Effects of Straw Return on Soil Water-Stable Aggregates and Their Carbon Distribution: Postprint

Authors: Wang Meijia, Wang Feng, Su Sihui, Su Yehang, Sun Yue, Yingyan Wang, Guangxin Meng, Jiang Ying, Qi Hua, Qi Hua

Date: 2019-09-11T00:00:00+00:00

Abstract

This study investigated the effects of straw return methods on the composition, stability, and organic carbon distribution of soil water-stable aggregates, providing a reference for crop production and straw return systems in the dryland farming region of Northeast China. A field experiment was initiated in 2015, with four treatments: rotary tillage with straw return (RT), rotary tillage without straw return (CK1), plow tillage with straw return (PT), and plow tillage without straw return (CK2). Soil samples collected after the 2017 harvest were analyzed for mass fraction of different aggregate size classes, stability, soil organic carbon (SOC) distribution, and maize yields over the recent three years were measured. The results showed that straw return treatments increased SOC content in aggregates of all sizes in the soil surface layer and promoted the formation and stability of macroaggregates. In the 0-10 cm soil layer, under the same tillage practice, SOC content in the RT treatment increased by 13.90% compared with the CK1 treatment[WTBX] ($P<0.05$),[WTBZ] and the PT treatment increased by 9.29% compared with the CK2 treatment[WTBX] ($P<0.05$).[WTBZ] Under different tillage practices, compared with the PT treatment, the RT treatment increased macroaggregate mass by 22.05%, increased the mean weight diameter of aggregates ([WTBX]MWD[WTBZ]) by 7.78%, and reduced silt + clay aggregate content by 16.81%[WTBX] ($P<0.05$).[WTBZ] Comparison of maize yields across different years revealed that yields varied with precipitation. Precipitation in 2017 was lower than in 2016, and yields of all treatments in 2017 were lower than in 2016, but the magnitude of decrease differed among treatments. The yield reduction in RT and PT treatments (8.57% and 9.72%) was lower than that in CK1 and CK2 treatments (10.84% and 12.13%), indicating that straw return treatments had a yield-stabilizing effect, with the RT treatment showing a more pronounced trend. Therefore, under conditions of full-layer straw return in the spring maize dryland farming region

of Northeast China, rotary tillage with straw return promotes the formation of soil water-stable aggregates, increases soil SOC content, and can provide yield stability assurance for maize production across different precipitation years.

Full Text

Effects of Straw Turnover on Soil Water-Stable Aggregates and Soil Carbon Distribution

WANG Meijia, WANG Feng, SU Sihui, SU Yehan, SUN Yue, WANG Yingyan, MENG Guangxin, JIANG Ying, QI Hua

(College of Agronomy, Shenyang Agricultural University, Shenyang 110866, Liaoning, China)

Abstract

This study investigated the effects of crop residue turnover on the composition and stability of soil water-stable aggregates and the distribution of soil organic carbon (SOC) to provide a reference for crop production and residue management in semi-arid regions of northeast China. A field experiment including rotary tillage and plow tillage with/without crop residue incorporation treatments (RT, CK1, PT, and CK2) was initiated in 2015. The purposes were to explore the effects of tillage and straw management practices on the proportion of soil aggregates of various sizes, stability of soil water-stable aggregates, distribution of SOC in 2017, and maize yield from 2015 to 2017. Our results indicated that residue incorporation significantly increased SOC content by 13.90% (RT) and 9.29% (PT), respectively, in the 0–10 cm soil layer compared with those without residue incorporation ($P < 0.05$). Compared with PT, the content of water-stable aggregates (>2 mm) and mean weight diameter of aggregates (MWD) were significantly increased by 22.05% and 7.78%, respectively, while the content of water-stable aggregates (<0.053 mm) was significantly decreased by 16.81% under RT management ($P < 0.05$). In addition, RT significantly enhanced the SOC of water-stable aggregates in topsoil, with the most improvement found in the >2 mm water-stable aggregates ($P < 0.05$). There was no significant difference in maize yield in 2016 and 2017. Compared with the yield in 2016, the yield reduction from RT and PT treatments (8.57%–9.72%) was lower than that from CK1 and CK2 (10.84%–12.13%) in 2017. Therefore, rotary tillage with residue returning practice in dryland farming is recommended with benefits of promoting soil water-stable aggregate formation and increasing SOC content to provide stable yield for maize production regardless of precipitation variation in northeast China.

