Bangladesh J. Bot. **48**(3): 893-899, 2019 (September) Special

EFFECTS OF DIFFERENT RATES OF STALK MULCHING OF MAIZE ON SOIL ORGANIC CARBON AND EARTHWORM BIOMASS IN MAIZE FIELD

CHANG TIAN, JUAN LI, ZHEN GUO, YANG WANG[1], LUYING SUN[1], XIAOQIN YANG[1] AND JICHANG HAN*

Institute of Land Engineering Technology in Shaanxi Province Co. Ltd., Xi'an, Shaanxi 710075, China

Keywords: Straw mulching, Infrared spectroscopy, Organic carbon, Lignin, Maize root system, Earthworm

Abstract

Effects of no-tillage with different rates of stalk mulching on infrared spectral characteristics of soil organic carbon, soil lignin content, lignin-derived carbon content in soil organic carbon, maize (*Zea mays* L.) root characteristics and earthworm biomass, were carried out in the long-term location test area of Dehui country, Jilin province. The results showed that after no-tillage planting with straw mulching in 2016-2017, the infrared absorption value of organic carbon, the content of soil lignin and lignin source carbon decreased with the deepening of soil layer, the higher the straw coverage, the higher the soil organic carbon, the plant root density and the earthworm biomass. In the 0 - 5 cm soil layer, the larger the coverage, the higher the content of lignin and lignin source carbon under no-tillage treatment. In the 5-20 cm soil layer, the content of lignin and lignin source carbon were highest by 378 and 17 mg/g under 67% straw mulching. It indicated that no-tillage straw mulching could effectively increase soil organic carbon, plant root density and soil earthworm biomass, the greater the coverage, the more obvious the effect would be. Under the stalk mulching treatment, most of the organic carbon was input into the soil, while the alkane carbon content was less.

Introduction

Conservation tillage refers to the straw coverage in the field more than 30% and minimize soil disturbance (Shao *et al.* 2007). No-tillage is a form of conservation tillage, which increases soil organic matter content, improves soil structure and quality, protects soil and water resources and ecological environment, reduces CO_2 emissions. Infrared spectroscopy is a rapidly developing analytical method of molecular structure analysis by selective absorption of infrared light by materials and qualitative and quantitative analysis by characteristic infrared absorption spectroscopy of compounds (Wang *et al.* 2004, Bu *et al.* 2006, Lv *et al.* 2010, Huang *et al.* 2011). The lignin with relatively low conversion rate is an important source of soil-stable organic carbon (Adani *et al.* 2007) and is closely related to the long-term stability of carbon intercepted in soil (Lützow *et al.* 2006). The effectiveness of water and nutrients depends not only on soil factors, but also on the distribution, volume, activity and total surface area of roots, which may affect absorption and migration of nutrients and water to the root surface. Compared with traditional tillage, conservation tillage measures maintained a high number of earthworm (Lee 1985) and crop straw had the same effect (He *et al.* 2014). In the present study, to evaluate the relationship of plant and soil nutrition under no-tillage with different stalk mulching in this important agricultural region, a field which was used for crop production to carry out a field experiment was selected and straw to field was added, hypothesizing that appropriate stalk mulching will benefit nutrient accumulation and living environment in soil. Thus, the objective was to evaluate the effects of no-tillage with different stalk mulching on crop yield and the nutrient contents in soil in order to contribute to black soil areas.

*Author for correspondence: <m15029206299_2@163.com>. [1]Northeast Institute of Geography and Agroecology, CAS, Changchun, Ji Lin 130102, China.

Materials and Methods

A field experiment was conducted at the Dehui Agricultural Experimental Station, which is located in Songliao Plain in central northeast China (47°27'N, 126°55'E) and characterized by a warm temperate and continental climate.

The size of each plot was 100 m × 40 m. Four treatments with five replicates were: (i) no-stalk mulching (NT-0), (ii) 33% stalk mulching (NT-33), (iii) 67% stalk mulching (NT-67) and (iv) 100% stalk mulching (NT-100). A randomized block design was followed. The crop varieties used in this study were locally grown maize (Liangyu 99) with fertilization amount is 252 kg N/ha, 135 kg P/ha, 90 kg K/ha.

