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Full Length Article

Degradation Characteristics of Maize Straw under Different Buried Depths in Northeast Black Soil and Their Effects on Soil Carbon and Nitrogen

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Abstract

Incorporation of straw in the improvement of soil fertility via increasing soil organic carbon has become an important method. But in this process of decomposition, a considerable portion of carbon will be released into the atmosphere. The present research dealt with experiments to make more straw-carbon to stabilize in the soil and to maintain the decomposition of crop straw. Based on this concept, the effects of maize straw incorporation at different depths on the nutrient status of soil were observed via three experiments conducted for 3 years on a Black Soil in Northeast of China. Four soil depths were tested. These are D_0 (0–5 cm), D_1 (5–15 cm), D_2 (15–30 cm) and D_3 (30–45 cm). The results showed that maize straw residues incorporation to sub-surface (D_1–D_3) layer had a significant difference compared with D_0 (68.7% C lost, $P < 0.01$) after 3 years of decomposition. The three treatments with buried residues into the soil had almost similar average diminution of C content (10.37–14.01%). Meanwhile, D_0 had a lower decomposition constant, straw lignin and cellulose decomposition than D_1–D_3 treatments. The content of urease and sucrase declined with the deep soil, and straw return increased the enzyme activity in this study. The D_1 treatment also had a higher soil microbial biomass carbon (SMBC) and labile soil organic carbon (SOC) fractions. These components also increased significantly with the seasonal change in the D_2 treatment. The content of SOC showed significant positive correlation with C/N and soil temperature. While sucrose and moisture showed significant negative correlation between them. The present simulation study reinforces the importance of analyzing SOC fractions and SMBC into the deep soil. It had indicated that maize straw incorporation in deep soil was very important for the maintenance of soil fertility. At the same time, it suggested a solution to the problems of large quantity of straw production in the maize cultivation zones. The results bear significant importance for agriculture. © 2020 Friends Science Publishers

Keywords: Straw incorporation; Soil depth; Soil organic carbon fractions; Microbial biomass carbon; Enzyme activity

Introduction

In the People's Republic of China, the North East area is one of the most important maize (*Zea mays* L., Fam.: Poaceae) growing areas. It produces annually more than 35% of country's total maize production and occupies 31% of maize growing areas of China (Fan *et al.* 2018). Residues produced after harvesting and processing of maize grains are important renewable resources. But managing this huge amount of maize residues is a big challenge. The annual production of maize residue has been estimated 239 mio MT/y. From this huge stock, only 23% of the residues are used for forage, 4% for industry materials and 0.5% for biogas generation. The rests of the production are then discarded and even directly burnt in the field (Liu *et al.* 2008).

After harvesting, straws returning into the soil are beneficial and can be considered as an important management practice (Zhang *et al.* 2014, 2016b; Wang *et al.* 2015a; Yin *et al.* 2018). It increases the input of nutrients and carbon storage in the top soil (Choudhury *et al.* 2014; Zhang *et al.* 2016a). Thereby, opens a great deal of potential in enhancing soil fertility, soil organic matter (SOM) content and microbial population (Lal 2004; Powlson *et al.* 2008). Al these activities help improving the soil structure (Zhang *et al.* 2008), especially the soil porosity (Wuest

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2007). Unfortunately, in the northeast of China, leaving residues onto the soil surface would not be efficient for soil quality improvement. Because the left-out straw, the field could not be decomposed completely under the low temperature (Wang *et al.* 2012). Moreover, maize straw returning to the field would lead to an exhaustion of soil moisture, and be harmful to the seed germination of the next crop (Liu 2014). Incorporating the straw into the subsurface soil may decrease the adverse effect in crop seeding and enhance the soil organic carbon (SOC) stabilization (Choudhury *et al.* 2014). This may be considered as a beneficial practice for the improvement of environment in the northeastern region of China (Kuang *et al.* 2014; Wang *et al.* 2015b; Yang *et al.* 2016; Chen *et al.* 2017).

