academicJournals

Vol. 8(47), pp. 5982-5988, 5 December, 2013
DOI: 10.5897/AJAR11.1182
ISSN 1991-637X ©2013 Academic Journals
http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Short-term effects of sustainable agricultural practices for spring maize (*Zea mays* L.) production on soil organic carbon characteristics

Zhang Jinjing[1], Gao Qiang[1], Wang Qinghe[1], Dong Peibo[1], Feng Guozhong[1], Li Cuilan[1] and Wang Lichun[2]*

[1]College of Resource and Environmental Science, Jilin Agricultural University, Changchun 130118, China.
[2]Agricultural Environments and Resources Research Centre, Northeast Agricultural Research Centre of China, Changchun 130124, China.

Accepted 5 September, 2013

The effects of the integrated adoption of several recommended sustainable agricultural practices (SAP) on maize grain yield and the quantitative and qualitative characteristics of soil organic carbon (SOC) were studied in 2 years, spring maize monoculture field plot experiment. The recommended agricultural practices included conservation tillage, combined application of organic manure and chemical fertilizers, and crop residue return. Compared with the conventional agricultural practices (CAP), the maize grain yield increased in the SAP treatment, and the difference between the two treatments was statistically significant ($P<0.05$) in the second season of the experiment (2010). The content of soil total organic carbon (TOC) and organic C fractions (that is, water soluble organic C, easily oxidizable organic C, particulate organic C, humus C and black C) were higher in the SAP than in the CAP treatment, although the differences between the two treatments were not significant. The relative intensities of O-alkyl C and carbonyl C and the aliphatic C / aromatic C ratio were higher, while the relative intensities of alkyl C and aromatic C and the ratios of alkyl C / O-alkyl C and hydrophobic C / hydrophilic C were lower in solid-state ^{13}C CPMAS NMR spectra of HF-treated soils in the SAP than in the CAP treatment. The recommended sustainable agricultural practices were beneficial for the increase of maize grain yield and the improvement of the quantity and quality of SOC during a short-term period.

Key words: Soil organic carbon, organic carbon fraction, agricultural practice, spring maize, ^{13}C CPMAS NMR.

INTRODUCTION

Anthropogenic activities have led to an increase in atmospheric concentration of carbon dioxide (CO_2) from 280 ppm in the pre-industrial era to almost 400 ppm at present, and is increasing at the rate of about 2.2 ppm per year (Lal, 2011). The sequestration of atmospheric CO_2 into terrestrial soils is a vital solution for mitigating climate change. The soil organic carbon (SOC) storage in the global agro-ecosystem nearly accounts for 10% of the total terrestrial SOC storage (Tang et al., 2010), and thus agricultural soils play an important role in the global carbon (C) cycle. At the same time, SOC in agro-ecosystem also is also vital for soil quality, crop productivity, and the sustainability of farming systems (Rees et al., 2001). Agricultural practices can have

*Corresponding author. E-mail: wlic1960@163.com, Tel: +86 431 87063168.

profound effects on the organic C contents of agricultural soils. Sustainable agricultural practices such as conservation tillage (Chen et al., 2009), manure application (Gong et al., 2009), crop residue return (Bakht et al., 2009) and crop rotation (Kelley et al., 2003) are effective in increasing SOC levels. However, the rate of soil C sequestration through the adoption of sustainable agricultural practices differs among eco-regions and is dependent on soil texture and structure, rainfall, temperature, farming systems and soil management (Lal, 2004).

Maize (*Zea mays* L.) is the second most important cereal crop after rice in China. Jilin province, located in the Songnen Plain of northeast China, is one of the major maize-growing regions of China and is also one of the major contributors to the maize belt of the world's temperate zone (Zhang et al., 2005). Nevertheless some conventional agricultural practices used by local farmers in this region are not correct for achieving the increase of SOC and thus increasing/stabilizing maize yield. These conventional practices included: (1) conventional tillage, (2) single application of chemical fertilizers, and (3) crop residues burning or removal. Analogous problems also exist in other major agricultural regions of China (Wang et al., 2008) and in many developing counties (Chivenge et al., 2007; Bakht et al., 2009; Moloto, 2009). Thus, the introduction of sustainable agricultural practices is necessary to increase SOC. A number of researches have been carried out on the effects of a single agricultural practice on SOC characteristics. However, the effect of the integrated and contemporary introduction of some sustainable agricultural practices on SOC characteristics, especially on the qualitative properties of SOC, was not yet fully investigated. The aim of this study is to assess the effects of the introduction of some sustainable agricultural practices on both quantitative and qualitative characteristics of SOC in 2 years, spring maize monoculture field plot experiment.

