Effects of various organic materials on soil aggregate stability and soil microbiological properties on the Loess Plateau of China

F. Wang[1], Y.A. Tong[1], J.S. Zhang[1], P.C. Gao[1], J.N. Coffie[2]

[1]*College of Resources and Environment, Northwest A&F University, Yangling, P.R. China*
[2]*Department of Environmental Science and Technology, University of Maryland, Maryland, USA*

ABSTRACT

A field experiment was conducted to examine the influence of various organic materials on soil aggregate stability and soil microbiological properties on the Loess Plateau of China. The study involved seven treatments: no fertilizer (CK); inorganic N, P, K fertilizer (NPK); low amount of maize stalks plus NPK (LSNPK); medium amount of maize stalks plus NPK (MSNPK); high amount of maize stalks plus NPK (HSNPK); maize stalk compost plus NPK (CNPK); cattle manure plus NPK (MNPK). The organic fertilizer treatments improved soil aggregate stability and soil microbiological properties compared with CK and NPK treatments. Compared with the NPK treatment, soil treated with LSNPK had a significant increase of 27.1% in 5–3 mm dry aggregates. The > 5 mm water stable aggregates treated with CNPK increased by 6.5% compared to the NPK. Soil microbial biomass C and N and urease activity were significantly increased in CNPK by 42.0, 54.6 and 19.8%, respectively. The study indicated that the variation trend in the amount of soil aggregate (0.5–5 mm) for organic fertilizer treatments was similar to the content of soil microbial carbon and nitrogen and soil enzyme activity. Considering the great availability of organic material, especially stalk compost in this region, application of organic materials is recommended to improve soil structure and fertility.

Keywords: availability of organic material; maize stalk compost; soil structure and fertility; microbial biomass C; microbial biomass N

The Loess Plateau is one of the most severely eroded areas in China. Extensive soil erosion has resulted in poor soil fertility. Sustaining agricultural production on the Loess Plateau is very important in order to ensure a sufficient food supply for the growing population (Zhang et al. 2009). It was suggested that improving soil fertility could increase agricultural production in this area as much as threefold (Fan and Zhang 2000). Although soil fertility has improved in recent years, soil organic matter content and crop yield are still low. Application of organic materials is effective at improving soil fertility, soil physical and biological properties (Talgre et al. 2012).

Maintaining high stability of soil aggregates is necessary for maintaining soil productivity, decreasing soil degradation and thus minimizing environmental pollution as well. Aoyama et al. (1999) found that an increase in soil organic matter with the addition of organic fertilizer caused

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formation of disperse-resistant aggregates. Soil microbial biomass and enzymatic activity are all more sensitive to the changes of soil quality than soil organic matter (Allison et al. 2008). However, organic fertilizers have the potential to increase soil microbial biomass and enzyme activities (Ebhin Masto et al. 2006).

Numerous studies investigated the effect of long term fertilization on soil aggregate stability or microbial biomass (Wang et al. 2012). However, there is limited information available for the short term effects of mixed inorganic and organic fertilizers on soil physical properties combined with soil microbiological properties. We assumed that short term addition of different fertilizers in arable soil would not only affect the soil aggregate distribution but also soil microbial biomass. The objectives of this study were to determine how the short term fertilization affected soil aggregate stability and microbiological properties on the Loess Plateau of China.

MATERIAL AND METHODS

Experimental site. A field experiment was established in September 2007 in Ganjin village, Heyang County, Shaanxi province in the southeast part of the Loess Plateau, China (35°19'87''N, 110°05'22''E, 880 m a.s.l.). The site has a mean annual temperature of 10.0°C and mean annual precipitation of 572 mm. The loess soil at the site is classified as Chromic Cambisols. The general soil properties (0–20 cm) of the site are as follows: pH 8.24, organic matter 12.5 g/kg, total N 0.81 g/kg, available P 9.57 mg/kg, available K 108 mg/kg, and soil bulk density 1.30 g/cm^3. Winter wheat (*Triticum aestivum* L.) was grown throughout the experiment.