After the crop harvest in 2016, about 500 g each soil sample with four replicates was collected from each plot at depths of 0 - 2, 2 - 5, 5 - 10 and 10 - 20 cm. The infrared transmission spectrum of the soil was measured by a KBr tablet (soil : KBr = 1 : 100) using a Nicolet 6700 Fourier infrared spectrometer. The measurement range of the spectrum was 400 - 4000 cm^{-1}, with 4 cm^{-1} resolution and 64 scanning. The lignin monomer was derivatized and determined by gas chromatography (Guggenberger *et al.* 1995, Cassman *et al.* 1996). During the maturity period in 2017, three representative plants were selected from the planting area. Taking the stem as the center, it was vertically excavated along the circumference which is a rectangle with a length of 50 cm and a width of 30 cm until no roots to soil column. From top to bottom along the soil column, soil samples were collected from each plot at depths of 0 - 5, 5 - 10, 10 - 15, 15 - 20, 20 - 30, 30 - 40 and 40 - 60 cm. The soil samples with seven replicates were mixed to produce a composite sample, which were soaked, rinsed and washed with water to obtain clean root samples. After that, the coarse roots and the fine roots were classified. The coarse roots were directly measured, the fine roots were first measured for the total weight, and then a part selected were measured for the length. The total length of the fine roots was converted according to the obtained length and the weight ratio. Finally, it was dried in an electric oven and weighed (Liu *et al.* 2009). Yield was measured using air drying 20 plants.

The mean values were calculated for each variable and analysis of variance was used to compare the effects of different treatments on the measured variables. If the F value was significant ($p < 0.05$), multiple comparisons of annual mean values were performed based on the least-significant difference. SPSS 23.0 was used to perform all of the statistical analyses.

Results and Discussion

The absorption bands of the infrared spectrum of the soil samples through the infrared spectral characteristics were mainly 900 - 1700 and 3000 - 3700 cm^{-1} (Fig. 1), in which the fingerprint region had more absorption peaks. The main absorption peaks were 1030, 1635 and 3400 cm^{-1}, indicating that there were many alcohols, phenols, ethers, aromatic compounds and carbohydrates in organic carbon in this area. However, the soil spectrum had no obvious absorption peak between 2870-2950 cm^{-1} and a strong absorption peak appeared between 1000 - 1050cm^{-1}, indicating that the organic carbon added into the soil at the most, while the carbonaceous carbon input was less. The map fully demonstrated that there were mainly kaolinite and possibly illite and montmorillonite in the area. The organic carbon absorbance at different soil depths decreased in 0 - 20 cm, showing that the top soil with more litter had higher organic carbon content than the sub soil. The organic carbon absorbance at different treatments decreased in the order: RT > NT - 0 > NT - 33 > NT - 67 > NT - 100, indicating that the soil organic carbon content after no-tillage was higher than that of conventional ridges, the greater the coverage, the higher the organic carbon absorbance.