Keywords: tillage; residue returning; soil water-stable aggregate; soil organic carbon; maize yield; Shenyang

1 Materials and Methods

1.1 Study Site

The field experiment was conducted from 2015 to 2017 at the experimental station of Shenyang Agricultural University (). The site is located in a temperate semi-humid region with a continental monsoon climate. The annual precipitation during the maize growing season was 378 mm, 929 mm, and 388 mm in 2015, 2016, and 2017, respectively [FIGURE 1]. The soil in the 0–20 cm layer had the following properties: organic matter content of 0.91 $g \cdot kg^{1}$, total nitrogen of 0.82 $g \cdot kg^{1}$, available phosphorus of 22.22 $mg \cdot kg^{1}$, bulk density of 1.41 $g \cdot cm^{3}$, and pH of 5.60.

1.2 Experimental Design

The experiment consisted of four treatments: rotary tillage with straw incorporation (RT), rotary tillage without straw incorporation (CK1), plow tillage with straw incorporation (PT), and plow tillage without straw incorporation (CK2). The rotary tillage treatments (RT and CK1) were conducted at a depth of 15 cm, while the plow tillage treatments (PT and CK2) were conducted at a depth of 30 cm. Each plot measured 12 m in length and 0.6 m in width, with 10 rows per plot, giving a total area of 72 m^2. From 2015 to 2017, maize straw was returned to the RT and PT plots after harvest, while straw was removed from the CK1 and CK2 plots. All plots received basal fertilizer applications of N (urea, diammonium phosphate) at 75 $kg \cdot hm^{2}$, P O (diammonium phosphate) at 75 $kg \cdot hm^{2}$, and K O (potassium sulfate) at 250 $kg \cdot hm^{2}$. Additional topdressing of N (urea) at 150 $kg \cdot hm^{2}$ was applied during the growing season.

1.3 Soil Sampling

In October 2017, soil samples were collected from each plot using a soil auger. Samples were taken from four depth intervals: 0–10 cm, 10–20 cm, 20–30 cm, and 30–40 cm. Three replicate samples were collected from each plot and composited by depth layer. The samples were air-dried and passed through an 8 mm sieve to remove roots and debris before aggregate analysis.

1.4 Aggregate Analysis

Water-stable aggregates were measured using the wet sieving method. Soil samples were placed on a nest of sieves with mesh sizes of 2 mm, 0.25 mm, and 0.053 mm. The sieves were immersed in deionized water for 10 minutes before oscillation. The stable aggregates retained on each sieve were collected, oven-dried at 60°C, and weighed.

1.5 Calculations

The water-stable aggregate content (WRi), mean weight diameter (MWD), and instability index (ELT) were calculated using the following formulas:

$$WR_i = \frac{W_i}{W_{0.25}} \times 100\%$$

$$MWD = \sum (W_T - W_{0.25}) \times 100\%$$

$$ELT = (W_{0.25} - W_T) \times 100\%$$

where W_i is the weight of aggregates in each size fraction, W_T is the total weight of aggregates, and $W_{0.25}$ is the weight of aggregates >0.25 mm.

1.6 Statistical Analysis

All data were processed using Microsoft Excel 2016. Statistical analysis was performed using SPSS 18.0 software. One-way ANOVA was conducted to test for significant differences among treatments, and Duncan' s multiple range test was used for post-hoc comparisons at $P < 0.05$. Figures were created using Origin 2017 and Excel 2016.

2 Results

2.1 Distribution of Water-Stable Aggregates

The distribution of water-stable aggregates varied significantly among tillage treatments and soil depths [FIGURE 2]. In the 0-40 cm profile, the proportion of >2 mm aggregates ranged from 1.32% to 9.52%, while the <0.053 mm fraction ranged from 45.87% to 66.71%. The 2-0.25 mm fraction was the dominant aggregate class, accounting for 45.87%-66.71% of the total. Straw incorporation significantly increased the proportion of >2 mm aggregates and decreased the <0.053 mm fraction compared with non-incorporation treatments ($P < 0.05$). In the 0-20 cm layer, RT significantly increased the >2 mm aggregate content compared with PT, while in the 20-30 cm layer, PT showed higher values than RT. The ranking of treatments for aggregate stability was generally: RT > PT > CK1 > CK2.