Experimental design. The study consisted of seven treatments: no fertilizer (CK); inorganic N, P, K fertilizer (NPK); low amount of maize stalks plus NPK (LSNPK); medium amount of maize stalks plus NPK (MSNPK); high amount of maize stalks plus NPK (HSNPK); maize stalk compost plus NPK (CNPK); cattle manure plus NPK (MNPK). Each treatment was replicated three times. The details of fertilizer rate for cropping system are given in Table 1. The LSNPK, MSNPK and HSNPK plots received 3750, 7500 and 15 000 kg (air-dried) maize stalks per ha, respectively. The compost comprised a mixture of maize stalk, chicken manure and fungicide. All fertilizers were applied once, just before wheat sowing.

Soil sampling and measurements. Soil samples were collected at the end of May 2009. For soil aggregate characterization and stability analyses, three undisturbed samples from each plot were taken from 0–20 cm depth by a hand spade, which consisted of larger clods that were then gently fractionated into 1–2 cm aggregates along natural break points. All samples from each plot were carefully mixed by hand to form a composite sample. For microbiological samples, seven soil cores (5 cm diameter) were collected from 0–20 cm depth. Cores from the same depth were bulked to form one sample per depth and per treatment. Distribution and stability of soil aggregates were determined by using separate dry and wet sieving

Table 1. Details of fertilizer rates for the cropping system (kg/ha)

Treatment	C	N	P	K
CK	0	0	0	0
NPK	0	150.0	39.3	49.8
LSNPK	1687.5	150.0 + 34.5[a]	39.3 + 5.6[a]	49.8 + 44.3[a]
MSNPK	3375.0	150.0 + 69.0[a]	39.3 + 11.3[a]	49.8 + 88.5[a]
HSNPK	6750.0	150.0 + 138.0[a]	39.3 + 22.5[a]	49.8 + 177[a]
CNPK	2250.0	150.0 + 68.3[a]	39.3 + 27.0[a]	49.8 + 48.8[a]
MNPK	2250.0	150.0 + 142.5[a]	39.3 + 52.5[a]	49.8 + 184.5[a]

[a]the amount of N/P/K contained in the added crop straw or organic manure. CK – no fertilizer; NPK – inorganic N, P, K fertilizer; LSNPK – low amount of maize stalks plus NPK; MSNPK – medium amount of maize stalks plus NPK; HSNPK – high amount of maize stalks plus NPK; CNPK – maize stalk compost plus NPK; MNPK – cattle manure plus NPK

methods (Dane and Topp 2002). The chloroform fumigation method was used for the determination of soil microbial carbon and nitrogen (Brookes et al. 1985, Vance et al. 1987). Urease, phosphatase and invertase activities were determined by the method described by Guan (1986).

Statistical analysis. Mean weight diameter (MWD):

$$\mathrm{MWD} = \sum_{i=1}^{n} x_i w_i$$

Where: x_i (mm) – average diameter of the openings of two consecutive sieves, and w_i – weight fraction in each class.

Geometric mean diameter (GMD):

$$\mathrm{GMD} = \exp\left[\frac{\sum_{i=1}^{n} w_i \log x_i}{\sum_{i=1}^{n} w_i}\right]$$

Where: w_i (g) – weight of aggregates in a size class with an average diameter, and x_i (mm) – the same as above. Percentage of aggregate destruction (PAD):

$$\mathrm{PAD} = (M_\mathrm{d} - M_\mathrm{w}) \times 100/M_\mathrm{d}$$

Where: M_d – mass fraction of > 0.25 mm aggregates (dry sieved) and M_w – mass fraction of > 0.25 mm aggregates (wet sieved) (Kemper and Rosenau 1986).

For determination of aggregate size distributions (ASD), the weight ratio of aggregates of each sieve to the total weight of aggregates was calculated.

All data (means ± standard deviation, $n = 3$) were analyzed by one-way ANOVA, and differences in means were compared by the least significant difference test at $P < 0.05$. All statistical analysis was carried out by SAS software (version 8.0, Cary, USA).