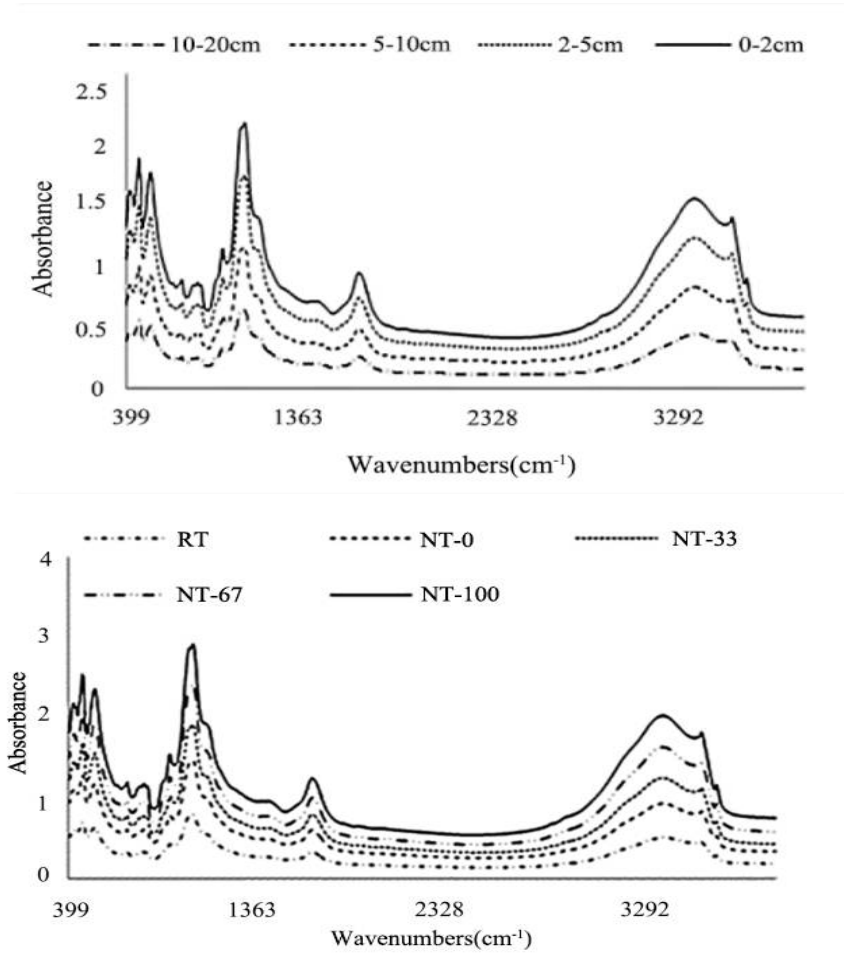

Fig. 1. The average spectra in 2016 (unit: cm^{-1}). The upper picture represents different soil depths. The bottom one represents different treatments. RT: Ridge-till, NT-0: No-stalk mulching, NT-33: 33% stalk mulching, NT-67: 67% stalk mulching and NT-100: 100% stalk mulching.

In general, the distribution of lignin in the soil decreased in 0 - 20 cm (Fig. 2), which might be due to the lignin derived from straw leached and deposited to the lower layer for a long time. In the 0 - 2 cm soil layer, the lignin content and the relative proportion of lignin in organic carbon decreased in the order: NT-100 > NT-67 > NT-33 > NT-0 > RT, under which NT-100 treatment was significantly higher than those of other treatments ($p < 0.05$). In the 2 - 5 cm soil layer, the lignin content under NT-100 treatment was significantly higher than those under 33% coverage and 67% coverage by 33.64 and 3.18% ($p < 0.05$). For the lignin-derived carbon accumulation, the difference between straw mulching and no-stalk mulching was significant ($p < 0.05$). Compared to the previous level, the lignin content and the lignin-derived carbon accumulation under NT-67 and NT-100 treatments decreased sharply. In the 5 - 20 cm soil layer, the lignin content under NT-67 treatment was higher than that under NT-100 treatments by 5.83%, which probably promoted microbial activity and accelerated the decomposition of straw for increase the lignin content. Although the amount of organic substrate under no-stalk mulching and 33% stalk mulching increased, the lower accumulation of lignin was due to the lower amount of organic substrate. The lignin-derived carbon accumulation under NT-67 treatment which was conducive to the accumulation of lignin-derived carbon in organic carbon pools, was higher than those of other three treatments, especially in the 5 - 10 cm soil layer, showing that the accumulation of soil lignin was related to the amount of straw incorporation and generally increased with the increase of the amount of return. In the 0 - 2 cm soil layer even to the 5 cm layer, the accumulation of lignin-derived carbon in soil organic carbon under 67% straw mulching was less than that under 100% straw mulching (Fig. 2). While in 5 - 20 cm soil layer, the contrary was the case. Because 100% straw mulching provided a richer energy and carbon source for lignin degradation. Under the action of a synergistic substrate such as carbohydrates, the degradation of lignin in the soil layer below 5 cm was enhanced on account of adding straw and the relative accumulation of lignin was relatively lower.

