

Effects of long-term various organic materials incorporation on characteristics of soil quality and crop yield

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Abstract. In order to study the effects of different organic materials on soil quality and crop yield, a seven -year, s field experiment was conducted in North China Plain. The experiment included six treatments: no organic materials (CK), compost (C), Cow Dung (PM), biogas residue (BgR), crop straw (Str), biochar (BC), all samples were separated into four aggregate-size classes by wet sieving, meanwhile we calculated the mean weight diameter (MWD), geometric mean diameter (GMD), fractal dimension (D) and unstable aggregate index (E_{LT}) of water-table aggregates. Compared with the CK treatment, the application of organic materials in 0~15 cm soil layer not only significantly increased MWD, GMD) of water-table aggregates ($P < 0.05$), but also decreased the D and E_{LT} of water-table aggregates. Also, the content of soil organic carbon (SOC) and total nitrogen (TN) increased significantly under different organic materials treatments ($P < 0.05$), therefore, the nutrient content and structural stability of soil was significantly enhanced. The total yield of wheat and maize of C, PM, Bg, S and BC treatments increased by 75.5%, 69.7%, 108.9%, 34.1% and 1.0%. The improvement effects of aggregate stability index and soil structure of BC and Str treatments were the best, while C, BC and BgR treatments were better to increase the content of SOC and TN in bulk soil. The application of organic materials could increase the content of SOC and TN, enhance the soil water-stability aggregate stabilization and soil fertility, while increase crop yield.

1. Introduction

Large quantities of agricultural by-products and animal waste are produced each year in China, in order to reduce the pressure on land-fill sites and conserve natural resources, we should compost these organic wastes and recycle them onto arable land. Application of organic materials such as sewage sludge, crop residues, compost, and poultry manure are well known environmental practices in soil restoration, maintaining soil organic matter, reclaiming degraded soils, and supplying plant nutrients to semi-arid lands (Tejada and Gonzales, 2008). Organic materials contain plant nutrients, and their use will reduce the amount of chemical fertilizer and increase crop productivity which China needs to import or manufacture (Chen F I et al, 2001). Agricultural organic materials recycling is an important factor influencing soil structure and soil fertility level, and Soil structure influences soil physical,



chemical and biological processes. (Sodhi G P et al, 2005). Since maintenance of optimum soil physical conditions is an important component of sustainable soil fertility, the relationship between physical soil properties and various organic materials needs to be further evaluated.

Soil aggregation and soil structure are important aspects of soil fertility in influencing the root distribution and nutrients (Bronick and Lal 2005). As the functional unit of soil structure, soil aggregates are important for maintaining soil porosity and providing stability against soil erosion. Soil aggregate is the pool of soil nutrients and the habitat of soil microorganism (Six et al. 2004). Application of organic materials can increase soil aggregation, nutrients and crop yield when compared to no-input systems, although the magnitude depends on organic materials quantity and quality (Chivenge et al, 2011). A suitable amount of organic materials is urgently needed to maintain the nutrient content of the soil at an appropriate level. In recent years, the research on biogas residue, black carbon and compost is not enough, it is difficult to distinguish the effects of different organic materials on soil aggregate stability and nutrient content, and the treatment and recycling of organic materials has become an important topic in China. Therefore, the objective of the study was to assess the effect of long-term organic materials on soil aggregate stability, crop yield and nutrient content, which provide a theoretical basis and technical support to improve the soil structure, increase crop yields and prevent soil erosion.

2. Materials and methods

2.1. Site description

The research site is located at the Wu qiao Agriculture and Ecology Experimental Station, in Wu qiao County, Hebei Province, China (37°41'N, 116°37'E). It has a warm temperate monsoon climate. The annual mean temperature is 12.9°C, above 0°C accumulated temperature is 4826°C, frost-free period is about 201 days, and annual average precipitation is 562 mm. The soil is a fluvo-aquic soil, the soil texture is silty loam, the soil organic carbon content is 7.4 g·kg⁻¹ and total nitrogen content is 0.82 g·kg⁻¹. The crop rotation is wheat in winter and maize in summer.