For the cultivated lands in the northeastern China, the soil organic status can be maintained at a relatively stable level after being returned the crop residues to the field. However, there are some strong physical constraints such as existence of hard pan below the plough layer at 20 cm depth. It limits the development of the root system. On the other hand, it was observed that because of low temperature the straw applied into the plough layer, decomposes slowly over a long winter. So, it hinders the seedling activity for the next planting season. However, putting the straw residues into the deeper part of the soil is a widespread practice in this region (Kuang *et al.* 2014). The process helps in improving fertility of the deep soil. This very concept actually helped to develop the present research plan. In order to understand the effects of burying residues in the cultivated fields of northeastern China, a field experiment was needed to be carried out. The basis of this experiment would be to put straw residues into the soil at different layers, and to measure the evolution of indicators of SOM dynamics. We hypothesized that, (i) the localization in deep horizons can accelerate the speed of maize straw decomposition due to temperature effect, (ii) the soil properties and microbial characteristics respond differently after straw return to different soil layers. In order to test the components of this hypothesis, the specific objectives for the present research undertaken, were: to return maize straw to different soil depths, to make sure that the straw biomass decomposition is accelerated into deep than surface of soil and to make sure that the process enhances the storing of straw carbon in deep soil and improves the soil nutrient content.

Materials and Methods

Experimental site

All the experiments for the present research were carried out in the micro-area test of the Academy of Agricultural Sciences of Heilongjiang, Northeast of China. The planting was done in the crop growing season ranging from May 26, 2015 to May 26, 2018. The average annual precipitation and temperature of the region were 553.5 mm and 3.6°C, respectively. Effective accumulated temperature is 2580 degrees Celsius and the frost-free season is about 135–140 d. Some of the soil chemical and straw properties in the study area have been presented in Table 1.

Experimental design

Mesh bags were used for the decomposition experiment. Maize straw (MS) was collected during harvesting time of September. Specifically, 50 g of dried maize straw were chopped into about 2–5 cm lengths in each bag (300 meshes). The amount of straw in the bags was selected according to the total maize straw biomass by the year which was about 7500 kg/hm^2. Urea was used to adjust the C/N ratio to 25:1 and field capacity was adjusted to 60%. Bags were placed in four different soil horizons. The depths of the horizons for burying the MS were: D_0, D_1 D_2 and D_3 Triplicate samples of bags were collected after 30, 45, 60, 90, 120 d and after 1, 2 and 3 y from the beginning of the experiment. At the same time, the soil of the upper and lower 5 cm of the mesh bags was also sampled. Immediately after sampling, part of the soil was sieved (1 mm mesh) and used for the analysis of enzyme activities and soil microbial biomass. The other part of the soil was air-dried and sieved (2 and 0.15 mm mesh) to test its chemical properties. Before the chemical analysis, the maize straw samples were oven dried at 60°C without washing. After this a definite volume of it weighed and the residual rate of straw was calculated. The samples were crushed to determine the straw organic carbon, lignin and cellulose contents. The Residue percentage of the straw was calculated using the formula $S_t/50\times100$ (where, S is the residual mass of straw (g) and 50 is the original straw mass (g), t is the different sampling time).

By putting thermometer at soil layers of 5, 10, 15, 20 and 25 cm, the temperature was recorded on the sampling dates.

Straw organic carbon

The above-mentioned oven dried straw sample (unwashed, 60°C) was smashed through a 100 mesh sieve and used for the determination of total organic carbon (TOC) (Multi N/C 2100 TOC total organic carbon/total nitrogen analyzer).

Soil organic carbon fractions analysis

The density fraction of soil organic carbon (SOC) refers to Golchin *et al.* (1998). In it, SOC was divided into free light fraction (LF), occluded light fraction (O-LF) and heavy fraction (HF). The methodology in brief follows: 5 g of air-dried soil was homogenized with 25 mL NaI solution (gravity 1.8 g·cm^{-3}) in a 50 mL centrifuge tube. The sample was gently shaken and let stand overnight at room temperature. Next day, it was centrifuged at 3500 rpm for 15 min. The supernatant was poured out; 50 mL of NaI was added to it and centrifuged again. This process was repeated twice. The residue was finally washed by 25 mL 0.01 mol L^{-1} $CaCl_2$ and 50 mL of distilled water, then dried on a water bath below 60°C and weighed. This dried part was LF. The extraction process was continued by adding 25 mL NaI solution to the residue material in the centrifuge tube, shaken and centrifuged for twice. This part was O-LF. Thirdly, 25 mL distilled water was added, shaking done for 20 min and then centrifuged at 4000 rpm for 20 min. The precipitation in the tube was repeatedly washed with 95% ethanol to colorless and was put into an oven below 40°C and dried to a constant weight. This part was HF. All dried parts passed through 0.25 mm sieve and analysed for organic carbon by wet oxidation method with K_2CrO_7 at 170–180°C.

