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Effects of long-term (23 years) mineral fertilizer and compost application on physical properties of fluvo-aquic soil in the North China Plain

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ABSTRACT

The influence of compost and mineral fertilization on soil organic carbon (SOC) and physical properties varied greatly in previous studies because of differences in site conditions such as climate and soil. This study was conducted as a long-term (1989–2012) field experiment to evaluate the effects of mineral fertilization and compost application on SOC content and some physical properties of an intensively cultivated sandy loam soil in the North China Plain. The experiment consisted of seven treatments: organic compost (OM); half organic compost plus half mineral fertilizer NPK (1/2OM1/2NPK); mineral fertilizer NPK (NPK); mineral fertilizer NP (NP); mineral fertilizer PK (PK); mineral fertilizer NK (NK); and unfertilized control (CK), each with four replicates. Relative to CK, the SOC content was higher in all of the compost and mineral fertilizer treatments, but increments in SOC under the compost application treatments were higher than mineral fertilization application. Compost application (OM, 1/2OM1/2NPK) decreased soil bulk density and increased total porosity significantly in comparison with that in the CK plots. Soil bulk density and total porosity for the mineral fertilization treatments, except NP, did not significantly differ from CK. The lowest penetration resistance at 0–20 cm soil depth was observed in the NK plots, and the highest penetration resistance was found in the CK plots. Compost application increased the total amount of water-stable macro-aggregates (>0.25 mm); however, MWD was not significantly affected by compost application. The MWD in the NK treatment was lower than in CK by 0.2 mm, while its variation among NPK, OM, 1/2OM1/2NPK, NP, PK, and CK was not significant. The compost- and mineral fertilizer-treated soil had 34.6–91.7% higher volume of macropores than the CK soil. The OM and 1/2OM1/2NPK-treated soil had a significantly higher proportion of small pores (<3.3 μm), and the mineral fertilizer-treated soil did not differ from CK. The hydraulic conductivity in the balanced fertilization plots (OM, 1/2OM1/2NPK, NPK) tended to be higher than in the unbalanced fertilization treatments (NP, PK, and NK) and CK. The results indicated that supplementation with organic manure such as compost is more beneficial to enhance soil fertility and maintain the sustainability of crop production in the North China Plain.

1. Introduction

The North China Plain is one of the most important agricultural production regions in China (Yang and Janssen, 1997), with a surface area of 350,000 km^2 containing approximately 18 million ha of agricultural land (Zhao et al., 2007). A double-cropping system with winter wheat and summer maize has been adopted as the main cropping system. In the past three decades, in order to obtain higher crop yields, massive amounts of chemical fertilizer were applied instead of traditional manure or compost in this area. However, compared with organic fertilizers, chemical fertilization resulted in obviously slower soil organic carbon accumulation due to the intensive cultivation and lack of residue return (Cai and Qin, 2006; Zhang et al., 2008). To maintain sustainable soil productivity, the research focus has changed in recent years toward the application of organic fertilizers and the return of crop residues to the soil.

Soil physical properties such as bulk density, porosity, and aggregate stability are the important components of soil quality, and their changes with time can reflect the sustainability of soil. The application of organic and chemical fertilizers could influence

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soil physical properties because they could change soil organic carbon (SOC) content (Schulten and Leinweber, 1991; Paustian et al., 1992; Aref and Wander, 1998; Ellmer et al., 2000) and the chemical composition of soil solution (Haynes and Naidu, 1998). SOC is considered as a binding agent and as a nucleus in the formation of soil aggregates (Bronick and Lal, 2005), and the chemical composition of soil solution can greatly be related with dispersion/flocculation of clay particles and thus soil aggregation. It is commonly accepted that organic manure and compost application can increase SOC content directly and then improve aggregation, hydraulic conductivity, total porosity, and penetration resistance (Arriaga and Lowery, 2003; Celik et al., 2004; Hati et al., 2007; Rasool et al., 2008). However, there have been many contradictory results of the effect of mineral fertilization on organic matter and soil physical properties. A number of studies concluded that SOC content and soil structure declined with the continuous application of inorganic fertilizers without organic inputs (Heenan et al., 1995; Robinson et al., 1996; Sarkar et al., 2003; Morari et al., 2006; Hati et al., 2008). One of the possible reasons was N fertilizers that contain or form NH_4^+ may tend to reduce aggregate stability by dispersing organic binding agents inside aggregates and soil colloids (Haynes and Naidu, 1998; Fonte et al., 2009). Other studies (Sheeba and Kumarasamy, 2001; Schjønning et al., 2005) did not find any deleterious effects of mineral fertilization on soil physical properties such as hydraulic conductivity in the plow layer of sandy loam. But Rasool et al. (2007, 2008) reported that balanced mineral fertilization in a rice–wheat rotation in sandy loam and in a wheat–maize rotation improved the mean weight diameter (MWD) of aggregates, total porosity, and water holding capacity since the application of balanced mineral fertilizer can improve the growth of crops and increase organic matter return to the soil (mainly as root hair). Therefore, many researchers have proposed that a combination of organic and mineral fertilization is the optimal strategy to improve soil organic matter content and physical properties (Hati et al., 2007; Bandyopadhyay et al., 2010). Nevertheless, few studies have been undertaken to determine the effects of manure and mineral fertilization on soil properties when the input of nutrients from both manure and mineral fertilization was equal.