MATERIALS AND METHODS

Site description

The field experiment was started in April 2009 on a farm field located in Sikeshu Township, Lishu County, Jilin Province, northeast China (124°03′ E, 43°20′ N). The site has a semi-humid monsoon continental climate of the temperate zone. The average annual temperature is 6.5°C during the study period. The annual effective accumulated temperature above 10°C ranges from 3 000 to 3 200°C. The average annual precipitation is between 525 and 550 mm, with 60% occurring between June and August. The average amount of sunshine each year is about 2 500 h, and the frost-free period is between 127 and 148 days.

The soil in the study site was classified as an Alluvic Primosols, according to the Chinese Soil Taxonomy (CRGCST, 2001), a Fluvent according to the USDA Soil Taxonomy (Soil Survey Staff, 1998), and a Fluvisol according to the World Reference Base (FAO-ISRIC-ISSS, 1998). Alluvic Primosols was one common soil type used for maize production in Jilin province. Before starting the experiment in 2009, the content of organic C, total N, hydrolysable N, available P, available K, and pH in the 0 to 20 cm soil layer were 7.08, 1.04, 92.0, 29.1, 52.0 and 5.15 mg kg^{-1}, respectively.

Experimental design and sampling

Two agricultural strategies, namely conventional agricultural practice (CAP) and sustainable agricultural practice (SAP), were adopted in the present study. Continuous spring maize monoculture is common in the region. The maize cultivar used was Xianyu 335, which was the dominant hybrid used in Chinese agriculture with planting area above 5 000 000 ha between 1980 and 2009 (Wu et al., 2011). The seeds were coated prior to sowing. The weeds were controlled by atrazine after sowing. The size of each plot was 120 m^2 (20 × 6 m). The experimental design was a completely randomized block with three replications for each of the two treatments.

CAP

Before sowing in spring, rotary tillage and maize stubble breaking were conducted in the 10 to 15 cm soil layer. The main purposes of stubble breaking were to ensure the quality of sowing and facilitate the decomposition of stubble. The sowing date was selected according to the usual practice of the local farmers (around 20 April of every year). The seeding rate was chosen to guarantee the final number of maize seedlings was 55 000 plants ha^{-1}. During the growth period of maize, intertillage was not conducted while N fertilizer was top dressed at the jointing stage. Only chemical fertilizers were applied for this treatment. The application rates of fertilizers were 225 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1} and 60 kg k_2O ha^{-1}. All of the P_2O_5 and K_2O and half of the N were applied as basal fertilizers before sowing, and the remaining N was applied as jointing fertilizer. After harvesting, the maize stubble was retained in the field, while the maize stalk was either removed from the field or burnt *in situ*.

SAP

There was no tillage operation prior to sowing in spring for this treatment. Sowing was carried out when the temperature of soil layer within 5 cm was stabilized at 5 to 6°C, and the air temperature was stabilized at 7 to 9°C (around 1 May of every year). The seed was sown manually in the plough furrow using disseminator by precision dibbling method. The sowing rate was chosen to guarantee the final number of maize seedlings was between 70 000 and 80 000 plants ha^{-1}. The maize roborant, which could confer enhanced resistance to stalk lodging, was sprayed at jointing stage. Both chemical and organic fertilizers were applied. The application doses of fertilizers were 240 kg N ha^{-1} as urea, 100 kg P_2O_5 ha^{-1} as superphosphate, 100 kg k_2O ha^{-1} as potassium sulfate, 75 kg ha^{-1} of $ZnSO_4$ and 2.0 to 2.5 t ha^{-1} of organic fertilizer. All of the P_2O_5 and organic fertilizer and 45% of the N and 80% of the K_2O were applied as basal fertilizers, $ZnSO_4$ and 35% of the N was applied as seed fertilizer, and the remaining N and K_2O were applied as ear fertilizer. After harvesting, the standing stubble of about 30 cm in height was retained with all maize stalk left as a mulch cover. Maize was cultivated in a three-year fallow rotation.