Soil microbial carbon and nitrogen analysis

Soil microbial biomass was determined by chloroform fumigation method (Vance *et al.* 1987). However, for the determination of soil microbial biomass carbon (SMBC) and soil microbial biomass nitrogen (SMBN) potassium dichromate oxidation method and Kjeldahl method were used, respectively.

Soil enzyme activity

Urease determination was carried out by indophenol blue colorimetry method. And 3, 5-dinitrosalicylic acid colorimetry was used for the determination of sucrase enzyme (Guan 1987).

The soil urease activity was determined by sodium phenolate-sodium hypochlorite colorimetric method, and the data was expressed as milligrams of NH_3-N produced per gram of soil at 24 h. On the other hand, the soil sucrase activity was determined by 3, 5-dinitrosalicylic acid colorimetric method. The data were expressed as milligrams of glucose produced per gram of soil at 24 h (Guan 1987).

Statistical analyses

All the statistical analysis of the data was subjected to ANOVA using the Statistical Package for Social Science (SPSS 17.00). Significant difference among means was identified using Duncan (D) test at $P < 0.05$.

Results

The decomposition of maize straw biomass

Fig. 2 shows the effect of straw decomposition on straw residue over time and soil depth. When different soil depths are compared, accelerated straw decomposition was evident in the deeper part of the tested soil. D_0 treatment, which is a surface soil showed a different response. At this level (Do) 68.7% of the mass was still left at the end of the experiment.

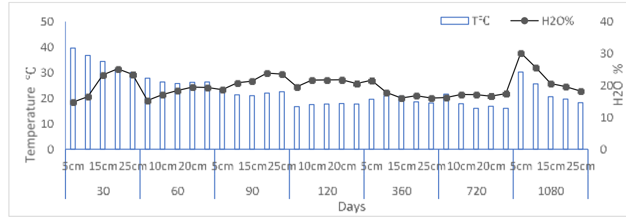

Fig. 1: The soil moisture (H_2O%) and temperature in the 5, 10, 15, 20 and 25 cm soil layers at the sampling days

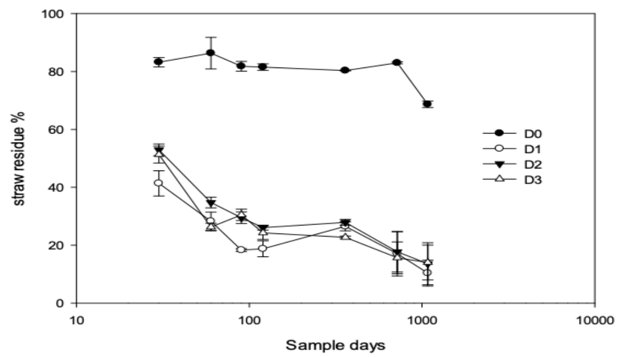

Fig. 2: Maize straw residue at different soil depths D_0 (0-5 cm), D_1 (5–15 cm), D_2 (15–30 cm) and D_3 (30–45 cm) versus time during the three years of study period

While the other treatments at deeper soil layers (D_1–D_3) had almost similar average straw residue (10.4–14.0%). Compared with the whole stage of decomposition, there was a fast stage which just began before 90 days (Fig. 2).

The organic carbon content of straw residue incorporation in different soil depths

Fig. 4 showed the mineralization pattern of maize straw organic carbon at different soil depths over time. The effects of depth and time on the mineralization process are very clear. The organic carbon content of the straw put into deep soil is higher. It means at those depths the straw keeping more carbon. On the other hand, straw left on the top of soil (Do) keeps less organic carbon. D_3 treatment had more organic carbon content than D_2 and D_1. After 1 year of decomposition, D_3, D_2 and D_1 were higher than D_0 by 50.5, 58.3 and 65.1%, respectively. It indicated a significant difference between D_0 and other deep straw returning treatments.