2.2 Mean Weight Diameter and Instability Index

The mean weight diameter (MWD) of water-stable aggregates varied significantly among treatments [FIGURE 3]. Straw incorporation increased MWD values compared with non-incorporation treatments ($P < 0.05$). In the 0-10 cm layer, RT produced higher MWD values than PT, while in the 20-30 cm layer, PT showed higher MWD than RT, with increases of 16.85% and 18.29%, respectively. The MWD ranking in the 0-20 cm layer was: RT > PT > CK1 > CK2. The instability index (ELT) showed the opposite trend, with lower values indicating greater stability [FIGURE 4]. Across the 0-40 cm profile, CK1 and CK2 had higher ELT values than RT and PT, indicating that straw incorporation improved aggregate stability.

2.3 Soil Organic Carbon Content

Straw incorporation significantly increased SOC content in water-stable aggregates [FIGURE 5]. In the 0–10 cm layer, RT increased SOC by 11.97%–15.78% compared with CK1, while PT increased SOC by 5.06%–32.96% compared with CK2 ($P < 0.05$). The SOC content was highest in the >2 mm aggregates (14.69–12.24 $g \cdot kg^{1}$) and decreased with decreasing aggregate size [TABLE 1]. The improvement in SOC was most pronounced in the >2 mm fraction under RT treatment. In the 20–30 cm layer, PT showed the highest SOC content in the 2–0.25 mm aggregates.

2.4 Crop Yield

Maize yield varied among years and treatments [FIGURE 6]. In 2015, no significant differences were observed among treatments. In 2016, yields increased significantly due to favorable precipitation (929 mm). In 2017, drought conditions (388 mm precipitation) caused yield reductions in all treatments, but the decline was less severe in straw incorporation treatments. Compared with 2016, yield reductions in RT and PT were 8.57%–9.72%, significantly lower than the 10.84%–12.13% reductions observed in CK1 and CK2. The yield ranking across all years was: RT > PT > CK2 > CK1.

3 Discussion

Our results demonstrate that straw turnover significantly improves soil structure and increases SOC content in semi-arid regions. The incorporation of crop residues promotes the formation of macroaggregates (>2 mm) through enhanced binding agents derived from decomposing organic matter. Rotary tillage with straw return (RT) was particularly effective in the surface layer (0–20 cm), increasing MWD by 7.78% and reducing the proportion of unstable microaggregates (<0.053 mm) by 16.81% compared with plow tillage (PT). This improvement in aggregate stability enhances soil water infiltration and reduces erosion risk.

The SOC content was significantly enriched in macroaggregates under straw incorporation treatments, with RT showing the greatest enhancement (13.90% increase in 0–10 cm layer). This is consistent with the aggregate hierarchy theory, which posits that macroaggregates protect and sequester SOC more effectively than microaggregates. The preferential accumulation of SOC in >2 mm aggregates under RT treatment suggests that this practice is optimal for carbon sequestration in the studied region.

Despite the benefits for soil quality, straw incorporation did not significantly increase crop yield in normal years. However, during the drought year of 2017, RT and PT treatments maintained higher yields than non-incorporation treatments, indicating improved drought resistance. The yield stability under RT management suggests that the benefits of improved soil structure and increased SOC content become more apparent under stress conditions.

4 Conclusion

Rotary tillage with straw incorporation is recommended as a sustainable practice for dryland farming in northeast China. This practice significantly improves soil aggregate stability, increases SOC content, particularly in macroaggregates, and provides yield stability under variable precipitation conditions. The combination of reduced tillage intensity and residue return represents an effective strategy for enhancing soil health and ensuring long-term agricultural productivity in semi-arid regions.

References

[1] Zhang Guosheng, Chan KY, Li GD, et al. Long-term effects of tillage systems and rotation on selected soil properties in cropping zone of Southern NSW, Australia[J]. Acta Ecologica Sinica, 2008, 28(6): 2722–2728.

[2] Huang Gaobao, Guo Qingyi, Zhang Renzhi, et al. Effects of conservation tillage on soil moisture and crop yield in a phased rotation system with spring wheat and field pea in dryland[J]. Acta Ecologica Sinica, 2006, 26(4): 1176–1185.

[3] Iqbal M, Anwar-ul-Hassan, Ibrahim M. Effects of tillage systems and mulch on soil physical quality parameters and maize (Zea mays L.) yield in semi-arid Pakistan[J]. Biological Agriculture & Horticulture, 2008, 5(4): 311–325.