2.2. Treatments and sampling

The organic materials experiment was started in 2008 with six treatments: no organic materials (CK), compost (C), Cow Dung (PM), biogas residue (BgR), crop straw (Str), biochar (BC), every treatment had three replicates. In total, there were 18 plots, and the area of each plot was 50 m² (12.5 m × 4 m). All the organic materials used in this experiment were processed from the harvested corn stalks. The organic materials were applied to the soil with the same amount of carbon (3200 kg · hm⁻²) before sowing wheat, which was equivalent to the total amount of carbon contained in the above-ground straw harvested by organic material processing in the previous quarter, nitrogen fertilizer was not applied in the long-term field experiment, and the amount of phosphorus and potassium fertilizer was the same, and the properties of the organic materials were showed in Table 1.

Soil samples were taken after summer maize was reaped in 2015, and divided into two layers of 0~15 and 15~30 cm. Each plot has three replicates. Soil samples were air-dried at the Wuxia Experimental Station. Soil organic matter was determined by wet oxidation (potassium dichromate oxidation with external heating). The total nitrogen content was measured by the Kjeldahl method (Hinds and Lowe 1980).

Table 1. Nutrient contents and pH of different organic materials

Organic materials	Chemical properties					
	pH	C (%)	N (%)	P (%)	K (%)	C/N
C	7.85	25.4	1.79	0.35	2.01	14.82
PM	6.98	26.72	1.56	0.38	0.82	17.00
BgR	7.21	22.46	2.02	0.72	0.94	11.31
Str		40.73	0.73	0.18	1.27	56.88
BC	8.30	68.31	1.23	0.13	0.40	57.07

2.3. Soil aggregate extraction

Soil aggregates were extracted by wet sieving soils through 2000, 250, and 53 μm sieves (Elliott, 1986). The MWD, GMD, E_{LT} and the D of water-table aggregates were calculated according to reference 11 (Zhou et al, 2007).

Statistically, all data were presented as means of three replicates with standard error. Mean comparisons were performed by Duncan's multiple range test ($P < 0.05$).

3. Results and analysis

3.1. Effects of different organic materials incorporation on SOC and TN

The content of SOC and TN increased significantly under different organic materials treatments in the 0~15 cm soil layer ($P < 0.05$). But in the 15~30 cm layers, there was no significant difference between these treatments (Figure 1). Compared with the CK treatment, the SOC of C, PM, Bg, S and BC treatments in the 0~15 cm soil layer increased by 64.6%, 36.8%, 65.2%, 38.4% and 205.8%, the TN of C, PM, Bg, S and BC treatments in the 0~15 cm soil layer increased by 42.2%, 20.2%, 38.3%, 24.1% and 33.9%, the results showed that different organic materials treatments all play a positive role to increase the content of SOC and TN in the surface layer. but the characteristics of different organic materials were different, which change the overall soil environment and the process of soil microbial activity, thus the decomposition process and the stability of SOC and TN were changed, in the end, these different organic materials showed the different trend to increase the content of SOC and TN (Zhou et al, 2008).

The content of SOC in the 0~15 cm layer was found to be in a general trend of $BC > BgR > C > PM > Str > CK$ treatment under different organic materials treatments, which BC treatment was the most conducive to increase the content of SOC. Meanwhile, the content of TN in the 0~15 cm layer showed the trend of $C > BC > BgR > Str > PM > CK$ treatment under different organic materials treatments, which C treatment was the most conducive to increase the content of TN. In the 15~30 cm layers, there was no significant difference between these different organic materials treatments by analysis of variance.

