strongly depends on the C input and output. Generally, increasing C input can increase SOC content before the soil is C-saturated. Many studies indicate that SOC increases under organic amendment, cropping rotation, conservation tillage (e.g., no-tillage), and reduced fallow (Bhattacharyya et al., 2007; Purakayastha et al., 2008; Tong et al., 2009). In agroecosystems, the change in SOC mainly occurs in topsoil of 0–20 cm, as crop roots and management disturbances usually were concentrated in this depth range. Chemical fertilizer application is one of the most common agricultural management practices, and its effect of SOC sequestration thus receives extensive attention. Generally, chemical fertilization can increase aboveground crop yield and belowground root biomass through directly supplying nutrients required for crop growth. Therefore, in most cases, chemical fertilization can increase SOC content by enhancing C input with rhizodeposition and returned residue (Haynes and Naidu, 1998; Purakayastha et al., 2008). Gong et al. (2009a), for example, reported that 18-year chemical NPK fertilization significantly increased annual residue (root + stubble) input and thus significantly sequestrated 3.3 Mg ha^{-1} SOC in surface soil (0–20 cm), compared with unfertilized control. However, other researchers reported that chemical fertilization produced no significant or even negative effects on SOC, although generally the fertilization increased crop yield (Halvorson et al., 2002; Nardi et al., 2004; Russell et al., 2005; Su et al., 2006; Huang et al., 2010). One of the major factors causing the inconsistent results may be the return regime of straw residue (Su et al., 2006), since amount of crop residue returned into soil is directly controlled by the integration of crop yield and residue management regime. Under straw removal, for instance, chemical fertilization may increase C input only through root biomass. This increase could be small and subsequently SOC change may be not significant especially under short-term condition. However, when straw is retained, fertilization might increase C input through both root and aboveground

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biomass. Such an increase could be relatively great and subsequently SOC sequestration might be significant. Straw return regime is often diverse in many countries and regions. In developed countries, straw is generally retained in fields to improve soil fertility and crop productivity. Conversely, farmers in many developing countries prefer to remove straw from fields for use as fuel or as construction materials (Bakht et al., 2009). The main objective of this study was to investigate C-sequestration effects of chemical fertilization in topsoil (0–20 cm) as affected by straw return rates through a 12-year field experiment in northeast China.

2. Materials and methods

2.1. Study site and experimental design

This study was conducted at a 12-year experimental site (41°40′N, 119°28′E), established on a maize (*Zea mays* L.) field in Jianping county, northeast China in 1998. The region belongs to a continental monsoon climate, with a mean annual 450 mm rainfall and 6.5 °C temperature. The tested soil was classified as a Hapli-Ustic Cambosol (Food and Agriculture Organization (FAO) taxonomy), with initial properties of 9.8 g kg^{-1} total SOC ($K_2Cr_2O_7$ oxidation method), 0.89 g kg^{-1} total N (Kjeldhal method), 66.4 mg kg^{-1} available N (Alkaline diffusion method), 4.6 mg kg^{-1} 1 available P (Olsen method), 112.2 mg kg^{-1} available K (NH_4AC extraction, atom absorb spectrophotometer (AAS) method), pH (H_2O) 8.5 (pH meter method), 16.4% sand, 68.6% silt and 15.0% clay (hydrometer method) at 0–20 cm depth. Crop root and stubble (about 10 cm aboveground) residues were remained in the field after harvest. This area had been continuously cultivated with the maize for more than 20 years before the experimental period.

The experiment was arranged by a split-plot design with three replicates. The four main treatments were consisted of a gradient of return rate of straw residue, namely 0%, 25%, 50% and 100% of the straw residues (referred to as 0%S, 25%S, 50%S and 100%S, respectively). The shattered straw residues were directly returned to the field after harvest, and were incorporated into the soil after mouldboard ploughing (about 20 cm depth). Mean absolute value of 100%S (dry weight basis) was 4819 kg ha^{-1} year^{-1} over the whole experiment. The three sub-treatments contained unfertilized control (CK), unbalanced N fertilization (N) and balanced NPK fertilization (NPK). The N, P and K sources were urea (248 kg N ha^{-1} year^{-1}), calcium superphosphate (115 kg P_2O_5 ha^{-1} year^{-1}) and potassium sulphate (120 kg K_2O ha^{-1} year^{-1}), respectively. The application rates of the fertilizers were worked out on the basis of the initial soil test results and the crop requirements. one third and two third of the N fertilizer were applied as basal and supplemental fertilizer, respectively. The whole P and K fertilizers were added as basal fertilizer. The size of each subplot was 60 m^2.