All the carbon fractions had a declined trend from the top soil to the deep soil layers. At day of 1 year after straw returning, the content of LF group in D_3 treatment were stable, but it declined with sampling time. This trend indicated that the LF group was faster than others in the process of decomposition. It can also be seen from these data that the existence of light organic carbon is unstable. The O-LF was the physical protection components of soil organic carbon because it exists as randomly distributed between soil aggregates. From Table 2, Fig. 1 in 30 days of

Table 1: Soil and straw properties of this experiment

Soil	Organic C g kg^{-1}	SMBC g kg^{-1}	Hydrolysable N mg kg^{-1}	Available P mg kg^{-1}	Available K mg kg^{-1}	pH
	50.8	268.1	103.1	70.8	167.7	6.62
straw	Organic C g kg^{-1}	Total N g kg^{-1}	Total P g kg^{-1}	Total K g kg^{-1}	C/N ratio	
	428.4	11.2	4.4	5.6	36.8	

Table 2: The soil carbon fractions of different soil layers with the decomposing days, which D_0 (0–5 cm), D_1 (5–15 cm), D_2 (15–30 cm) and D_3 (30–45 cm)

		30 d	60 d	90 d	120 d	360 d
LF	D 0	89.07 ± 19.43a	127.95 ± 6.00a	51.84 ± 0.76c	106.83 ± 8.89b	117.44 ± 12.12a
	D 1	110.55 ± 16.75a	51.83 ± 1.74c	68.06 ± 3.22b	164.91 ± 33.67a	83.11 ± 16.49b
	D 2	99.21 ± 9.34a	77.69 ± 2.88b	69.41 ± 8.08b	104.77 ± 12.16b	91.47 ± 10.49ab
	D 3	42.83 ± 1.64b	58.28 ± 7.87c	91.94 ± 5.29a	58.78 ± 7.15c	97.31 ± 20.24ab
O-LF	D 0	115.17 ± 19.92a	102.79 ± 14.94ab	52.40 ± 0.63b	88.23 ± 10.99b	95.80 ± 6.31a
	D 1	115.66 ± 3.32a	67.29 ± 21.61c	84.17 ± 10.97a	84.76 ± 10.27b	53.56 ± 1.01bc
	D 2	118.43 ± 9.65a	130.88 ± 17.98a	58.42 ± 2.19b	117.43 ± 4.57a	34.94 ± 25.40c
	D 3	51.28 ± 4.34b	89.87 ± 14.17bc	78.82 ± 10.24a	72.37 ± 17.26b	78.38 ± 3.62ab
HF	D 0	13.71 ± 0.73b	13.00 ± 0.23c	14.12 ± 0.39a	15.17 ± 0.50a	13.27 ± 0.54a
	D 1	13.95 ± 0.47ab	14.66 ± 0.08a	13.50 ± 0.25b	15.23 ± 0.89a	12.35 ± 0.84a
	D 2	14.77 ± 0.14a	13.77 ± 0.50b	14.22 ± 0.19a	14.50 ± 0.45a	13.36 ± 0.19a
	D 3	9.06 ± 0.35c	14.33 ± 0.22ab	14.00 ± 0.35ab	14.20 ± 0.42a	13.02 ± 0.61a

Table 3: The correlation analysis between soil organic carbon and other factors

	SMBC	C/N	SMBN	Urease	Sucrase	Temp.	Moisture
Z score (SOC)	-0.270	0.819**	-0.202	0.352	0.353	0.508*	-0.060
Z score (SMBC)		-0.282	-0.166	0.068	-0.444	0.066	0.220
Z score (C/N)			-0.090	0.390	0.433	0.319	-0.336
Z score (SMBN)				-0.151	0.212	-0.161	-0.155
Z score (Urease)					0.200	0.119	-0.130
Z score (Sucrase)						0.276	-0.555*
Z score (Tem.)							0.129

**Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed). N=20

straw putting, O-LF content of D_0, D_1 and D_2 were significantly increased than D_3 treatments; while the latter did not change too much. The soil heavy organic carbon humidification degree is higher. Because soil organic carbon combining with different graded mineral particles form organic-inorganic compounds. It reflects the ability to hold soil organic carbon, ascertains the stability of soil carbon and soil quality. All these play significant roles in the mobilization of soil organic carbon. It showed that the HF content did not vary among all the soil depths after decomposing for 1 year.

The SMBC/N in different soil depths

The SMBC and SMBN content have been plotted in Fig. 3. From the Fig. it is seen that the straw lignin and cellulose decreased with sampling days. The straw lignin of D_0 treatment was lowest than all other treatments.