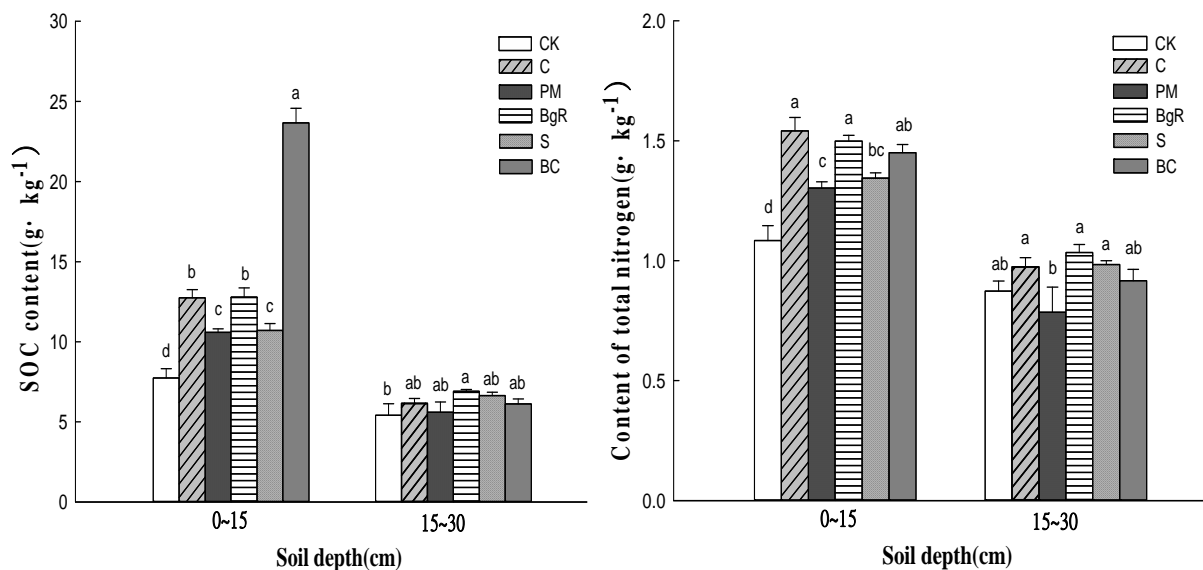


Figure 1. Effects of different organic materials incorporation on SOC and TN in the 0-15 cm and 15-30 cm soil layer.

Note: Different lowercase letters indicate difference of significance at $P < 0.05$ under different organic materials treatments, the same below.

3.2. Effects of different organic materials incorporation on the MWD, GMD, E_{LT} and D of water-stable aggregate stability

MWD, GMD, E_{LT} and D are four common indicators for characterizing size distribution of soil aggregates. The higher the values of MWD and GMD are, the lower the values of E_{LT} and D , the higher the degree of aggregation and the stronger the stability is (Nimmo et al, 2002; Zhang et al, 2012). Table 2 shows the results of MWD, GMD, E_{LT} and D of wet sieving under different organic materials incorporation.

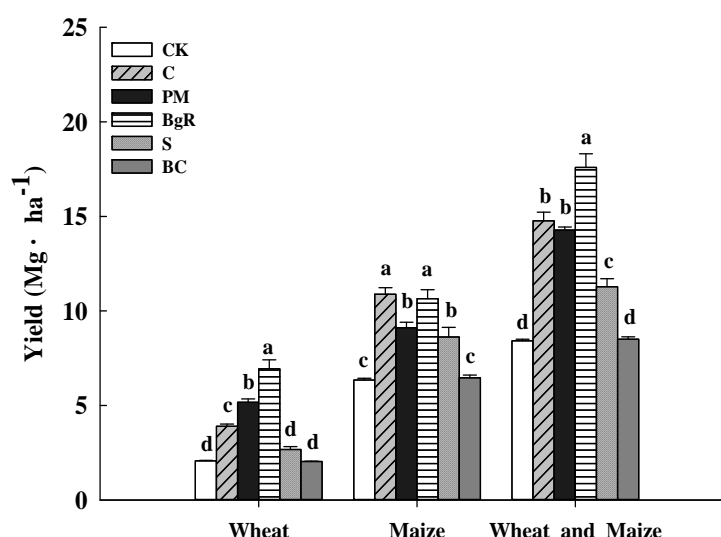
Compared with the CK treatment, the application of organic materials in the 0~15 cm soil layer not only significantly increased the MWD, GMD of water-table aggregates, but also D and E_{LT} of water-table aggregates ($P < 0.05$) (Table 2). The MWD of C, PM, Bg, S and BC treatments increased by 35.5%, 51.6%, 19.4%, 58.1% and 61.3%, the GMD values increased by 41.7%, 41.7%, 33.3%, 66.7% and 83.3%, D and E_{LT} values decreased by 1.7% ~ 4.1% and 10.5% ~ 41.7%, respectively. The improvement effects of aggregate stability index and soil structure of BC and Str treatments were the best between these treatments. Therefore, five different organic materials incorporation all can enhance the aggregate stabilization and improve soil structure in the 0~15 cm soil layer. In the 15~30 cm soil layer, the stability-related indexes of water-stable aggregates between these treatments were not significantly changed, the effect of improving the structure of the soil aggregates in the lower layer is not obvious (Table 2).