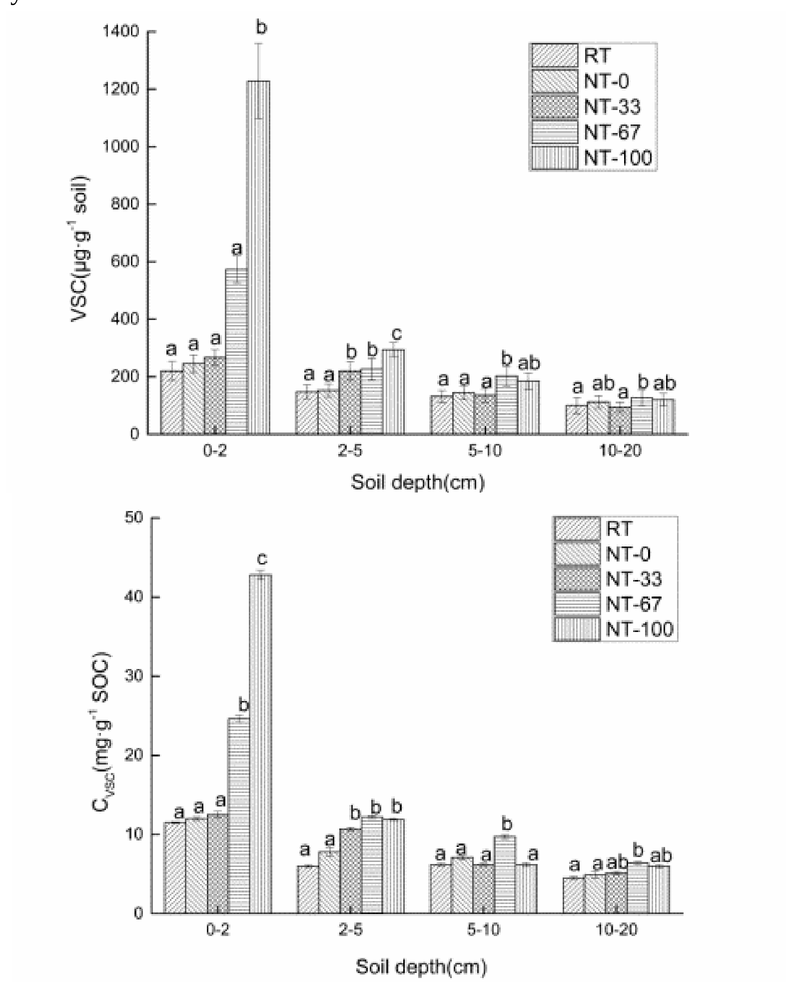

Fig. 2. The upper picture represents the contents of lignin. The bottom one represents the relative accumulation of lignin-derived carbon. RT: Ridge-till, NT-0: No-stalk mulching, NT-33: 33% stalk mulching, NT-67: 67% stalk mulching and NT-100: 100% stalk mulching. Data are means ± Sd (n = 5). Bars with different lower-case letters indicate significant differences at $p < 0.05$.

It was observed from Fig. 3 that in terms of root weight and root length, straw mulching (33, 67, 100%) in different soil layers was higher than that without straw mulching, indicating that straw mulching was beneficial to the development of maize root system. In the 0 - 5 cm soil layer, the root weight and root length under straw mulching (33, 67, 100%) were higher than those without straw mulching by 38.78, 40.82, 87.76 and 66.90%, 55.78, 122.15%, respectively. The root weight and root length under NT-100 treatment ranked first, NT-33 ranked second and NT-67 ranked third. Under the different straw mulching amount, the root weight and root length showed obvious difference in 0 - 5 cm soil layer. With the increase of depth, the difference was less. When the soil depth reaches 40 cm or more, the difference in root weight and root length under different treatments was small. The difference in the root system was mainly due to the influence of different coverage on soil temperature and moisture. A barrier layer between the soil and the atmosphere was formed on the surface after mulching, which affected the heat transfer and water evaporation of the soil and near-surface air, which were the key factors for root growth.