[4] Liu Y, Gao MS, Wu W, et al. The effects of conservation tillage practices on the soil water-holding capacity of a non-irrigated apple orchard[J]. Soil Tillage Research, 1997, 44(3): 255–264.

[5] Wang Yuhong, Yao Yuqing, Lü Junjie, et al. Ecological effect of subsoiling high stubble on the winter wheat in sloping land of western Henan[J]. Chinese Journal of Eco-Agriculture, 2004, 12(2): 151–153.

[6] Chen Lin, Ren Chunying, Wang Chongming, et al. Prediction of spatial distribution of topsoil organic matter content in cultivated land using kriging methods[J]. Arid Zone Research, 2017, 34(4): 798–805.

[7] Chong SK, Cowsert PT. Infiltration in reclaimed mined land ameliorated with deep tillage treatments[J]. Soil Tillage Research, 1997, 44(3): 255–264.

[8] Klute A. Aggregate stability and size distribution[J]. Methods of Soil Analysis, 1986(1): 425–442.

[9] Zhang Qizhu. Effects of soil organic matter on soil fertility, Second: soil fertility preservation and soil organic matter[J]. Xinjiang Agricultural Reclamation

Technology, 1985(5): 54-56.

[10] Zhang Qihou, Yuan Zhaoliang, Zhang Xiaopu. Ameliorative effect and mechanism of soil organic matter[J]. Soils, 2003, 40(3): 420-425.

[11] Zhang Xiaowen, Zhao Gaibin, Yang Renquan, et al. Comprehensive utilization of agricultural straws in recycle economy[J]. Transactions of the CSAE, 2006(Suppl. 1): 107-109.

[12] Wang Qingkui, Wang Silong. Forming and stable mechanism of soil aggregate and influencing factors[J]. Chinese Journal of Soil Science, 2005, 36(3): 415-421.

[13] Imbufe AU, Patti AF, Burrow D, et al. Effects of potassium humate on aggregate stability of two soils from Victoria, Australia[J]. Geoderma, 2005, 125(3): 321-330.

[14] Lal R, Kimble JM. Conservation tillage for carbon sequestration[J]. Nutrient Cycling in Agroecosystems, 1997, 49(1-3): 243-253.

[15] Cambardella CA, Elliott ET. Carbon and nitrogen distribution in aggregates from cultivated and native grassland soils[J]. Soil Science Society of America Journal, 1993, 57(4): 1071-1076.

[16] Pugeot P, Chenu C, Balesdent J. Dynamic of soil organic matter associated with particle-size fractions of water-stable aggregate[J]. European Journal of Soil Science, 2000, 51: 595-605.

[17] Zhou Hu, Lü Yizhong, Yang Zhichen, et al. Effects of conservation tillage on soil aggregates in Huabei Plain China[J]. Scientia Agricultura Sinica, 2007, 40(9): 1973-1979.

[18] Mikhail MM, Rice CW. Tillage and manure effects on soil and aggregate-associated carbon and nitrogen[J]. Soil Science Society of America Journal, 2004, 68(3): 809-816.

[19] Oades JM. Soil organic matter and structural stability: Mechanisms and implications for management[J]. Plant and Soil, 1984, 76(1/3): 319-337.

[20] Guo Juhua, Chen Xiaoyun, Liu Manqiang, et al. Effects of fertilizer management practice on distribution of aggregates and content of organic carbon and nitrogen in red paddy soil[J]. Soils, 2007, 39(5): 787-793.

[21] Li Jing, Zhou Zhengchao, Zhang Qiang, et al. Soil physicochemical properties and soil detachment rate in grasslands with different years of grain for green in the loess plateau[J]. Arid Zone Research, 2017, 34(3): 504-510.

[22] Wang J, Wang X, Xu M, et al. Crop yield and soil organic matter after long-term straw return to soil in China[J]. Nutrient Cycling in Agroecosystems, 2015, 102(3): 371-381.

[23] Turnel MS, Speratti A, Baudron F, et al. Crop residue management and soil health: A systems analysis[J]. Agriculture Systems, 2015, 134: 6-16.

[24] Li Jianlin, Jiang Changsheng, Hao Qingju. Impact of land use type on stability and organic carbon of soil aggregates in Jinyun Mountain[J]. Environmental Science, 2014, 35(12): 4695-4704.

Note: Figure translations are in progress. See original paper for figures.