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Effects of cattle manure compost combined with chemical fertilizer on topsoil organic matter, bulk density and earthworm activity in a wheat–maize rotation system in Eastern China

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ABSTRACT

Cattle manure compost (CMC) combined with chemical fertilizer (CF) was applied to a wheat–maize rotation field, in Eastern China, to assess soil physical and chemical properties, biological activity and land productivity. Indicators of organic matter, carbon storage and sequestration, bulk density, water content, total N content and earthworm population from topsoil (0–20 cm) were quantified. This consecutive study (2009–2014) was carried out on the base of the same total N, P, K application rate (375.0 kg N ha^{-1} yr^{-1}, 92.4 kg P_2O_5 ha^{-1} yr^{-1} and 316.3 kg K_2O ha^{-1} yr^{-1}) in each treatment that was fertilized. Six treatments were designed as: (1) CK, without any fertilizer; (2) NPK, 100% CF; (3) NPKM1, 25% CMC combined with 75% CF; (4) NPKM2, 50% CMC combined with 50% CF; (5) NPKM3, 75% CMC combined with 25% CF; and (6) CM, 100% CMC. The results demonstrated that organic matter, water content, total N content and earthworm density from topsoil were significantly and positively ($P \leq 0.01$) related to CMC input, with significantly negative correlation being observed between soil bulk density and CMC input. The average annual yield of the wheat–maize rotation system significantly increased ($P \leq 0.05$) in NPK, NPKM1, NPKM2, NPKM3, and CM compared with CK, with the highest yield being obtained from NPKM1. Applying merely CF not only led to the lower SOM, water content and total N content, but also resulted in negative effects on earthworm activity, while CMC alleviated such negative effects. Our finding may help to increase food supply by improving soil conditions with organic fertilizer compost application.

1. Introduction

Soil organic matter (SOM) content is generally regarded as one of the key indicators of soil quality (Riley et al., 2008). Maintaining adequate amount of SOM is particularly important for sustaining the productivity of an agro-ecosystem (Lal et al., 1999; Carter, 2002; Ding et al., 2012). Numerous studies have found strong correlations among soil structure, soil aggregate stability and SOM content (Darwish et al., 1995; Haynes and Naidu, 1998). For instance, some studies have shown that increase in SOM improves soil's aggregation, total porosity, hydraulic conductivity, water-holding capacity, resistance to water and wind erosion, and lowers bulk density and the degree of compaction (Celik et al., 2004; Leroy et al., 2008). Otherwise, a decline in SOM content increased soil compaction which has a negative impact on root growth through reducing the supply of water and nutrients (Martinez and Zinck, 2004; Celik et al., 2010). Bulk density is largely related with soil compaction, which alters the air-soil and water-soil interactions then further affects microbiological activity, nutrient uptake and water retention (Abu-Hamdeh, 2003; Martinez and Zinck, 2004). Soil organic matter retains water and helps soil particles to bind and resist against soil compaction (Celik et al., 2010). Preserving an adequate amount of SOM stabilizes soil structure which makes the soil more resistant to degradation (Thomas et al., 1996). Excess use

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of chemical fertilizers, however, has resulted in a significant depletion of SOM and serious water and soil pollution (Liu et al., 2003a,b; Minuto et al., 2006; Zhao et al., 2006; Li et al., 2007; Ju et al., 2009; Zhen et al., 2014). Serious losses of SOM have deteriorated soil quality and crop productivity, which has spurred scientist to explore ways to restore SOM (Liu et al., 2010; Ding et al., 2011). Studies have shown that maintaining SOM at optimum level can be achieved by fertilization practices (Zebarth et al., 1999; Wu et al., 2004; Yang et al., 2005; Blair et al., 2006; Verma and Sharma, 2007; Purakayastha et al., 2008; Gong et al., 2009). However, perhaps as cost saving measure, more and more chemicals have been added to soils, which would further degrade soil quality. Researchers therefore urgently needed to continue investigating management practices that can reduce soil degradation.

It is well documented that earthworm can maintain and improve soil fertility, soil structure and aggregate stability, nutrient cycling as well as plant productivity (Edwards and Lofty, 1977; Clements et al., 1991; Marinissen, 1994; Smetak et al., 2007; Riley et al., 2008). The experimentally induced absence of earthworms in grassland was found to increase soil bulk density and shear strength, greatly reduce SOM, pH, soil moisture and initial infiltration rate (Clements et al., 1991). Mineral fertilizers may have positive effects on earthworms by increasing the amount of plant biomass, thereby increasing their food supply (Edwards and Lofty, 1982). But the soil pH must be regulated to avoid negative effects of acidifying fertilizers (Ma et al., 1990). Organic fertilizers, such as animal manure, can also provide food for and increase the biomass of earthworms (Andersen, 1979). For instance, organic cropping systems have displayed higher earthworm biomass and density than conventional ones (Mäder et al., 2002). However, less is known how the long term application of organic manure combined with chemical fertilizer (CF) will affect the soil biodiversity.