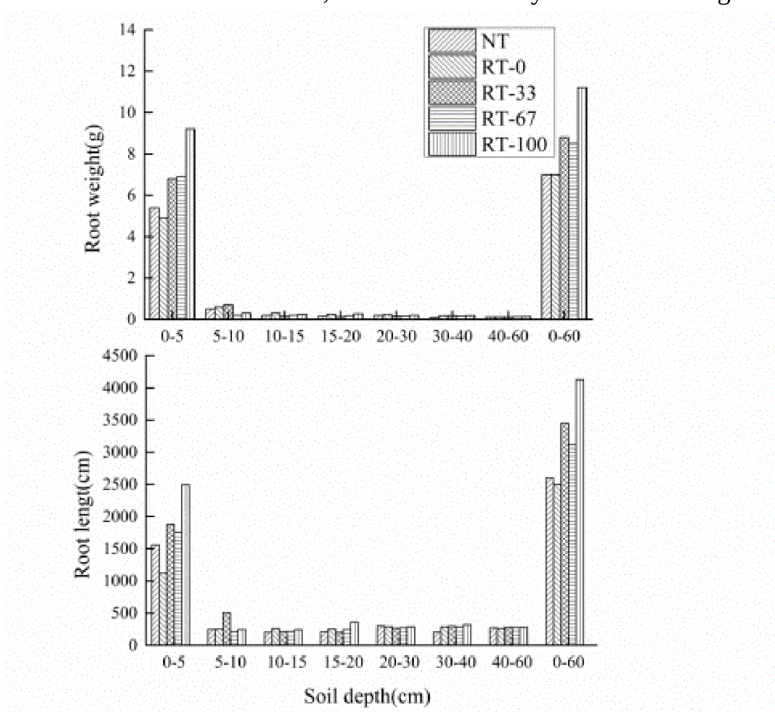

Fig. 3. The root weight and length of maize of different depth in 2017. RT: Ridge-till, NT-0: No-stalk mulching, NT-33: 33% stalk mulching, NT-67: 67% stalk mulching, NT-100: 100% stalk mulching. Data are means ± Sd (n = 3).

It was seen from Fig. 4 that the amount and weight of earthworm in the soil under no-tillage treatment were higher than those under conventional ridge, but the difference did not reach a significant level. The difference of the number and weight of earthworm among four treatments were extremely significant. With the increase of straw coverage, the number of earthworm increased gradually with 288.12, 49.74 and 26.06% respectively, the weight of earthworm also increased gradually with the increase of 230.77, 137.21 and 60.78%, respectively. It showed that no-tillage significantly increased the amount of earthworm in the soil and the more straw was covered, the higher the soil earthworm biomass.

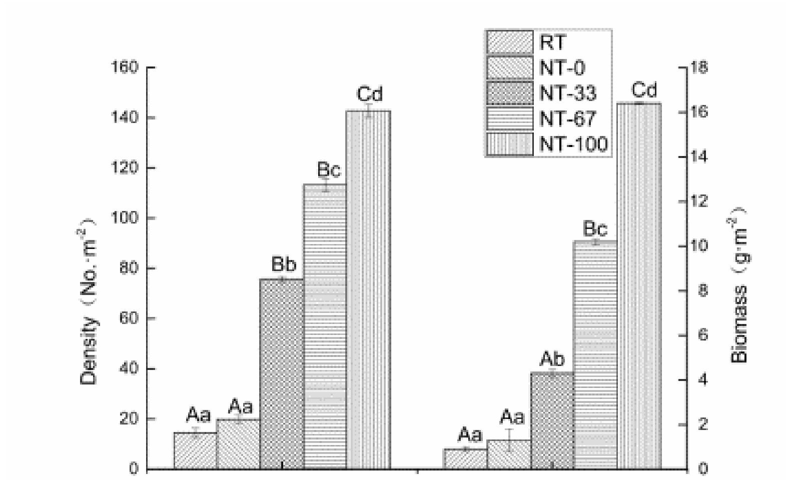

Fig. 4. The amount and weight of earthworm in 2017. RT: Ridge-till, NT-0: No-stalk mulching, NT-33: 33% stalk mulching, NT-67: 67% stalk mulching and NT-100: 100% stalk mulching. Data are means ± Sd (n = 3). Different small and capital letters in a column at the same sampling date mean significantly different at the 5 and 1% levels, respectively.

