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Long-term effect of chemical fertilizer, straw, and manure on soil chemical and biological properties in northwest China

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ABSTRACT

A field experiment was conducted to investigate the effect of long-term (30-year) fertilizer and organic manure treatments on grain yield, soil chemical properties and some microbiological properties of arable soils in Pingliang, Gansu, China. Six treatments were chosen for this work: unfertilized control (CK), nitrogen fertilizer annually (N), nitrogen and phosphorus (P) fertilizers annually (NP), straw plus N added annually and P fertilizer added every second year (NP + S), farmyard manure added annually (FYM), and farmyard manure plus N and P fertilizers added annually (NP + FYM). Mean winter wheat yields for the 20 years ranged from 1.60 Mg ha^{-1} for the CK treatment to 4.62 Mg ha^{-1} for the NP+FYM treatment. Maize yields for the 8 years averaged 3.40 and 7.66 Mg ha^{-1} in the same treatments. The results showed that there was no interaction between farmyard manure and NP fertilizers. Compared with the CK treatment, the average soil organic carbon (SOC) and total nitrogen (TN) content were 2.0 and 3.1%, 1.9 and 13.3%, 32.7 and 24.5%, 23.0 and 19.4%, and 39.9 and 27.6% larger, respectively, for N, NP, FYM, NP + S and NP + FYM. The N only resulted in not only lowering of pH but also deficient of both P and K in the soil. Soil available K declined rapidly without straw or manure additions. The microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) contents increased with the application of nitrogen and phosphorus inorganic fertilizers. However, there was greater increase of these parameters when organic manure was applied along with inorganic fertilizers. Organic manure application also increased soil dehydrogenase, alkaline phosphatases, β-glucosidasen and urease activity significantly. The results indicated that long-term additions of organic manure have the most beneficial effects on grain yield and soil quality among the investigated types of fertilization.

1. Introduction

Soil and crop management practices such as fertilization, crop rotation and land-use change exert a considerable influence on soil chemical and biological properties over time. Routine applications of inorganic fertilizer and manure are an essential component of soil management in arable crop production systems. These amendments are used primarily to increase nutrient availability to plants, but they can also affect soil microorganisms. The benefits of using organic manure and straw in maintaining soil quality have been increasingly recognised (Chander et al., 1997).

Soil microorganisms and the processes that they control are essential for the long-term sustainability of agricultural systems (Wardle et al., 1999) and are important factors in soil formation and nutrient cycling. It has been frequently reported that soil microbial biomass and activity is an important aspect of soil quality (Schloter, et al., 2003). Research has shown that soil microbial biomass and activity responds to crop and soil management practices such as organic manure and inorganic fertilizers application (Livia et al., 2005), crop rotation (Yusuf et al., 2009), tillage and fallow (Wang et al, 2008; Liu et al, 2010) and land-use change (Wang et al., 2009). Soil enzymes are essential components involved in the dynamics of soil nutrient transformations (Masto et al., 2006). Enzyme activity in the soil environment is considered to be the major contributor of overall soil microbial activity (Frankenberger and Dick, 1983) and soil quality (Roldán et al., 2005).

Northwest China is a vast semi-arid area with an average annual precipitation ranging from 300 to 600 mm and more than 90% of the cropland in this area receives no irrigation. The main crops are wheat (*Triticum aestivum* L.) and maize (*Zea mays L.*) which are periodically rotated. This rotation is necessary for food security in this dryland region (Xing et al., 2001). For many centuries manure application to

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the soil was the common practice, but this traditional management practice changed since the 1980s due to increasing affordability of chemical fertilizers. More chemical and less organic fertilizers are now used in the area (Gong et al., 2009). So, a long-term experiment was established in 1979 to study the effects of the change in fertilizer application practices on soil properties. We hypothesized that changes in the fertilization system have considerable effects on soil microbial activity especially in dryland North China, which are known to be susceptible to the input of organic material. With time, such improved metabolic efficiency results in improved soil quality, which in turn, favors crop productivity and sustainability. To prove these hypotheses we measured SOC, microbial biomass, soil respiration and soil enzymatic activities (dehydrogenase, alkaline phosphatases, β-glucosidasen and urease activity) in soil with 30 years' application of organic manure and inorganic fertilizer under a winter wheat–maize cropping system in the North China Plain.

2. Materials and methods

2.1. Experimental site

A long-term experiment has been conducted since April 1979 at the Gaoping Agronomy Farm (35°16′N, 107°30′E, 1254 m altitude), Pingliang, Gansu, China. The soil is a dark loessial soil classified as calcarid regosols (FAO/UNESCO, 1988). Analysis of soil samples taken from the experimental area in October 1978 indicated that the surface 15 cm of soil had a pH of 8.2, SOC content of 6.2 g kg^{-1}, total N of 0.95 g kg^{-1}, total P content of 0.57 g kg^{-1}, available P of 7.2 mg kg^{-1} and available K of 165 mg kg^{-1}. Under average climatic conditions, the area has an aridity index (P/PET: precipitation/potential evapotranspiration) of 0.39 and receives 540 mm precipitation, about 60% of which occurs in the summer from July through September. May through June is the driest period for crop growth and little precipitation occurs during the winter months of December and January. The mean annual temperature is 9.8 °C. The mean annual sunshine period is 2834 h.