The soil samples were collected to a depth of 0 to 20 cm in October 2010 from five locations in each plot, and then thoroughly mixed into a composite sample. The collected soil samples were air-dried, milled and sieved through a 2 mm sieve. Prior to solid-state ^{13}C NMR analysis, all soil samples were pre-treated with 10% hydrofluoric acid (HF) as recommended by Schmidt et al. (1997) to remove magnetic materials, concentrate the organic matter, and increase the signal-to-noise (S/N) ratio of the resultant NMR

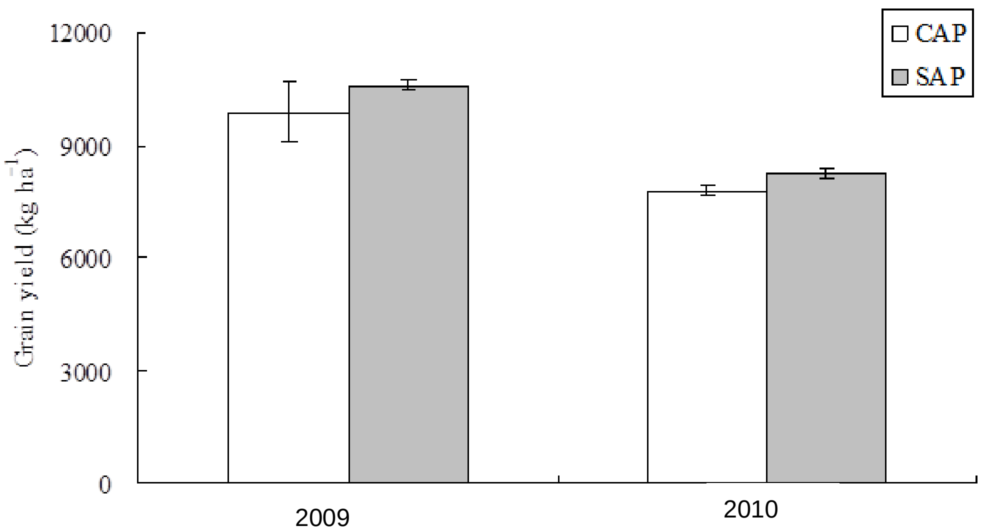

Figure 1. Maize grain yield under conventional agricultural practices (CAP) and sustainable agricultural practices (SAP) in 2009 and 2010.

spectra.

Soil analysis

Soil total organic carbon (TOC) was determined by $K_2Cr_2O_7$ oxidation and total N by semi-micro Kjeldahl method (Lao, 1988). The water soluble organic carbon (WSOC) and humus carbon (HC) in each sample were successively analyzed according to the method described by Zhang et al. (2010). Briefly, the soil samples were first suspended in distilled water at 70±1°C for 60 min. The supernatant was referred to as the water soluble fraction (WSF). After centrifugation, the remaining soil was further extracted using a solution of 0.1 mol l^{-1} NaOH and 0.1 mol l^{-1} $Na_4P_2O_7$ at 70±1°C for 60 min. The dark brown alkaline supernatant solution, corresponding to the total alkali-soluble humic extract (HE), was separated into the acid-insoluble humic acid (HA) and the acid-soluble fulvic acid (FA) fractions by acidifying the alkaline supernatant to pH 1.0. The residue remaining after extraction was referred to as the humin (HM) fraction. The carbon contents of WSF (WSOC), HE (HEC) and HA (HAC) were directly determined, while that of HM (HMC) was calculated by subtraction. Easily oxidizable organic carbon (EOC) was determined as described by Blair et al. (1995). Soil samples containing 15 mg of organic carbon were reacted with 333 mmol l^{-1} $KMnO_4$ solution for 60 min, and the amount of EOC was spectrophotometrically determined from the amount of $KMnO_4$ reduced. Particulate organic carbon (POC) was measured following Cambardella and Elliott (1992). Soil samples were dispersed in 100 ml of 5 gL^{-1} $(NaPO_3)_6$ solution and shaken at 90 r min^{-1} for 18 h. The suspension was passed through a 53 μm screen and the retained coarse fraction was rinsed with distilled water, dried at 65°C, weighed and ground for determination of organic C.

Black carbon (BC) was analyzed by the method given by Aiken et al. (1985). Soil samples were reacted with 25 ml of 0.1 mol L^{-1} $K_2Cr_2O_7$+2 mol L^{-1} H_2SO_4 solution at 55±1°C for 60 h, and the oxidized organic C was determined by titration using 0.2 mol L^{-1} $FeSO_4$ solution. The content of BC was calculated by subtracting the oxidized organic carbon from the TOC.

