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The effects of two organic manures on soil properties and crop yields on a temperate calcareous soil under a wheat–maize cropping system

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ABSTRACT

To improve soil fertility, efforts need to be made to increase soil organic matter content. Straw manure is considered another important management practice to maintain soil organic matter content. This study compared effects of two organic manures (straw and farmyard manure) on soil properties and crop yields in a crop rotation system under semi-arid conditions. Soil physical, chemical and biological characteristics were determined in the experiment. After 25 years cropping and fertilization, two organic manures significantly influenced soil properties and crop yields. Farmyard manure combined with chemical fertilizer management (M + NP) resulted in higher increase in SOC, available-N, available-P, and higher activities of protease, urease, and alkaline-phosphatase compared with those found under straw manure combined with chemical fertilizer management (S + NP). However, soil of straw treatment had higher levels of potential soil respiration, soil water retention, microbial biomass, soil porosity, invertase, catalase and lower bulk density than farmyard manure treatment. M + NP produced the highest crop yields at all treatments. Biochemical properties of both treatments were positively correlated with SOC and nutrient content. These results indicate that straw management positively affected soil physical, chemical and biochemical properties as manure treatment in calcareous soil. Adding straw manure, as a replacement of farmyard manure, could be a promising strategy on some soil physical and biological properties as compared to farmyard manure in calcareous soil.

1. Introduction

Intensive agriculture has caused negative effects on soil environment over past decades (e.g. loss of soil organic matter (SOM), soil erosion, water pollution). These problems have led to concentration on development and promotion of organic farming management systems. Organic farming is increasingly becoming of interest because of the perceived health and environmental benefits, especially in arid-area. Sustaining agricultural production on the arid-area is very important to ensure a sufficient food supply for the growing population. Calcareous soil, characteristic with low content of SOM, was main soil of arid-area, where the equilibrium of biogeochemical cycles is continuously and rapidly altered by human actions, such as soil tillage, fertilization and irrigation. Organic matter should be maintained in the soil for sustainable agriculture.

Straw complement is considered an important management practice with potential to reduce the dependence on mineral fertilizers and to maintain soil organic matter content. Straw manure commonly replaces farmyard manure amendments on stockless farms. As other amendments, straw provides nutrient for plant growth and the organic carbon containing in straw serves as an energy supply for heterotrophic soil microorganisms. Inputs crop residue can increase the size and activity of soil microbial communities, and increase soil enzyme activity (Bolton et al., 1985; Martens et al., 1992; Kautz et al., 2004). Crop residue amendments have caused shifts in microbial community composition, and influenced microbial carbon source utilization profiles (Lupwayi et al., 1998; Schutter and Dick, 2001). A question of great concern is whether straw can be considered to be equal to farmyard manure as a carbon source for improving and sustaining soil biological properties and fertility. Also, it is not clear how the impact of straw differs compared with other organic fertilizers. Most studies have reported on short-term responses of straw, which may differ considerably from long-term responses to different fertilizer regimes.

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Soil chemical and physical parameters are sensitive indicators of treatment effects on soil process that indicate nutrient flow in agro-ecosystems. Also, soil quality is very closely linked to its biological properties. It has been well established that the more dynamic characteristics such as microbial biomass, soil enzyme activity and soil respiration respond more quickly to changes in crop management practices than do characteristics such as total SOM (Doran et al., 1996). Soil enzymes integrate soil chemical, physical, and biological characteristics and may be used to monitor the effects of soil management on long-term productivity. In part, enzymatic activities in soil are controlled by physical and chemical conditions, although the major limiting factors for microorganisms are temperature and water content. Quantification of these characteristics is important to understand the effects of crop management practices on soil quality and crop yield.

Our objective was to study the changes of soil physical, chemical and biological characteristics in calcareous soil under a long-term field experiment involving fertility treatments and a maize-wheat cropping sequence. The enzymes were chosen due to their importance in the cycling of C (invertase), N (protease, urease), P (alkali-phosphatase) and redox (catalase, phenol peroxidase). This paper can put a high light on the effects of two different manures on changes of soil quality and soil productivity after long-term fertilization and cropping.

2. Materials and methods

2.1. Site description and experimental design

The study site was located in northwest of China (latitude 35°34′N and longitude 106°41′E). Total mean precipitation was 573 mm and mean annual evaporation is 660 mm. The experiment was started in 1978 on silty clay soil (23% sand, 43% silt and 33% clay) with initial soil pH 8.2, organic matter 9.7 g kg^{-1}, CEC 34 cmol kg^{-1}, soil organic carbon (SOC) 5.6 g kg^{-1}, Olsen's P 4.8 mg kg^{-1}, available-N 60.2 mg kg^{-1} and available-K 165 mg kg^{-1}. In China, the soil is referred to as a Heilu soil, which corresponds to a calcarid regosol according to the FAO/UNESCO classification system (FAO/UNESCO, 1988). Winter wheat and maize have dominated the crop rotation in the area (16 years winter wheat, 6 years maize, and 3 years soybean or grain sorghum).