We could find the change of SMBC not obvious except D_2 treatment which had a high SMBC value and occurred from 90–120 d and also had a peak in the whole sampling period. The content was higher than D_0, D_1 and D_3 by 43.7, 24.3 and 23.8%, respectively (Fig. 3). D_0 had a lowest content in all the soil horizons and there was no significant difference between D_1 and D_3 throughout the whole period of the experiment. In the D_2 treatment and at 120 d of the experimental period, the SMBN value was also higher. There was no significant difference with D_0, D_1 and D_3 treatments. There was a positive, linear, and significant relationships between SMBC and SMBN (y=-2.087-0.1636x, R-sq=0.88%, P < 0.01). Regression analysis showed that the retention rate increased significantly with time.

The urease and sucrase carbon content of straw residue incorporation in different soil depths

Straw incorporation into the soil could increase the urease and sucrase content in the different soil depths (Fig. 5). There was a significant difference with straw incorporation and not incorporation in D_0, D_1 and D_2 treatments (P < 0.05). But this difference was not significant in D_3 experiment. Sucrase did not show significant difference in different treatments but showed a downward trend with soil depths.

Relationship between the factors

After standardizing the results of the correlation analyses for all the soil indicators and as presented in Table 3, it has been seen that SOC significantly and positively correlated with C/N (0.819) and temperature (0.508). On the other hand,

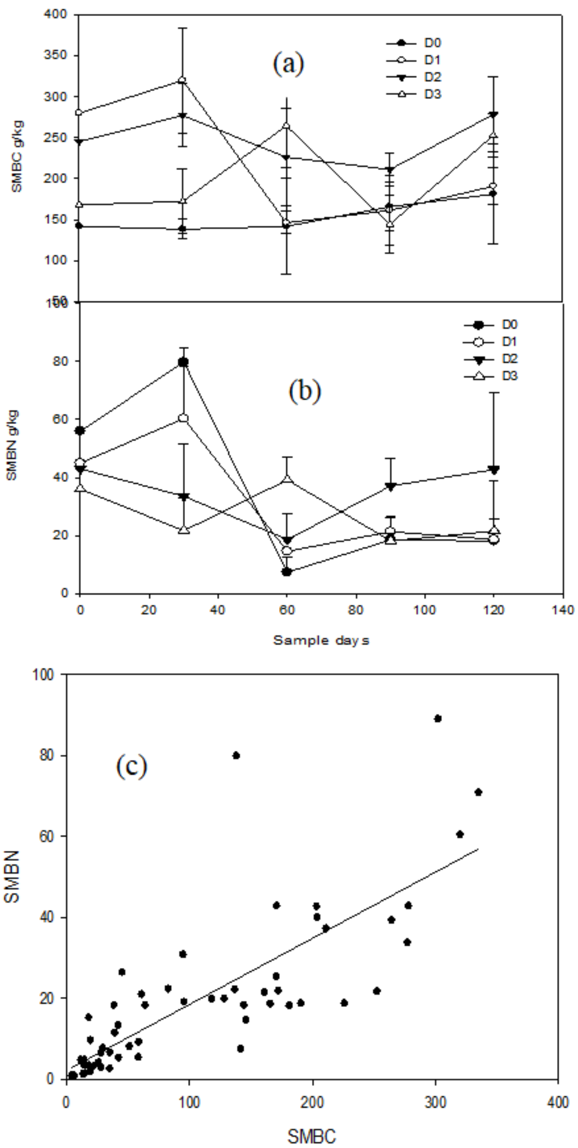

Fig. 3: The relationship between soil microbial carbon and Nitrogen. (**a**) And SMBC with maize straw returning to different soil depths, which D_0 (0-5 cm), D_1(5-15 cm), D_2 (15-30 cm) and D_3 (30-45 cm). For (b), SMBN with maize straw returning to different soil depths, which D_0 (0-5 cm), D_1(5-15 cm), D_2 (15-30 cm) and D_3 (30-45 cm), (c) is the correlation between SMBC and SMBN

sucrase correlated negatively and significantly with moister (-0.555).