RESULTS AND DISCUSSION

Distribution of aggregate size classes. The amount of aggregates (> 10 mm) at organic fertilization treatments were lower than at NPK treatment, and the LSNPK treatment had the lowest amount (19.4%) of aggregates of this size (Table 2). There was a greater proportion of aggregates of 5–3 mm (with an increasing trend from 2.5% to 27.1%) at the organic fertilizer treatments (LSNPK, MSNPK, CNPK, MNPK) compared with the NPK treatment. The proportion of aggregates 1–0.5 mm at organic fertilization treatments, except CNPK, were significantly higher than at NPK. The percentage of < 0.25 mm aggregates in all treatments was approximately 35%, and the HSNPK and CNPK treatments were lower than NPK treatment (Table 2). These results are similar to other studies which indicated that long-term application of chemical fertilizer especially combined with organic fertilizer could increase the amount of larger aggregate

Table 2. Effect of different fertilizer treatments on aggregate size distributions (dry sieved, %)

Treatment	Size class (mm)								
	> 10	10–7	7–5	5–3	3–2	2–1	1–0.5	0.5–0.25	< 0.25
CK	30.0 ± 3.80^a	7.40 ± 1.05^a	2.61 ± 0.40^a	5.40 ± 0.47^a	0.48 ± 0.04^c	2.22 ± 0.24^b	10.8 ± 1.19^{ab}	4.5 ± 0.71^{ab}	36.6 ± 2.18^a
NPK	32.5 ± 10.90^a	6.78 ± 0.68^a	2.21 ± 0.47^a	5.54 ± 1.45^b	0.53 ± 0.09^{bc}	2.54 ± 0.52^{ab}	10.1 ± 1.98^b	4.36 ± 0.70^b	35.4 ± 5.66^a
LSNPK	19.4 ± 3.66^b	7.98 ± 2.06^a	3.44 ± 0.40^a	7.04 ± 0.31^a	0.64 ± 0.06^{abc}	3.67 ± 0.19^a	12.5 ± 0.66^a	4.80 ± 0.43^a	39.7 ± 2.40^a
MSNPK	29.6 ± 4.89^a	6.01 ± 0.49^{ab}	2.60 ± 0.61^a	5.68 ± 1.11^b	0.78 ± 0.07^a	3.30 ± 0.37^{ab}	11.8 ± 1.30^a	4.59 ± 0.48^{ab}	35.6 ± 1.56^a
HSNPK	32.9 ± 10.01^a	7.27 ± 0.78^a	2.41 ± 0.55^a	5.41 ± 0.92^b	0.74 ± 0.12^{ab}	2.75 ± 0.57^{ab}	10.3 ± 1.83^{ab}	4.38 ± 0.84^b	33.8 ± 5.56^a
CNPK	32.55 ± 4.26^a	7.97 ± 0.61^a	2.81 ± 0.48^a	5.95 ± 0.76^b	0.64 ± 0.10^{abc}	2.67 ± 0.50^{ab}	10.24 ± 1.11^b	4.32 ± 0.14^b	32.8 ± 0.72^a
MNPK	26.47 ± 2.05^a	5.53 ± 0.59^b	2.55 ± 0.44^a	5.94 ± 0.26^b	0.67 ± 0.04^{abc}	3.17 ± 0.27^{ab}	12.23 ± 0.45^a	5.06 ± 0.40^a	38.4 ± 1.26^a

Values are means ± SD ($n = 3$). Values with different letters within a column are statistically significantly different at $P < 0.05$. CK – no fertilizer; NPK – inorganic N, P, K fertilizer; LSNPK – low amount of maize stalks plus NPK; MSNPK – medium amount of maize stalks plus NPK; HSNPK – high amount of maize stalks plus NPK; CNPK – maize stalk compost plus NPK; MNPK – cattle manure plus NPK

Table 3. Effect of different fertilizer treatments on aggregate size distributions (wet sieved, %) and PAD (%)