Soil roots which were mainly distributed in the tillage layer above 10 cm absorbed carbon from the surface soil and grew well with a wide distribution range, providing a good living environment for the survival of soil animals. In turn, earthworms, through feeding on soil, drilling holes and producing by their metabolism the excrement and secretion, improved the productivity of vegetation, increased the soil carbon inventory and carbon flux between soil and atmosphere and promoted the increase of soil nutrients. The close relationship between soil biota and SOM dynamics was clarified by studying the formation and stabilization of aggregates in temperate and tropical soils. The reason was as follows: when earthworms absorb granular organic matter, they could add a large amount of water-like mucus to the soil and then thoroughly mix the soil. The molding process of the soil destroyed the bonds between soil particles, thus reducing soil stability (Li *et al.* 2013, Peng *et al.* 2013). In the case of root growing actively, gelling agents (root exudates) which had a strong adsorption effect on inorganic materials and contribute to stabilize the soil were produced (Guo 2018). In addition, root exudates stimulated microbial activity and subsequently produced microbial binders. During plant transpiration, the root system exerted lateral pressure and constantly removed water to affect roots aggregation which resulted in part soil drying and soil particles flocking around the roots. It was the synergistic and complementary relationship between plant roots and earthworms that enabled soil to release nutrients and maintained good stability during the alternate process of tightness. All in all, no-tillage straw mulching can effectively increase soil nutrients and biological activity.

Acknowledgements

The authors are grateful for financial support from the Fund Project of Shaanxi Key Laboratory of Land Consolidation (2019-JC08).

References

Bu YS, Miao GY, Zhou NJ, Shao HL and Wang JC 2006. Analysis and comparison of the effects of plastic film mulching and straw mulching on soil fertility. Sci. Agr. Sin. **5**(10): 1069-1075.

Cassman KG, de Datta SK, Amarante ST, Liboon SP, Samson MI and Dizon MA 1996. Long-term comparison of the agronomic efficiency and residual benefits of organic and inorganic nitrogen sources for tropical lowland rice. Exp. Agr. **32**(2): 427-444.

Guggenberger G, Zech W and Thomas RJ 1995. Lignin and carbohydrate alteration in particle-size separates of an oxisol under tropical pastures following native savanna. Soil Biol. Biochem. **27**(4): 1629-1638.

Guo HM 2018. Effects of cultivation methods on root growth and water use efficiency of maize. Seed Sci. **11**(3): 63-65.

He H, Zheng HB, Liu JX, Yao L and Huang W 2014. Advances in the effects of earthworms on soil carbon and nitrogen cycles and their mechanisms of action. Chinese Agr. Sci. Bull. **33**(3): 120- 126.

Huang JX, Chen YQ, Liu WR, Zheng HB, Sui P, Li YY, Shi XP, Nie SW and Gao WS 2011. Effect on net greenhouse gases emission under different conservation tillages in Jilin Province. Sci. Agr. Sin. **14**(6): 2935-2942.

Lee KE 1985. Earthworms: Their ecology and relationships with soils and land use; Academic Press: Orlando, FL, USA.

Li J, Li ZX, Xie HT, Dong Z, Bai Z, Wang GM, Chen ZW and Zhang XD 2013. Effects of different straw mulching on soil lignin content under no-tillage conditions. Sci. Agr. Sin. **46**(9): 2265-2270.

Liu JW, An SQ, Liao RW, Ren SX and Liang H 2009. Distribution of maize roots in soil profiles. Chinese. J. Eco-Agr. **17**(6): 517-521.

Lützow MV, Kögel-Knabner I and Ekschmitt K 2006. Stabilization of organic matter in temperate soils: Mechanisms and their relevance under different soil conditions-a review. European J. Soil Sci. **57**(10): 426-445.

Lv YZ, Lian XJ, Zhao H and Liu WR 2010. Effects of conservation tillage patterns on content and density of organic carbon of black soil. Trans. Chinese Soc. Agr. Eng. **11**(5): 163-169.

Peng Y, Xie HT, Li J, Dong Z, Bai Z, Wang GM, Chen ZW and Zhang XD 2013. Infrared spectral characteristics of soil organic carbon under different straw mulching conditions under no-tillage conditions. Sci. Agr. Sin. **46**(4): 2257-2264.

Shao JA, Tang XH, Wei CF and Xie DT 2007. Effects of no-tillage with straw mulching on soil organic matter in paddy soils. Chinese J. Eco. **11**(6): 4434-4442.

Wang CS, Wang ZY, Su CG, Li H, Wang J and Wu GH 2004. Development and application of protective farming technique. Trans. Chinese Soc. Agr. Mach. **1**(9): 167-169.

(Manuscript received on 16 May, 2019; revised on 26 September, 2019)