Discussion

After three-year of the maize straw return to the experimental fields, those applied at 5–45 cm was completely decomposed. But, the straws on the top soil layer were partially decomposed. The residues of D_1, D_2 and D_3 treatments were reached to less than 20% and declined dramatically than D_0 treatment. But correlation analysis

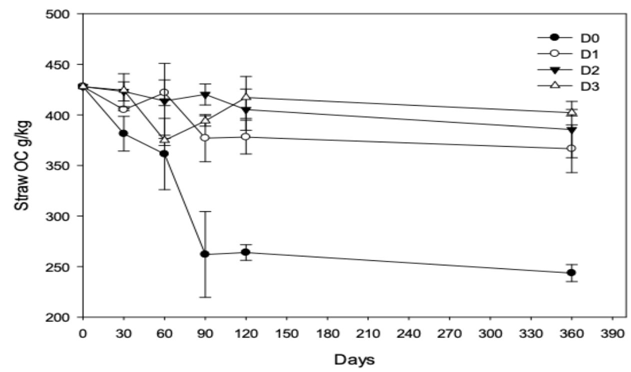

Fig. 4: The straw organic carbon of different soil layers with the decomposing days, which D_0 (0-5 cm), D_1 (5-15 cm), D_2 (15-30 cm) and D_3 (30-45 cm)

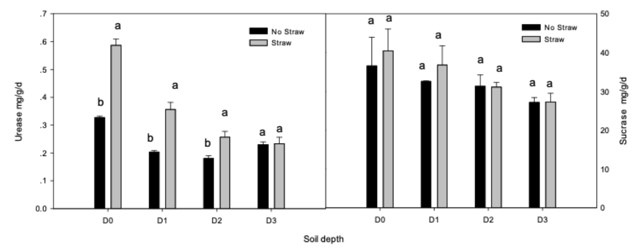

Fig. 5: The different content of Urease and Sucrase between straw return to the soil and not, which D_0 (0-5 cm), D_1 (5-15 cm), D_2 (15-30 cm) and D_3 (30-45 cm)

showed no significant differences among the D_1, D_2 and D_3 treatments. Straws returned into deep soil have been recommended as an effective method to reduce the straw biomass (Zou *et al.* 2016; Yang *et al.* 2016).

Crop straw is a source of organic carbon that can influence the balance of SOC accumulation and decomposition (Bakht *et al.* 2009), especially the LOCF (Malhi *et al.* 2011). There had been some other reports about straw mulch that showed positive (Whitbread *et al.* 2003), or no obvious (Xu *et al.* 2011) or negative effects (Ma *et al.* 2013) in 1–2 year experiments. Generally, maize straw returning to deep soil had benefited for decomposition and carbon storage in Northeast of China (Lal 2004; Wu *et al.* 2016). Kuang *et al.* (2014) showed a regularity in the decomposition of straw which showed a fast rate in the early stage but went into slow in the later stage. The decomposition of straw under buried condition showed 9–20% higher than those mulched on soil. But the straws were buried only at 20 cm soil layer without considering the effect of seeding for the next year. In the present research similar results were shown. The straw returning to the deep soil (D_1–D_3) treatments showed beneficial effects for straw decomposition (70–80%). The reasons were that the soil layers had a good condition about moisture, temperature and more microorganisms for straw decomposition (Zou *et al.* 2016). At the stage of 30 d of straw incorporation into the experimental soil, the decomposition rate reached in peak.

The C/N ratio is an important factor which effects the decomposition of maize straw (Billings 2006). A C/N ratio of 25:1 facilitates the maize straw decomposition and the release of N (Chan *et al.* 2002). On the other hand, a suitable C/N ration could increase crop production (Li *et al.* 2016). Therefore, it was necessary to apply appropriate amounts of nitrogen fertilizer to adjust the C/N ratio.

SOC played an important role in mediating soil available nutrients, soil structure and carbon balance (Shafi *et al.* 2007). The phenomenon has certain lag in response to climate change, land cultivation and farmland management measures could be considered as an optimal way of sustainable crop production (Chen *et al.* 2008). However, most of the researches focus on the returning of straw to deep soil layers because of having an effective increase in the soil organic carbon content. And this could be done by using a deep-ditching-ridge-ploughing method (Soon and Lupwayi 2012) and DB-SR method (Wang *et al.* 2015b). The methodology is different from the methods used in the present investigation. But there is a similarity and the result provides a good conclusion about returning of the straw to 20 cm soil depth.