Treatment	Size class (mm)						PAD
	> 5	5–2	2–1	1–0.5	0.5–0.25	< 0.25	
CK	3.66 ± 1.46^{b}	3.11 ± 0.15^{b}	3.86 ± 0.91^{c}	6.76 ± 1.02^{c}	12.2 ± 1.16^{b}	70.5 ± 2.58^{c}	50.4
NPK	3.18 ± 1.99^{bc}	3.27 ± 1.21^{b}	4.80 ± 1.47^{ab}	9.93 ± 1.76^{b}	17.0 ± 5.5^{ab}	61.8 ± 11.12^{bc}	40.8
LSNPK	1.33 ± 0.05^{c}	3.33 ± 0.82^{b}	3.84 ± 0.87^{c}	9.76 ± 2.17^{b}	15.3 ± 2.36^{b}	66.5 ± 6.15^{c}	44.4
MSNPK	3.53 ± 1.55^{b}	4.29 ± 0.78^{ab}	6.29 ± 1.62^{a}	15.9 ± 4.03^{a}	20.3 ± 1.85^{ab}	49.8 ± 6.66^{b}	22.0
HSNPK	5.68 ± 0.28^{a}	5.82 ± 1.45^{a}	6.23 ± 2.17^{a}	11.6 ± 3.00^{ab}	29.5 ± 12.84^{a}	41.3 ± 19.36^{a}	11.2
CNPK	6.49 ± 2.44^{a}	4.97 ± 1.01^{ab}	4.29 ± 0.77^{b}	12.1 ± 3.61^{ab}	17.1 ± 1.44^{ab}	55.1 ± 6.29^{bc}	33.1
MNPK	3.85 ± 1.19^{b}	4.87 ± 0.30^{ab}	5.01 ± 1.42^{ab}	11.9 ± 0.59^{ab}	23.0 ± 2.80^{ab}	51.4 ± 5.59^{b}	21.2

Values are means ± SD ($n = 3$). Values with different letters within a column are statistically significantly different at $P < 0.05$. CK – no fertilizer; NPK – inorganic N, P, K fertilizer; LSNPK – low amount of maize stalks plus NPK; MSNPK – medium amount of maize stalks plus NPK; HSNPK – high amount of maize stalks plus NPK; CNPK – maize stalk compost plus NPK; MNPK – cattle manure plus NPK; PAD – percentage of aggregates destruction

and decreased the amount of dispersed substance (< 0.25 mm) and large peds (> 10 mm). Liu (2007) found that long-term fertilization especially combined with organic fertilizer played an important role in increasing the amount of aggregates (2–5, 1–2, 0.5–1, 0.25–0.5 mm) on surface soil. This increase may be attributed to the increased microbial biomass and activity results in extra cellular polysaccharides which act as the good cementing agent of soil aggregates.

Aggregate water stability and soil aggregation are known to play a major role in improving soil fertility and grain production. The application of manure increases the percentage of large sized water stable aggregates (> 5 mm) (Aoyama et al. 1999). Similar results were found in this study. Water-stable aggregates (> 5 mm) in CNPK treatment was significantly higher than NPK and also had the highest amount (6.49%) in all treatments (Table 3). The amount of aggregates 5–2 mm increased weakly with organic amendments and the CNPK treatment increased by 78.0% compared to NPK treatment. The percentage of the aggregates with other sizes (2–1, 1–0.5, 0.5–0.25 mm) were higher in the MNPK, HNPK, CNPK treatments by 4.4–31.0%, 16.3–59.6% and 18.9–72.9% than the NPK respectively, which is in agreement with the results of Huo et al. (2008). Lignin and cellulose can be derived from stalk as available C and can promote soil aggregation degree and stability. Our results showed that the percentage of aggregates destruction (PAD) ranged from 11.2–53.4% (Table 3). This happened because there was an increase in soil organic matter with addition of stalks and

Table 4. Mean weight diameter (MWD; mm) and geometric mean diameter (GMD; mm) of dry and wet sieved under different fertilizer treatments