The solid-state ^{13}C CPMAS NMR experiment was performed in the National Analytical Research Center of Electrochemistry and Spectroscopy, Changchun Institute of Applied Chemistry, Chinese Academy of Sciences, Changchun, China. The spectra were obtained on a Bruker AVANCE III 400 WB spectrometer (Fällanden, Switzerland) operating at 100.62 MHz, equipped with a 4 mm probe head. The dried and finely powdered soil samples (<0.1 mm) were packed in the ZrO_2 rotor closed with Kel-F cap. The conditions used were: spinning rate 5 KHz, contact time 2 ms, recycle delay 6 s, line broadening 50 Hz, and 8000 total scans. Chemical shifts were referenced to the resonances of Adamantane standard (δ=29.5). Spectra were divided into four main chemical shift regions (Mathers et al., 2003), namely alkyl C (0 - 50 ppm), O-alkyl C (50 - 110 ppm), aromatic C (110 - 160 ppm) and carbonyl C (160 to 210 ppm). The relative intensity for each chemical shift region was obtained with the integration routine of the spectrometer. The ratios of alkyl C to O-alkyl C (alkyl C / O-alkyl C), of aliphatic C to aromatic C (aliphatic C / aromatic C), and of hydrophobic C to hydrophilic C (hydrophobic C / hydrophilic C) (Zhang et al., 2009) were calculated.

Statistical analysis

Data were analyzed statistically by analysis of variance (ANOVA) procedure. Least significant difference (LSD) was employed to assess differences between treatment means at 5% significance level. Standard deviations were calculated for means values of all the determination. All statistical analyses were performed using the SPSS 16.0 for Windows statistical software package (SPSS, Chicago, IL, USA).

RESULTS

Maize yield

Maize grain yields under CAP and SAP treatments are shown in Figure 1. In the first experimental season (2009), the difference between maize grain yields obtained by different agricultural practices was not statistically significant, but a higher value could be observed in the SAP treatment than in CAP. The grain yield was significantly higher in the second experimental

Table 1. The contents of total organic carbon (TOC), water soluble organic carbon (WSOC), easily oxidizable organic carbon (EOC), particulate organic carbon (POC), total alkali-soluble humic extract carbon (HEC), humic acid carbon (HAC), humin carbon (HMC) and black carbon (BC) in soils under conventional agricultural practices (CAP) and sustainable agricultural practices (SAP).

Agricultural practices	TOC ($g\ kg^{-1}$)	WSOC ($g\ kg^{-1}$)	EOC ($g\ kg^{-1}$)	POC ($g\ kg^{-1}$)	HEC ($g\ kg^{-1}$)	HAC ($g\ kg^{-1}$)	HMC ($g\ kg^{-1}$)	BC ($g\ kg^{-1}$)
CAP	7.30±0.65	0.23±0.12	2.05±0.63	1.17±0.24	2.91±0.54	2.45±0.22	4.40±0.12	3.29±0.61
SAP	8.07±0.80	0.24±0.10	3.66±1.01	1.53±0.13	3.29±0.38	2.50±0.30	4.78±0.42	3.49±1.75
F(*P*)	1.58 (>0.05)	0.02 (>0.05)	5.48 (>0.05)	5.26 (>0.05)	1.00 (>0.05)	0.06 (>0.05)	2.34 (>0.05)	0.03 (>0.05)

Mean values ± standard error of three replicates are presented. *F*, variance ratio; *P*, significance level.

season (2010) for the SAP treatment (8.24 t ha^{-1}) than for the CAP treatment (7.78 t ha^{-1}). Moreover, maize grain yield was significantly lower in 2010 than in 2009.

Soil total organic carbon and organic carbon fractions

The contents of soil total organic C and organic C fractions are shown in Table 1. The contents of TOC, WSOC, EOC, POC, HEC, HAC, HMC, BC were all higher in the SAP than in the CAP treatment, although the differences between the two treatments were not statistically significant. The increase amplitudes were larger for the EOC and POC (78.5 and 30.8%, respectively) than for the HEC, HAC, HMC and BC (13.1, 2.04, 8.64 and 6.08%, respectively).

Solid-state ^{13}C CPMAS NMR spectra of HF-treated soils

The solid-state ^{13}C CPMAS NMR spectra of HF-treated soils under CAP and SAP treatments are shown in Figure 2. In the alkyl C region, three major peaks at 20, 25 and 43 ppm could be identified. The peaks were assigned as $-CH_3$, $-CH_2-$, and branched aliphatic C, respectively. In the region for O-alkyl C, the signals at 54 - 57, 71 - 73 and 101 - 104 ppm were generally ascribed to methoxyl C, carbohydrate C and di-O-alkyl C, respectively. In the aromatic C region, the signal at 122 to 129 ppm was due to aryl C. The small peaks at 151 to 156 ppm were the signal of phenolic C. The signals in the carbonyl C region were concentrated between 170 and 188 ppm, indicating that there was carbonyl C of carboxylic acids, esters and amides (Kögel-Knabner, 1997; Mathers et al., 2003; Zhang et al., 2009).