2.2. Experimental design and treatments

The experiment began in 1979 with a maize crop on land that had been cropped to maize during previous one year. There was only one crop each year. Six fertilization treatments were arranged in a randomized complete block design with three replications. The rotation treatments used in this study are as follows (Table 1). Data for the 20 years of winter wheat and 8 years of maize are presented in this paper.

Winter wheat (Qingxuan 8271, Longyuan 935, and Ping 93-2) was seeded in rows 14.7 cm apart at rates of 165 kg ha^{-1} on about 20 September each year when wheat followed wheat, and in early October when wheat followed maize. Maize was seeded about 20 April each year that maize was grown and Zhongdan 2 was seeded by hand in clumps every 33 cm in rows 66.5 cm apart. About 3 weeks after seeding, maize plants were thinned to one plant per clump. Later, if tillers developed, they were removed to avoid competition. Hand weeding was done to control weeds and plant protection measures were applied when needed. Crops were harvested manually close to the ground and all harvested biomass was removed from the plots. Grain yields were determined by harvesting 20 for wheat and 40 m^2 for maize at centers of the plots. Grain samples were air-dried on concrete, threshed, and oven-dried at 70 °C to a uniform moisture level, and then weighed.

Table 1
Description of the rotation treatments used in this study.

Crop	Year
Maize	1979–1980, 1985–1986, 1991–1992, 2005–2006
Wheat	1980–1984, 1986–1990, 1992–1998, 2000–2004
Soybean	1999
Sorghum	2000

The experimental area was 0.44 ha. Each plot was 16.7 m × 13.3 m with a buffer zone of 1.0 m between each plot. The six treatments were (1) CK, unfertilized control, (2) N, nitrogen fertilizer annually, (3) NP, nitrogen and phosphorus (P) fertilizers annually, (4) NP + S, straw (S) plus N added annually and P fertilizer added every second year, (5) FYM, farmyard manure added annually, and (6) NP+FYM, farmyard manure plus N and P fertilizers added annually. Urea was the N source and was applied to supply 90 kg N ha^{-1}. Superphosphate was the P source and applied to supply 30 kg P ha^{-1} yr^{-1}. Farmyard manure was added at rate of 75 t ha^{-1} (wet weight). Deep plowing of approximately 23 cm was performed in July after wheat harvest or in October after maize harvest except for the years in which wheat followed maize. In those years, shallow disk tillage was done after maize harvest and wheat was seeded immediately.

Generally, the farmyard manure was a mixture of about 1:5 ratio of wet cattle manure to loess soils and so its nutrient content was quite variable from year to year. The SOC, N, P, and K contents of manure were 11.37, 1.07, 0.69, and 12.3 g kg^{-1} in dry weight, indicating that manure is very low in N, and high in P and K. Although the specific amounts of nutrients added with manure each year were not determined, an application of approximately 75 t ha^{-1} (wet weight) supplied roughly 425 kg C ha^{-1}, 40 kg N ha^{-1}, 26 kg P ha^{-1}, and 460 kg K ha^{-1} in manure annually to crops. For NP + S treatment, 3.75 t ha^{-1} of wheat straw approximately 10 cm in length was returned to the soil prior to plowing, and P fertilizer was added every second year. There was very little wheat straw or maize residue on the other treatments because all crops were harvested at soil surface and removed from the plots before thrashing the grain. The NP + S treatment was the only treatment that had residue returned to the plots. The straw contained 1.6 t C ha^{-1}, 20 kg N ha^{-1}, 5 kg P ha^{-1}, and 23 kg K ha^{-1}.

2.3. Soil sampling

Soil samples (0–20 cm depth) were collected in June 2008. In each plot the soil was collected from ten points randomly, and mixed into one sample. After carefully removing the surface organic materials and fine roots, each mixed soil sample was divided into two parts. One part of the soil sample was air-dried for the estimation of soil chemical properties and the other part was sieved through a 2 mm wide screen and immediately transferred to the laboratory for biochemical analysis. Soil fresh samples were kept at 4 °C in plastic bags for a few days to stabilize the microbiological activity and analyzed within 2 weeks.

2.4. Soil chemical analyses

Soil pH was determined through a suspension sample with a soil (air-dried) to water (w/w) ratio of 1:2.5 and measured with a pH meter. Soil organic matter (SOM) was determined by wet oxidation (Black, 1965) and the percentage of organic carbon was calculated by applying the Van Bemmelen factor of 1.73 (Piper, 1950). Total nitrogen (TN) in soil was measured using the Kjeldahl digestion–distillation method (Black, 1965). Total phosphorus (TP) was measured by spectrophotometer after wet digestion with H_2SO_4 and $HClO_4$ (Parkinson and Allen, 1975). Available phosphorus (AP) in soil was determined by extracting samples with 0.5 M $NaHCO_3$, and determining P colorimetrically using molybdate (Olsen et al., 1954). Available potassium (AK) was extracted ammonium acetate, and then determined by a flame photometry (Shi, 1976).