Type	Diameter	Treatment						
		CK	NPK	LSNPK	MSNPK	HSNPK	CNPK	MNPK
Dry sieved	MWD	6.51 ± 0.81^{a}	6.52 ± 1.73^{a}	5.52 ± 0.47^{a}	6.23 ± 0.93^{a}	6.54 ± 1.47^{a}	6.68 ± 0.67^{a}	5.97 ± 0.35^{a}
	GMD	4.23 ± 0.89^{a}	4.43 ± 1.64^{a}	3.33 ± 0.34^{a}	3.94 ± 0.83^{a}	4.42 ± 1.62^{a}	4.44 ± 0.67^{a}	3.61 ± 0.36^{a}
Wet sieved	MWD	1.46 ± 0.34^{ab}	1.17 ± 0.23^{ab}	1.09 ± 0.03^{b}	1.20 ± 0.26^{ab}	1.40 ± 0.31^{ab}	1.56 ± 0.33^{a}	1.23 ± 0.11^{ab}
	GMD	0.86 ± 0.18^{a}	0.73 ± 0.08^{a}	0.70 ± 0.02^{a}	0.76 ± 0.15^{a}	0.81 ± 0.20^{a}	0.91 ± 0.14^{a}	0.73 ± 0.05^{a}

Values are means ± SD ($n = 3$). Values with different letters within a column are statistically significantly different at $P < 0.05$. CK – no fertilizer; NPK – inorganic N, P, K fertilizer; LSNPK – low amount of maize stalks plus NPK; MSNPK – medium amount of maize stalks plus NPK; HSNPK – high amount of maize stalks plus NPK; CNPK – maize stalk compost plus NPK; MNPK – cattle manure plus NPK

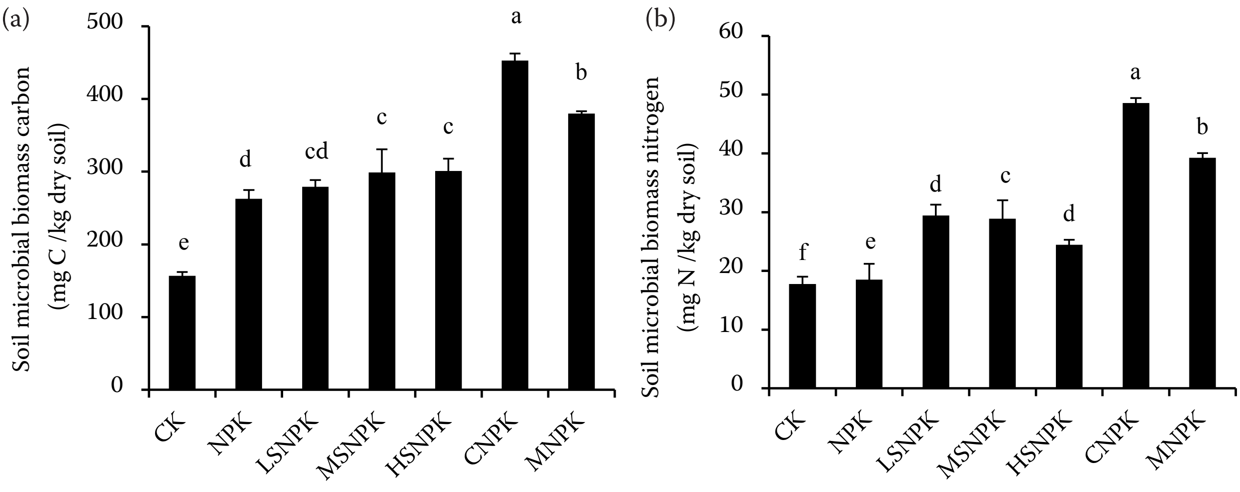

Figure 1. Microbial biomass C (MBC) (a) and microbial biomass N (MBN) (b) at 0–20 cm depth. Different letters between treatments show significant differences at $P < 0.05$. CK – no fertilizer; NPK – inorganic N, P, K fertilizer; LSNPK – low amount of maize stalks plus NPK; MSNPK – medium amount of maize stalks plus NPK; HSNPK – high amount of maize stalks plus NPK; CNPK – maize stalk compost plus NPK; MNPK – cattle manure plus NPK

consequently the formation of organic cementing material, so aggregate stability increased (Tisdall and Oades 1982).