The relative intensity of carbon functional groups of HF-treated soils is shown in Table 2. Although there was no significant difference in the relative intensity of alkyl C, O-alkyl C, aromatic C and carbonyl C regions between the CAP and SAP treatments, an increase in the O-alkyl C and carbonyl C and a decrease in the alkyl C and aromatic C were observed in the SAP treatment. The ratios of alkyl C / O-alkyl C and hydrophobic C / hydrophilic C were lower, whereas the aliphatic C / aromatic C ratio was higher in the SAP than in the CAP treatment.

DISCUSSION

Previous studies showed that the maize grain yield was higher under the combined application of organic manure and chemical fertilizers than under the application of chemical fertilizers only (Fan et al., 2005), under rational sowing date and planting density than under conventional ones (Andrade, 1995; Otegui et al., 1996), and under crop residue return than under residue removal (Sharma et al., 2011). However, the results on the effect of tillage practices on maize grain yield were not consistent among studied. Some studies showed that maize grain yield was higher under reduced/no tillage than under conventional tillage (Wang et al., 2007; Sharma et al., 2011), other studies indicated that reduced/minimum/no tillage (Atreya et al., 2008; Sharma et al., 2011) could give similar or even lower maize grain yield as compared to conventional tillage. In the present study, we found that maize grain yield increased by the integrated application of the recommended sustainable agricultural practices with respect to the conventional agricultural practices (Figure 1). Thus, the recommended agricultural practice was suitable for the local maize production. The significantly lower maize grain yield during the second year than during first could be due to lower precipitation from early June to early July in 2010 than in 2009.

In previous studies, higher soil organic C contents under no tillage with residue return than under conventional tillage with residue removal (Razafimbelo et al., 2008), under reduced tillage than under conventional tillage (Šimanský et al., 2008), under tillage with organic manure than under tillage without organic manure (Agbede and Ojeniyi, 2009), and under the combined application of organic manure and chemical fertilizers than under the application of organic manure or chemical fertilizers (Cai and Qin, 2006; Zhu et al., 2007), have been reported. These could explain our present result that the content of SOC was higher in the recommended than in the conventional agricultural practices (Table 1). By the application of some different sustainable