Usage of organic materials, such as sewage sludge, crop residues, compost and poultry manure, are well known to be beneficial practices in soil restoration (Tejada and Gonzales, 2008; Tejada et al., 2008). A long-term fertilizer experiment in paddy soil derived from barren land in subtropical China showed that applying CF in combination with farmyard manure increased SOM content more significantly than using CF alone (Li et al., 2010). However, organic inputs at normal level (2–4.5 Mg ha^{-1}) in Northeastern China did not yield remarkable effects on restoring SOM level (Li et al., 2002). Although some found higher level of organic inputs could lead to a corresponding increase in soil carbon sequestration, they only evaluated the effects of organic fertilizer on soil properties at different rates or focused on adding organic fertilizer on the basis of CF application rates. On one hand, they did not consider the nutrients (N, P, K) in organic fertilizer, and the fact that the total nutrients were not the same among treatments. On the other hand, not all chemical fertilizers were fully utilized. As excess use of CF alone has resulted in numerous negative effects, it is necessary to find the suitable application rates of organic materials mixed with CF.

Organic fertilizers release nutrients over time. On the basis of the same level nutrients (N, P, K), we want to know the effects of increased organic fertilizer combined with decreased CF on yield, soil characteristics and biological activity. Although earthworm activity is considered to be a biological indicator of soil quality (Doran and Zeiss, 2000), information is limited on the impact of using a mix of inorganic and organic fertilizers as treatments. We therefore hypothesized that utilizing a mix of inorganic and organic fertilizer could improve the soil quality, make the soil suitable for earthworms to live and achieve high crop yield in the long term. So in the present study, our objectives were to: (1) assess crop yield; (2) evaluate the changes in topsoil carbon storage and sequestration, and bulk density under different organic fertilization application rates; and (3) assess the effects of increased organic fertilizer combined with decreased CF at various rates on earthworm activity. We hope the findings from this experiment can help to increase food supply while reducing possible chemical fertilization pollutions through organic fertilizer compost application.

2. Materials and methods

2.1. Experimental site

The field experiment was conducted at the Eco-farm Research Station of Shandong Agricultural University, based in Pingyi County, Shandong Province, Eastern China (35°26′21″N, 117°50′11″E). It was initiated on 25 September, 2009. The study area experiences a typical temperate and monsoonal climate, with the mean annual rainfall being 770 mm and average annual temperature 13.2 °C. The daily rainfall from 1 October, 2013 to 9 October, 2014 was listed in Fig. 1. The soil is Alfisols, according to the soil taxonomy (IUSS Working Group WRB, 2014). The main cropping system is winter wheat (*Triticum aestivium*L.)—summer maize (*Zea mays*L.) rotation. Winter wheat grows from early October to early June of the following year and summer maize from middle June to early October. At the beginning of the experiment, the topsoil (0–20 cm) had a pH of 6.12 (soil:water = 1:2.5) and contained 7.40 g C kg^{-1} soil and 0.74 g N kg^{-1} soil. The soil bulk density was 1.43 g cm^{-3}.

2.2. Preparation of cattle manure compost

Cattle manure was obtained from the nearby Hongyi Organic Farm, in Jiang Jiazhuang Village of Pingyi County. It was shaped into cuboids with width 1.5 m, height 0.5 m, with moisture content of 70%. The compost was covered with plastic film, stirred and mixed every 20 days. After 90 days, the resulting cattle manure compost (CMC) was applied into the fields before sowing. The manure compost contained organic matter 40.61%, total nitrogen (N) 2.11%, total phosphorus (P_2O_5) 0.52%, total potassium (K_2O) 1.78% and had moisture content of 68.9%.

2.3. Experimental design

The treatments were arranged as: (1) CK, without any fertilizer; (2) NPK, 100% chemical fertilizer (CF); (3) NPKM1, 25% CMC combined with 75% CF; (4) NPKM2, 50% CMC combined with 50% CF; (5) NPKM3, 75% CMC combined with 25% CF; (6) CM, 100% CMC.

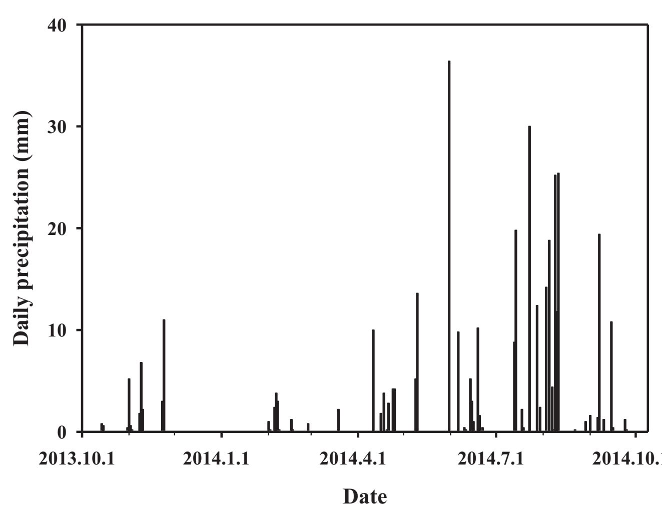

Fig. 1. The daily precipitation from 1 October, 2013 to 9 October, 2014 in the study area, Jiang Jiazhuang Village, Pingyi County, Eastern China.