Mean weight diameter and mean weight diameter of soil aggregates. Mean weight diameter (MWD), mean weight diameter (GMD) of soil aggregates and the amount of > 0.25 mm aggregates can strongly reflect the distribution and stability of aggregates. Overall, MWD and GMD of dry aggregates generally decreased in the order CNPK > HSNPK > NPK > CK > MSNPK > MNPK > LSNPK (Table 4). MWD and GMD of water-stable aggregates were higher than NPK by 2.6–33.3% and 0–24.7% in all of the organic fertilization treatments. Usually, there was a significant positive correlation between MWD and the amount of > 0.25 mm aggregates (Guber et al. 2005). This agrees with our results. Most of the organic fertilization treatments had large MWD and high amount of > 0.25 mm aggregates.

Soil microbial biomass. Soil microbial biomass can indicate soil biological processes, including organic matter degradation, mineralization and nutrient recycling. Our results showed that microbial biomass C (MBC) ranged from 156.5 to 453.0 mg/kg and microbial biomass N (MBN)

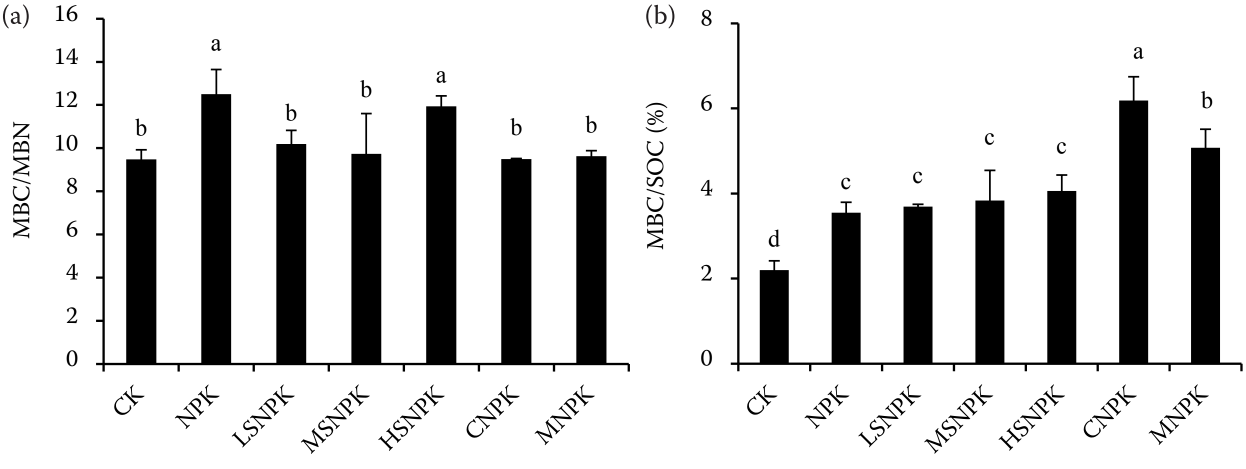

Figure 2. Microbial biomass C (MBC)/microbial biomass N (MBN) (a) and MBC/soil organic carbon (SOC) (b) at 0–20 cm depth. Different letters between treatments show significant differences at $P < 0.05$. CK – no fertilizer; NPK – inorganic N, P, K fertilizer; LSNPK – low amount of maize stalks plus NPK; MSNPK – medium amount of maize stalks plus NPK; HSNPK – high amount of maize stalks plus NPK; CNPK – maize stalk compost plus NPK; MNPK – cattle manure plus NPK

Table 5. Soil urease, alkaline phosphatase and invertase activities in 0–20 cm depth (μg/g/h)

Treatment	Urease	Phosphatase	Invertase
CK	71.3 ± 4.32^{e}	70.1 ± 3.53^{c}	906.78 ± 6.76^{d}
NPK	90.4 ± 6.00^{d}	71.9 ± 3.40^{bc}	1 002.2 ± 2.55^{c}
LSNPK	97.9 ± 8.37^{cd}	73.1 ± 1.79^{abc}	1 033.3 ± 4.42^{b}
MSNPK	101.7 ± 7.13^{b}	73.8 ± 7.66^{abc}	1 035.5 ± 12.55^{b}
HSNPK	101.8 ± 2.84^{abc}	75.9 ± 5.44^{ab}	1 178.2 ± 26.67^{a}
CNPK	112.6 ± 13.01^{a}	77.6 ± 3.50^{a}	1 031.1 ± 18.64^{b}
MNPK	109.2 ± 3.05^{ab}	76.4 ± 1.05^{ab}	847.2 ± 21.82^{e}