Soil organic carbon pool is one of the most important dynamic carbon pools in the earth's terrestrial ecosystem. Most important to it is that its small change can lead to a large fluctuation in the global atmospheric CO_2 content (Kumar *et al.* 2010). Different land use patterns and management measures have a great impact on the soil organic carbon storage (Han *et al.* 2017). From the perspective of carbon sequestration in farmland, it is hoped that the higher the stability of organic carbon, lower will be the carbon emission. Straw returning increases the content of active organic carbon and the proportion of active organic carbon in the total organic carbon pool (Navarro-Noya *et al.* 2013).

Marschner *et al.* (2011) showed no significant differences of SOC during the growth stages. This result was similar to those obtained in some previous studies, where the SOC was insensitive to recent agricultural management activities (Cusack *et al*. 2011; Laird and Chang 2013). There may be more influence in physical protection of straw returning. So, we choose the physical method to analyse the effect of the straw returning which was referred to Golchin *et al.* (1998). Chen *et al.* (2008) opined that straw returning could increase the content of LF and had a significant effect on improving soil organic carbon quality. From the perspective of the grouping of organic carbon, the content of LF and O-LF would have been changed easily in all the soil depths, in those HF was relatively stable. Straw incorporation could stimulate microorganisms and might produce more active organic carbon. So the net effect could consequently be predicted in the short term basis (Soon and Lupwayi 2012). The arable degree of culturing in the cultivated soil layer was relatively higher, and the soil recombined organic carbon content does not fluctuate significantly in the short term. However, our study showed that the straw OC of D_3 treatments had a highest content than other depths, except for D_0 treatment which had a lower straw OC (58.0%) than D_1 and D_3. In other words, there was more than 58% of straw carbon flowing into the air when the straws were put on top soil. It indicated that the straw carbon could be saved in the soil when straw returned into deep soil while reducing the volatilization of straw carbon and lower CO_2 emission (Kumar *et al.* 2010). According to Han *et al*. (2017), straw application could increase CO_2–C emission because they change the soil total porosity and organic carbon content.

Bolinder *et al*. (1999) indicated that the soil microbial biomass, specifically soil enzymes, is more sensitive to changes in the soil quality. It showed that the long-term incorporation of crop residues caused significant increases in urease and invertase activity levels over a five-year period (Wei *et al.* 2015). The trends in the enzyme activity levels were also similar in the present study. Compared with no straw incorporation (CK), the treatments of straw return greatly increased the activity levels of soil urease. The function was evident especially in D_0 treatment which had the highest content, but there was no significant difference in soil sucrase. As described in the previous studies (Jin *et al.* 2009), the activity levels were higher in the topsoil which may have been caused due to the "surface activation effect" (Bandick and Dick 1999). These increases may have been attributable to both microbial growth and the stimulation of microbial activity due to enhanced resource availability (Zhao *et al.* 2009).

Crop residues return significantly affected bacterial community structure and increased their population (Navarro-Noya *et al.* 2013). Different microbial communities are responsible for specific functions in the decomposition of crop residues. For example, bacteria dominate in the initial phases, while fungi dominate in the later stages of the crop residues decomposition (Marschner *et al.* 2011). Although the SMBC only have a 5–8% of SOC, it has a higher activity and dynamics in soil carbon which playing a key role in the nutrient cycling (Cusack *et al.* 2011) and acting as a driving force for microbial activity (Li *et al.* 2012). It is considered as a sensitive indicator of changes in soil quality and soil health caused by cultivation (Powlson *et al.* 1987). In this study, SMBC was decreased with the deepening of soil layers and showed a significant difference between soil layers. The D_2 treatment had a highest content of SMBC which is consistent with the result of Zou *et al.* (2016). For this, conditions fulfilled, should be to put straw into deep soil and that a phenomenon of surface microbial aggregation in the soil does exist (Lal 2004).

Conclusion

In a 3 years trial, the maize straw residue returning to deep soil could decompose quickly than putting the maize straw on top of soil (P < 0.01). To incorporate the straw, especially for the straw lignin, decomposing rate and the SMBC content, 15–30 cm soil depth was the best method.

Straw returning to the deep soil also can store more stable carbon in the soil and can increase the accumulation of organic matter. The effects of farming practices and straw returning to the field and activating carbon, not only stir up soil layer but also distribute crop residues. The application also effects the soil physical, chemical and biological changes over a long-term. We, however, have studied for only a short-term farming. The lack of scientific knowledge for a long-term farming, so to say >10 years on the impact of soil activated carbon components requires further exploration.

Acknowledgement

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