Table 2. Effects of different organic materials incorporation on aggregate stability

soil layer	Treatments	MWD(mm)	GMD(mm)	$E_{LT}/\%$	D
0~15 cm	CK	0.31±0.06c	0.12±0.010c	83.15±2.03a	2.91±0.02a
	C	0.42±0.01b	0.17±0.013b	74.45±1.43bc	2.86±0.01bc
	PM	0.47±0.04ab	0.17±0.007b	73.20±0.43bc	2.84±0.01bc
	BgR	0.37±0.02bc	0.16±0.003b	75.83±0.85b	2.87±0.01b
	Str	0.49±0.05a	0.20±0.025a	69.50±3.50cd	2.82±0.02cd
	BC	0.50±0.01a	0.22±0.007a	64.61±0.10d	2.79±0.01d
15~30 cm	CK	0.26±0.02b	0.11±0.011a	85.84±2.59a	2.92±0.02a
	C	0.40±0.03a	0.15±0.011a	78.47±0.42a	2.88±0.01a
	PM	0.25±0.02b	0.11±0.010a	85.49±2.81a	2.92±0.02a
	BgR	0.34±0.01ab	0.14±0.004a	80.06±0.57a	2.89±0.01a
	Str	0.36±0.04ab	0.13±0.014a	79.06±3.27a	2.89±0.02a
	BC	0.39±0.04a	0.15±0.026a	78.71±5.19a	2.88±0.03a

3.3. Effects of different organic materials incorporation on the yields of wheat and maize

The total yield of wheat and maize was significantly affected by C, PM, Bg and S treatments (Figure 2). C, PM, and Bg treatments showed a significant effect on the yield of wheat among these different organic materials treatments ($P<0.05$), however, no significant effect of S and BC treatments on wheat grain yield was observed. In addition to BC treatment, the effect of C, PM, Bg and S treatments on the yield of summer maize was significant. Compared with the CK treatment, the total yield of wheat and maize of C, PM, Bg, S and BC treatments increased by 75.5%, 69.7%, 108.9%, 34.1% and 1.0%, the total yield of wheat and maize showed the trend of BgR>C>PM>Str>BC>CK treatment under different organic materials treatments, which BgR treatment was the most conducive to increase the total yield of wheat and maize.

**Figure 2.** Effects of different organic materials incorporation on the yields of wheat and maize.

4. Conclusion

Through the comparison and analysis, we can find that the application of organic materials in 0~15 cm soil layer not only significantly increased MWD, GMD of water-table aggregates ($P<0.05$), but also

decreased the D and E_{LT} of water-table aggregates. Also, the content of SOC and TN increased significantly under different organic materials treatments. The content of SOC and TN was not significant among different organic material treatments in 15~30 cm soil layer. Consequently, the application of organic materials could increase the content of SOC and TN, enhance the soil water-stability aggregate stabilization and soil fertility, while increase crop yield.

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