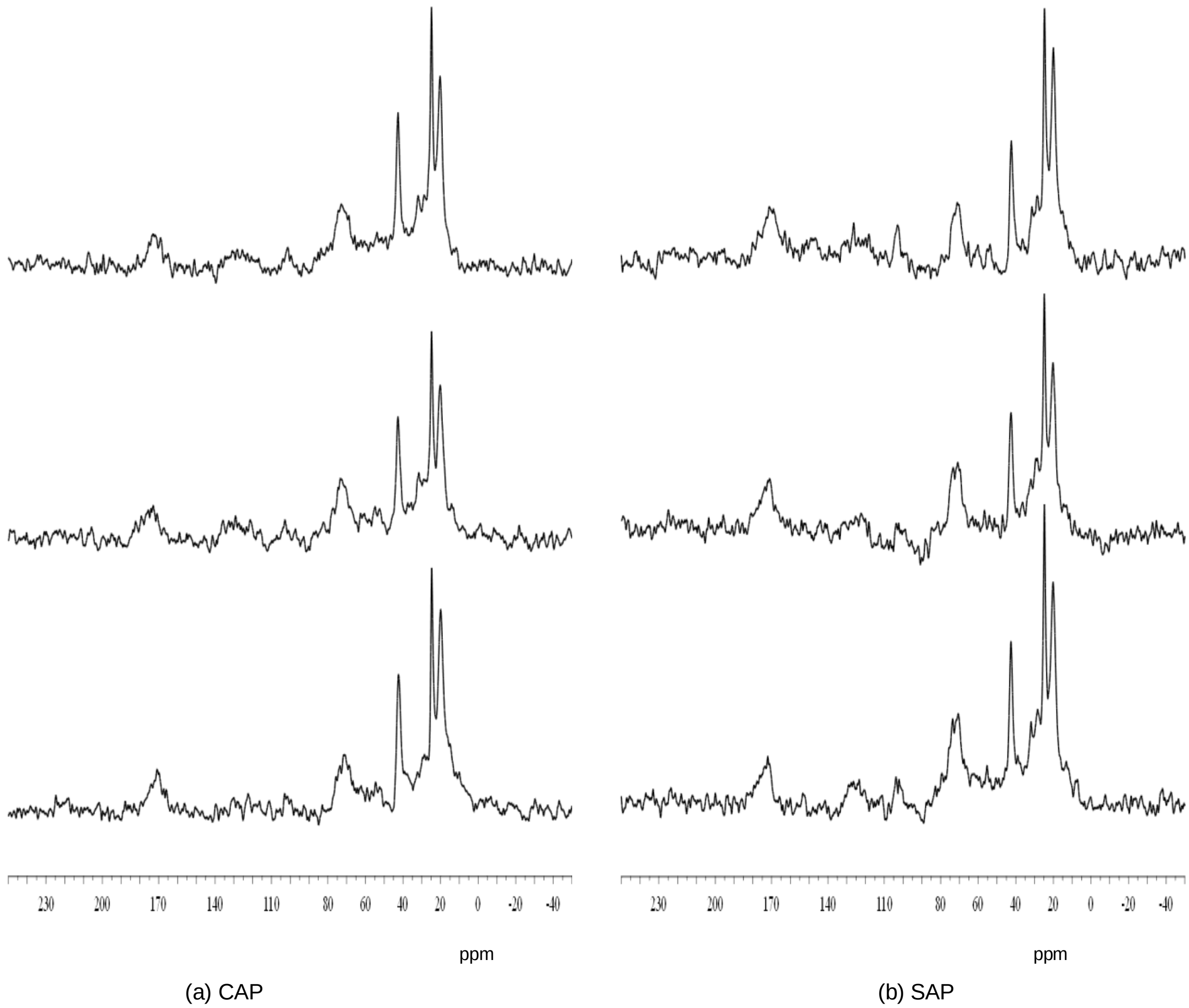

Figure 2. ^{13}C CPMAS NMR spectra of HF-treated soils under (a) conventional agricultural practices (CAP) and (b) sustainable agricultural practices (SAP).

Table 2. Distribution of different carbon types from ^{13}C CPMAS NMR spectra of HF-treated soils under conventional agricultural practices (CAP) and sustainable agricultural practices (SAP) (%).

Agricultural practices	Alkyl C	O-alkyl C	Aromatic C	Carbonyl C	Alkyl C/ O-alkyl C	Aliphatic C/ Aromatic C	Hydrophobic C/ Hydrophilic C
CAP	58.2±6.73	24.6±2.71	8.46±2.27	8.37±1.89	2.41±0.56	10.3±2.84	2.07±0.47
SAP	56.0±7.15	27.0±1.09	7.37±3.05	9.12±3.15	2.08±0.33	13.1±6.92	1.78±0.30
F(*P*)	0.14 (>0.05)	2.09 (>0.05)	0.24 (>0.05)	0.12 (>0.05)	0.78 (>0.05)	0.44 (>0.05)	0.82 (>0.05)

Mean values ± standard error of three replicates are presented. *F*: variance ratio; *P*: significance level.

agricultural techniques, some researchers (Jhamtani, 2007; Moloto, 2009) found that farms that were managed under sustainable agricultural practices generally contain higher soil organic C content than farms that were managed under conventional agricultural practices, in accordance with our results. The larger increase in the active organic carbon fractions (EOC and POC) than in the resistant organic carbon fractions (HEC, HAC, HMC and BC) (Table 1) implied that the two active organic carbon fractions could be a more sensitive index for the effects of agricultural practices.

The ratios of alkyl C / O-alkyl C, aliphatic C / aromatic

C, and hydrophobic C / hydrophilic C have been used as indicators of the degree of decomposition or humificationaliphaticity or aromaticity, and hydrophobicity of SOC, respectively (Webster et al., 2001; Chen and Chiu, 2003; Mathers et al., 2003; Ussiri and Johnson, 2003; Chen et al., 2004; Zhang et al., 2009). A larger value of the ratios indicates that SOC was more decomposed, aliphatic and hydrophobic. Thus, our results (Table 2) implied that the degree of decomposition and hydrophobicity of SOC was lower while that of aliphaticity was higher in the SAP than in the CAP treatment. Moreover, the alkyl C: O-alkyl C ratio has been used as an indicator of the quality of SOC (Chen et al., 2004). The lower alkyl C/O-alkyl C ratio in our study in soil under SAP than under CAP treatment indicated that less accumulation of relative recalcitrant carbon components and thus the quality of SOC was better in the SAP treatment. The increase of aliphatic C / aromatic C ratio and the decrease of hydrophobic C / hydrophilic C ratio were identical with the decrease of alkyl C / O-alkyl C ratio under SAP with respect to the CAP treatment. The improved SOC quality under SAP could also be ascribed to the use of conservation tillage, combined organic and chemical fertilizers, and crop residue return. In the previous studies, it was found that the carbohydrate was higher and aromatic C was lower in no tillage than in conventional tillage soils (Arshad et al., 1990).