2.2. Sampling and analysis

Soil samples were collected from each subplot at 0–20 cm depth two weeks after plouging in autumn in 1999, 2004, and 2009. SOC concentration was determined by a titration method after oxidation with $K_2Cr_2O_7$. At the same time, bulk density (dry weight basis) was measured using a conventional core (2.5 cm diameter) method at 0–20 cm depth in each subplot. SOC storage (Mg C ha^{-1}) at 0–20 cm depth was calculated on an area basis. The amount of sequestered organic C (Mg C ha^{-1}) by the N, and NPK treatments in topsoil (0–20 cm) was estimated after deducting the SOC storage in the CK from the treatments under each straw return rate condition. Statistical analysis was performed with SPSS for Windows 11.5. Mean annual grain yield and estimated annual residue input were subjected to a two-way (straw return × fertilization) analysis of variance (ANOVA) in a split-plot arrangement. SOC storage was subjected to a three-way (straw return × fertilization × sampling time) ANOVA. Difference with $P < 0.05$ was considered statistically significant. The relationship between SOC storage in 2009 and annual residue input was quantified using a regression analysis.

3. Results and discussion

3.1. Crop yield and residue input

In this study, mean annual grain yield under the 50%S and 100%S treatments was significantly increased compared with that under the 0%S and 25%S treatments (Table 1). The reason is that increasing straw retention can improve soil fertility including organic C, nutrients and physical properties (Roldán et al., 2003; Dolan et al., 2006). In the studied soil, N was seriously deficient as well as P and K throughout the experimental stage. Consequently, mean annual grain yield was more effectively increased by the NPK treatment than the N treatment (Table 1). Amount of crop residue returned into soil directly depends on the integration of crop yield and residue management regime. Normally, mean annual residue input (root + stubble + straw) was significantly increased with the straw return rates, and also increased in the order of CK, N and NPK (Table 1). Increases in annual residue input due to the N, and NPK treatments relative to the CK significantly increased with the straw return rates (Fig. 1). This reflects the

Table 1
Mean annual grain yield and estimated residue input (root + stubble + straw) under the different treatments (kg ha^{-1}) (mean ± SD; n = 3).

Item	Straw return	Chemical fertilization				Impacts		
		CK	N	NPK	Mean	S	C	S × C
Grain yield	0%S	612 ± 48 cB	2045 ± 146 bC	4028 ± 187 aB	2228 B	**	**	**
	25%S	720 ± 60 cAB	2604 ± 127 bB	4405 ± 224 aB	2576 B			
	50%S	860 ± 85 cA	3612 ± 184 bA	5404 ± 245 aA	3292 A			
	100%S	872 ± 72 cA	3720 ± 169 bA	5440 ± 256 aA	3344 A			
	Mean	766 c	2995 b	4819 a				
Residue input	0%S	344 ± 46 cD	1112 ± 86 bD	2444 ± 167 aD	1300 D	**	**	**
	25%S	686 ± 48 cC	2400 ± 122 bC	4605 ± 182 aC	2564 C			
	50%S	1040 ± 74 cB	4024 ± 156 bB	7440 ± 198 aB	4168 B			
	100%S	1892 ± 144 cA	6900 ± 202 bA	10482 ± 298 aA	6425 A			
	Mean	991 c	3609 b	6243 a				

S: straw return; C: chemical fertilization. Different lowercase letters in a row indicate significant difference between the fertilizer treatments with LSD. Different uppercase letters in a column indicate significant difference between the straw treatments with LSD.
** Significant difference at $P < 0.05$.