It is hardly possible to transfer those findings to the North China Plain, due to variations in soil type, crop management and climate conditions. Concerning the North China Plain, Cai and Qin (2006) had found the different SOC contents under fertilization treatments; however, little is known about the effect of mineral and organic fertilizer application on the porosity and hydraulic properties of fluvo-aquic soil in this area. The objectives of this study were to evaluate the long-term (23 years) effects of compost and mineral fertilizer application with the same nutrients on crop yield, SOC and soil physical properties, such as bulk density, characteristics of soil pores, and hydraulic conductivity.

2. Materials and methods

2.1. Site description

This long-term experiment is conducted in Fengqiu County, Henan Province, China (35°00′N latitude and 114°24′E longitude), which is a region typical of the North China Plain. The average annual temperature was 13.8 °C, and the annual precipitation was 240 mm in 2012. The soil, derived from alluvial sediments of the Yellow River, has a sandy loam texture (sand:silt:clay = 52:33:15) and is classified as Calcaric Fluvisols according to WRB (Shi et al., 2010). The experiment was established in 1989 and the experimental field was not fertilized in the 3 years before the start of the experiment. Soil basal characteristics of the plough layer (0–20 cm) in September 1989 are shown in Table 1. The crop system is a winter wheat (*Triticum aestivum L.*)–summer maize (*Zea mays L.*) rotation system in 1 year.

Table 1
Soil basal characteristics (0–20 cm) in September, 1989 (mean of 28 samples ± standard deviation).

Characteristic	Soil depth 0–20 cm
pH	8.66 ± 0.03
Soil organic carbon (g kg^{-1})	4.42 ± 0.15
Total N (g kg^{-1})	0.44 ± 0.02
Total P (g kg^{-1})	0.50 ± 0.01
Total K (g kg^{-1})	18.6 ± 0.38
Inorganic N (g kg^{-1})	9.50 ± 0.88
Olsen-P (g kg^{-1})	1.92 ± 0.21
Exchangeable K (g kg^{-1})	78.7 ± 3.50

2.2. Experimental design

The experiment consisted of seven treatments in a randomized block design with four replicates. The seven treatments were organic compost (OM); half organic compost plus half mineral fertilizer NPK (1/2OM1/2NPK); mineral fertilizer NPK (NPK); mineral fertilizer NP (NP); mineral fertilizer PK (PK); mineral fertilizer NK (NK); and an unfertilized control (CK). Each replicate plot was 9.5 m long and 5 m wide, and the plots were separated by cement banks, which were 60 cm deep and extended 10 cm above the soil surface. The application rates of NPK corresponded with common agricultural practice. The application rates of N, P, and K, if they were applied, were the same for all treatments at 150 kg N ha^{-1}, 75 kg P_2O_5 ha^{-1}, and 150 kg K_2O ha^{-1} for winter wheat, and 150 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1}, and 150 kg K_2O ha^{-1} for maize. The mineral N, P, and K fertilizers used were urea, calcium superphosphate, and potassium sulfate, respectively. The urea application ratio between the basal fertilizer and the supplemental fertilizer was 6:4 and 4:6 for maize and wheat, respectively. The calcium superphosphate and potassium sulfate were applied as basal fertilizers.

For the OM treatment, compost was applied at an average of approximately 4500 kg ha^{-1} (oven dry weight) prior to each cropping season (wheat and maize). For the 1/2OM1/2NPK treatment, compost was applied at half the rate of the OM treatment. The compost was composed of wheat straw, oil rapeseed cake, and cottonseed cake in a ratio of 100:40:45. These materials were machine-chopped into 3–5-mm lengths, mixed completely with a limited amount of water, and composted for 2 months. The total N, total P, and total K content of the compost was measured before fertilization, and the amount of organic manure applied in the OM and 1/2OM1/2NPK treatments was calculated according to 150 kg N ha^{-1} and 75 kg N ha^{-1}, respectively. The total P and K contained in the compost that was applied to the OM and 1/2OM1/2NPK treatments were less than those in the NPK treatment, so to match the same rate of NPK, chemical P and K fertilizers were supplied to the OM and 1/2OM1/2NPK treatments. All organic compost and mineral P and K fertilizers were applied as a basal fertilizer for each crop. All basal fertilizers were evenly spread onto the soil surface by hand and incorporated into the topsoil (0–20 cm) by tillage before sowing. Supplemental urea was also surface applied by hand and then integrated into the plowed layer with irrigation water, generally at the jointing stage for wheat and at the booting stage for maize.

2.3. Sampling and analytical procedures

Nine soil samples (0–20 cm) from each plot were taken and mixed after the maize harvest in September 2012. The SOC content