The treatments were unfertilized (CK), inorganic N and P (NP), straw and NP (S + NP), and farmyard manure with NP (M + NP). Urea and super-phosphate were used as the source of N and P fertilizer. Farmyard manure came from pig. Organic matter of the manure was 20–25 g kg^{-1}, total N 1.5–2.0 g kg^{-1}, total P 0.8–2.5 g kg^{-1}, available-N 180–250 mg kg^{-1}, available-P 30–40 mg kg^{-1}, and available-K was 280–350 mg kg^{-1}. Wheat straw was as a straw amendment and was chopped to about 2–4 cm. In all the fertilizer treatments, the N rate was 90 kg ha^{-1}, the P rate was 75 kg ha^{-1}, the straw rate was 3750 kg ha^{-1} and the manure rate was 75,000 kg ha^{-1}. The organic amendments were added in the autumn every second year and inorganic fertilizers were applied annually in the spring just before sowing. Each treatment had three replicates, randomly distributed in blocks with plot sizes of 2 m × 2 m.

2.2. Sampling and soil analysis

Soil samples (0–15 cm) were collected on 23 September 2003. Eight soil cores were taken with an auger from each replicate of the individual treatments to a depth of 15 cm, and then combined to a composite sample for each replicate. After sampling, the soil was sieved, mixed and stored immediately at 4 °C for enzymatic activities and microbiological analysis. The other was air-dried for chemical analysis.

Soil pH and electrical conductivity were determined in a 1:5 soil/water extract. Available-N was determined by the method described by Hesse (1971), available-P using the Olsen et al. (1954) method. SOC (or organic matter) was determined by dichromate oxidation (Walkley and Black, 1934) method. Microbial biomass C (Cmic) contents were estimated by chloroform fumigation-extraction (Vance et al., 1987). Soil structural stability was determined according to Hénin and Monnier (1956). Soil bulk density was determined using the core method, according to the official methods of the Spanish ministry of agriculture (MAPA, 1986). Soil respiration was determined according to Anderson (1982).

2.3. Soil enzyme activities

All enzyme activities values were calculated on the basis of oven-dry (105 °C) weight of soil. Protease activity was determined according to Kandeler (1996). Alkaline-phosphatase and urease were determined according to Tabatabai (1994). Catalase activity was determined by the method of permanganimetric method, and invertase activity was determined by the method of DNS titration method (Guan, 1986).

2.4. Statistical analysis

Analysis of variance (ANOVA) was performed using the program SPSS 11.0 for windows. The significant of the treatment effect was determined using *F*-test. When ANOVA indicated that there was a significant value, multiple comparisons of mean value were performed using the least significant difference method (LSD).

3. Results

3.1. Crop yield

M + NP treatment gave an yield production significantly higher than that obtained in the other treatments ($p < 0.05$). S + NP treatment in the 16 analyzed years gave an yield production significantly higher than M + NP only in 1989. The S + NP crop production was close to that of M + NP treatment only in 2 years, 2001 and 2002, while in all the other cases, S + NP production was significantly lower than that obtained on M + NP soil treatment. The highest yields recorded were 7152 kg ha^{-1} in M + NP treatment in 1984. The lowest grain yields were obtained in no fertilizer treatment (CK) (Table 1). There was a significant difference between the mean yields of organic treatments and nonorganic treatments ($p < 0.05$) (Table 1). But, the grain yields of NP and S + NP treatments were no significant difference from 1982 to 1998 ($p = 0.39649$, $p > 0.05$).

3.2. Soil organic carbon and microbial biomass

SOC of the soil ranged from 8.03 to 12.14 g kg^{-1}(Table 2). Soils that received farmyard manure application or straw had statistically higher amounts of SOC compared with the unfertilized soil ($p < 0.05$). And farmyard manure caused a higher SOC content when compared with straw treatment. NP treatment had no significant effect on SOC concentration compared with CK ($p > 0.05$). All four treatments caused a higher amount of SOC when compared with the initial level (5.6 g kg^{-1}). In continuous fertilization, SOC concentration under straw and farmyard manure treatments was 27.6% and 33.8% higher than unfertilized plots. The results showed that the level of organic matter tends to be enhanced in soils amended with organic fertilizers (manure and straw). The increase is particularly important in the soil, where the levels of organic matter in agricultural soils are normally <10 g kg^{-1}.