In conclusion, the recommended sustainable agricultural practice could increase maize grain yield and improve the quantitative and qualitative characteristics of SOC with respect to the conventional agricultural practice during a short-term period. Further studies are necessary to assess long-term effects of sustainable agricultural practice on SOC dynamics.

ACKNOWLEDGEMENTS

This work was supported by the National Basic Research Program of China (grant no. 2009CB118600), the National Agricultural Department Public Benefit Research Foundation (grant no. 201103030), the Postdoctoral Project of Northeast Agricultural Research Centre of China (grant no. 00225), and the Postdoctoral Project of Jilin Province (grant no. 01912). We wish to thank Zhiyong Liu for help in the collection of soil samples. We also wish to thank Dr. Zijiang Jiang for his technical support in solid-state ^{13}C CPMAS NMR spectroscopy. Moreover, we would like to express our great respect for the editors and anonymous reviewers.

REFERENCES

Aiken GR, Mcknight DM, Wershaw RL (1985). Humic Substances in Soils, Sediment and Water: Geochemistry, Isolation and Characterization. New York: John Wiley & Sons.

Agbede TM, Ojeniyi SO (2009). Tillage and poultry manure effects on soil fertility and sorghum yield in southwestern Nigeria. Soil Tillage Res. 104:74-81.

Andrade FH (1995). Analysis of growth and yield of maize, sunflower and soybean grown at Balcarce, Argentina. Field Crops Res. 41:1-12.

Arshad MA, Schnitzer M, Angers DA, Ripmeester JA (1990). Effects of till vs no-till on the quality of soil organic matter. Soil Biol. Biochem. 22:595-599.

Atreya K, Sharma S, Bajracharya RM, Rajbhandari NP (2008). Developing a sustainable agro-system for central Nepal using reduced tillage and straw mulching. J. Environ. Manage. 88:547–555.

Bakht J, Shafi M, Jan MT, Shah Z (2009). Influence of crop residue management, cropping system and N fertilizer on soil N and C dynamics and sustainable wheat (*Triticum aestivum* L.) production. Soil Till. Res. 104:233-240.

Blair GJ, Lefroy RDB, Lisle L (1995). Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for agricultural systems. Aust. J. Agric. Res. 46:1459-1466.

Cai ZC, Qin SW (2006). Dynamics of crop yields and soil organic carbon in a long-term fertilization experiment in the Huang-Huai-Hai Plain of China. Geoderma 136:708–715.

Cambardella CA, Elliott ET (1992). Particulate soil organic matter changes across a grassland cultivation sequence. Soil Sci. Soc. Am. J. 56:777–783.

Chen CR, Xu ZH, Mathers NJ (2004). Soil carbon pools in adjacent natural and plantation forests of subtropical Australia. Soil Sci. Soc. Am. J. 68:282–291.

Chen H, Hou R, Gong Y, Li H, Fan M, Kuzyakov Y (2009). Effects of 11 years of conservation tillage on soil organic matter fractions in wheat monoculture in Loess Plateau of China. Soil Till. Res. 106:85-94.

Chen JS, Chiu CY (2003). Characterization of soil organic matter in different particle-size fractions in humid subalpine soils by CP/MAS ^{13}C NMR. Geoderma, 117:129–141.

Chivenge PP, Murwira HK, Giller KE, Mapfumo P, Six J (2007). Long-term impact of reduced tillage and residue management on soil carbon stabilization: Implications for conservation agriculture on contrasting soils. Soil Till. Res. 94:328-337.

Cooperative Research Group on Chinese Soil Taxonomy (CRGCST) (2001). Chinese Soil Taxonomy. Beijing & New York: Science Press.

Fan T, Wang S, Tang X, Luo J, Stewart BA, Gao Y (2005). Grain yield and water use in a long-term fertilization trial in Northwest China. Agric. Water Manage. 76:36–52.

FAO-ISRIC-ISSS (1998). World Reference Base for Soil Resources. Rome: World Soil Resources Report 84, FAO.

Gong W, Yan X, Wang J, Hu T, Gong Y (2009). Long-term manure and fertilizer effects on soil organic matter fractions and microbes under a wheat-maize cropping system in northern China. Geoderma 149:318-324.

Jhamtani H (2007). Putting Farmers First in Sustainable Agriculture Practices. Macalister: Third World Network.

Kelley KW, Long Jr JH, Todd TC (2003). Long-term crop rotations affect soybean yield, seed weight, and soil chemical properties. Field Crops Res. 83:41-50.