Values are means ± SD (n = 3). Data are means ± SD (n = 3) and values followed by different letters between treatments show significant differences at $P < 0.05$. CK – no fertilizer; NPK – inorganic N, P, K fertilizer; LSNPK – low amount of maize stalks plus NPK; MSNPK – medium amount of maize stalks plus NPK; HSNPK – high amount of maize stalks plus NPK; CNPK – maize stalk compost plus NPK; MNPK – cattle manure plus NPK

ranged from 16.6 to 47.7 mg/kg in the 0–20 cm depth (Figure 1). After 2 years of amendments, MBC and MBN generally decreased in the order CNPK > MNPK > (LSNPK, MSNPK, HSNPK) > NPK > CK. MBC and MBN in fertilized treatments were significantly higher than CK. The CNPK and MNPK treatments increased the MBC significantly. This was similar to other studies which showed that application of organic materials increased MBC in fluvo-aquic soil (Ni et al. 2003). This increase may be attributed to increased inputs to the soil from above- and below-ground residues. These materials are the main C and N source for soil microorganisms and could improve the utility of nitrogen and help to protect the environment (Zhou et al. 2007).

MBC/MBN can show the information of microbial population. Generally, C/N of bacteria is 5:1, actinomyces 6:1 and fungus 10:1. MBC/MBN of CK was the lowest for the few microorganisms there (Figure 2a). Except for MBC/MBN in the NPK and HSNPK treatments being higher, it was about 10:1 in the other treatments and had no significant difference. MBC/SOC (soil organic carbon) is better to show the soil carbon capacity and activity compared to MBC and SOC alone (Li et al. 2008). MBC/SOC ranged from 2.20% to 6.18% in all treatments and in fertilized treatments was significantly higher than CK (Figure 2b). These results were likely due to the addition of manure and fungicide. The compost could have more organic matter from stalks carbon decomposing compared to manure.

Soil enzymatic activity. Soil enzymatic activity can indicate soil biological activity. Soil urease relates to soil ability of N supply closely, which stands for degree of N supply. Our results showed that the urease activity was 21.1% in the NPK treatment, which was higher than CK and the urease activity in organic fertilization treatments were all higher than the NPK (Table 5). Of all the organic fertilization treatments, the CNPK had the greatest increase of 19.7% for urease activity. Soil phosphatase activity is the indicator of soil phosphorus status. Overall, soil phosphatase activity showed an increasing trend. Compared with the NPK treatment, MNPK increased significantly, in particular, the CNPK, increased by 7.93% (Table 5). The addition of organic materials significantly increased soil phosphatase activity and capacity (Taylor et al. 2002). The invertase activity reflects the accumulation and decomposition of soil organic carbon. In addition to the MNPK, all fertilization treatments were higher than CK to varying degrees. The invertase activity in the HSNPK treatment was significantly higher than the other treatments and differences among the other organic treatments were generally small (Table 5). Long-term application of organic fertilizer can improve invertase activity markedly, which can then stimulate the turnover of soil organic carbon (Albiach et al. 2000). Our results showed that the application of stalks could improve the activity of invertase, and invertase stimulated the decomposition again, so a synergic relationship was created.

In conclusion, finding reasonable methods to improve soil fertility to promote sustainable agricultural production on the Loess Plateau of China is very necessary. Application of organic materials is a promising soil management practice which can improve soil structure and increase soil microbial activity, especially in the CNPK treatment. However, whether this is the optimum fertilization method for the region, needs to be studied with a long term comprehensive evaluation.

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Corresponding author:

Prof. Yan'An Tong, Northwest A&F University, College of Resources and Environment, Yangling,
712100 Shaanxi, P.R. China
phone: + 86 29 8708 1213, fax: + 86 29 8708 1200, e-mail: tongyanan@nwsuaf.edu.cn