Kögel-Knabner I (1997). ^{13}C and ^{15}N NMR spectroscopy as a tool in soil organic matter studies. Geoderma 80:243-270.

Lal R (2004). Soil carbon sequestration impacts on global climate change and food security. Science 304:1623-1627.

Lal R (2011). Sequestering carbon in soils of agro-ecosystems. Food Policy, 36:533-539.

Lao JC (1988). Handbook of Soil Agro-Chemistry Analysis. Beijing: China Agriculture Press.

Mathers NJ, Mendham DS, O'Connell AM, Grove TS, Xu Z, Saffigna PG (2003). How does residue management impact soil organic matter composition and quality under *Eucalyptus globulus* plantations in southwestern Australia. Forset Ecol. Manag. 179:253-267.

Moloto KP (2009). The potential of sustainable agricultural practices to enhance soil carbon sequestration and improve soil quality. Thesis of Masters of Philosophy, The University of Stellenbosch, Matieland, South Africa.

Otegui M, Ruiz RA, Petruzzi D (1996). Modeling hybrid and sowing date effects on potential grain yield of maize in a humid temperate region. Field Crops Res. 47:167-174.

Razafimbelo TM, Albrecht A, Oliver R, Chevallier T, Chapuis-Lardy L, Feller C (2008). Aggregate associated-C and physical protection in a tropical clayey soil under Malagasy conventional and no-tillage systems. Soil Till. Res. 98:140-149.

Rees RM, Ball BC, Campbell CD, Watson CA (2001). Sustainable Management of Soil Organic Matter. UK: CABI Publishing.

Schmidt MWI, Knicker H, Hatcher PG, Kögel-Knabner I (1997). Improvement of ^{13}C and ^{15}N CPMAS NMR spectra of bulk soils, particle size fractions and organic material by treatment with 10% hydrofluoric acid. Eur. J. Soil Sci. 48:319-328.

Sharma P, Abrol V, Sharma RK (2011). Impact of tillage and mulch management on economics, energy requirement and crop performance in maize-wheat rotation in rainfed subhumid inceptisols, India. Eur. J. Agron. 34:46–51.

Šimanský V, Tobiašová E, Chlpík J (2008). Soil tillage and fertilization of Orthic Luvisol and their influence on chemical properties, soil structure stability and carbon distribution in water-stable macro-aggregates. Soil Till. Res. 100:125–132.

Soil Survey Staff (1998). Keys to Soil Taxonomy. 8th edition. USDA Natural Resources Conservation Service, Washington.

Tang HJ, Qiu JJ, Wang LG, Li H, Li CS, van Ranst E (2010). Modeling soil organic carbon storage and its dynamics in croplands of China. Agr. Sci. China 9:704-712.

Ussiri DAN, Johnson CE (2003). Characterization of organic matter in a northern hardwood forest soil by ^{13}C NMR spectroscopy and chemical methods. Geoderma 111:123–149.

Wang L, Qiu J, Tang H, Li H, Li C, Van Ranst E (2008). Modelling soil organic carbon dynamics in the major agricultural regions of China. Geoderma 147:47-55.

Wang XB, Cai DX, Hoogmoed, WB, Oenema O, Perdok UD (2007). Developments in conservation tillage in rainfed regions of North China. Soil Till. Res. 93:239–250.

Webster EA, Hopkins DW, Chudek JA, Haslam SFI, Šimek M, Pîcek T (2001). The relationship between microbial carbon and the resource quality of soil carbon. J. Environ. Qual. 30:147–150.

Wu QP, Chen FJ, Chen YL, Yuan LX, Zhang FS, Mi GH (2011). Root growth in response to nitrogen supply in Chinese maize hybrids released between 1973 and 2009. Sci. China Life Sci. 54:642–650.

Zhang JJ, Dou S, Song XY (2009). Effect of long-term combined nitrogen and phosphorus fertilizer application on ^{13}C CPMAS NMR spectra of humin in a Typic Hapludoll of Northeast China. Eur. J. Soil Sci. 60:966-973.

Zhang J, Hayakawa S, Zhou D, Zhang H (2005). Risk assessment and regionalization of agro-meteorological hazards in Jilin province, China. J. Agric. Meteorol. 60:921-924.

Zhang JJ, Wang LB, Li CL (2010). Humus characteristics after maize residues degradation in soil amended with different copper concentrations. Plant Soil Environ. 56:120-124.

Zhu P, Ren J, Wang L, Zhang X, Yang X, MacTavish D (2007). Long-term fertilization impacts on corn yields and soil organic matter on a clay-loam soil in Northeast China. J. Plant Nutr. Soil Sci. 170:219–223.