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Dynamics of crop yields and soil organic carbon in a long-term fertilization experiment in the Huang-Huai-Hai Plain of China

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Abstract

We analyzed the dynamics of crop yields and soil organic carbon content (SOC) in a long-term fertilization experiment carried out in the Huang-Huai-Hai Plain of China. The experiment with crop rotation of winter wheat and summer maize started in 1990 and had seven treatments receiving N, P, and K at the same rates if it was applied. The treatments were inorganic fertilization (NPK, NP, PK, NK), organic fertilization (ON), half amount of N from inorganic fertilizer and another half from compost (1/2ON), and no fertilization as control (CK). On average, over 14 years (1990–2003), both wheat and maize yields were the highest and most stable in the NPK treatment. Average wheat and maize yields were 23.7% and 18.0% lower in ON, respectively, and slightly but significantly lower (1.9% and 1.5%, respectively) in 1/2ON than those in NPK. Unbalanced inorganic fertilization without K (NP) was not sustainable for achieving high yields. There was a significant logarithmic relationship between roots and compost input and SOC content in 0–20 cm in 2003. Over the time of the study SOC storage in 0–20 cm increased by 12.2 Mg C ha^{-1} in ON, 7.8 Mg C ha^{-1} in 1/2ON, and 3.7 Mg C ha^{-1} in NPK, and decreased by 1.6 Mg C ha^{-1} in NK and 1.4 Mg C ha^{-1} in CK. Measured dynamics of SOC and model simulation predictions showed that the SOC in NPK, ON and 1/2ON almost reached equilibrium in 2003. These results indicate that although the balanced application of chemical fertilizers of N, P, and K maintains the crop production in the region, it is not an ideal practice from the point view of carbon sequestration in soil. Application of compost alone has a reverse effect on crop yields and carbon sequestration in soil. Therefore, mixed application of organic and inorganic fertilizers is a compromise between food security and soil carbon sequestration in the region.

Keywords: Balanced fertilization; Long-term experiment; Carbon sequestration; Food security

1. Introduction

Intensive cropping with no return of crop residues and other organic inputs results in the loss of soil organic carbon (SOC), which is assumed to be a non-sustainable practice (Singh et al., 2004). Results obtained from long-term experiments have already substantially improved our knowledge on changes in soil productivity with various fertilization practices. There are many reports that soil fertility has declined with continuous application of inorganic fertilizers without organic inputs. Soil acidification (Malhi et al., 2000; Graham et al., 2002; Malhi et al., 2003) and depletion of soil structure (Graham et al., 2002; Edmeades, 2003) have resulted. On the other hand, there are also numerous reports showing that balanced application of inorganic fertilizers maintains soil productivity and even slightly increase SOC content along with increased crop yields (Rasmussen and

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Collins, 1991; Cavazzna and Volk, 1996; Glendining et al., 1996; Buyanovsky and Wagner, 1998; Kanchikerimath and Singh, 2001; Shen et al., 2004).

With an increasing concern about the increase in CO_2 concentration in the atmosphere and the role of croplands in carbon sequestration, long-term field experiments carried out in cropland are widely employed to develop options for increasing soil carbon sequestration (Follett, 2001). The data generated from these studies are used in verifying models for carbon dynamics in cropland soils (Falloon and Smith, 2002, 2003; Skjemstad et al., 2004). SOC storage in cropland soils is dependent on agricultural practices. Smith (2004) claimed that croplands are the largest biospheric source of carbon lost to the atmosphere in Europe each year, and estimated that croplands (for Europe as far as east as the Urals) lose 300 Tg C per year. However, there is a potential for carbon storage in European (EU15) cropland of 90–120 Tg C per year with a range of options available.

Most soils in the Midwestern USA have lost 30 to 50% of their original SOC, or 25 to 40 Mg C ha^{-1}, after conversion from natural to agricultural ecosystems. Sixty to 70% of the lost SOC can be re-sequestered through adoption of recommended soil and crop management practices. Adoption of recommended management practices (RMPs) can lead to sequestration of SOC at an annual rate of 45 to 98 Tg in croplands in USA (Lal, 2002; Lal et al., 2003). Pan et al. (2003) estimated that the paddy soils of China have an easily attainable SOC sequestration potential of 0.7 Pg under present conditions and may ultimately sequester 3.0 Pg. The global potential of SOC sequestration and restoration of degraded/desertified soils is estimated at 0.6 to 1.2 Pg C yr^{-1} for about 50 years with a cumulative sink capacity of 30 to 60 Pg (Lal, 2003). Generally, an increase in soil SOC storage in cropland soils benefits soil productivity, thus it is recognized as a "win–win strategy" (Lal, 2002; Smith, 2004).

In China, because of the concern of soil fertility degradation by replacement of organic fertilizers by inorganic fertilizers, a number of long-term experiments were set up in agricultural regions at the end of 1980's to monitor changes in soil fertility with application of either inorganic fertilizers or organic manure alone or a mixed application of both (Qin et al., 1998; Wu et al., 2001; Zhang et al., 2002; Dang et al., 2003). Some of these experiments were set up in the Huang-Huai-Hai Plain, which is located in low reaches of the Yellow, Huai, and Hai rivers within an area of 350×10^3 km^2 (Qin et al., 1998). This is one of the most important agricultural regions in China (Yang and Janssen, 1997). In this paper, we summarize the changes of crop yields and SOC during a 14 year (1990–2003) long-term experiment carried out in Fengqiu, Henan Province which is located in the Huang-Huai-Hai Plain. The equilibrium of SOC is estimated in the various treatments and the practices which compromise food security and carbon sequestration are discussed.

2. Materials and methods

2.1. Description of the long-term experiment

The long-term experiment was set up in Fengqiu (35°04′N, 113°10′E), Henan province, located in the Huang-Huai-Hai Plain of China in 1990. The annual precipitation in the area ranged from 355 mm to 800 mm over the time of the study, of which 60–90% took place from May to October. Mean temperature was 14.5 °C. The crop rotation in the region, which was practiced in the long-term experiment, was winter wheat (*Triticum aestivum* L.) followed by summer maize (*Zea mays* L.) every year. Before treatments were established in 1990, the field was homogenized by planting crops without application of any fertilizers from 1987 to 1989. The long-term experiment includes seven treatments: no fertilization (CK); N, P, and K were applied (NPK); N and P were applied without K (NP); N and K were applied without P (NK); P and K were applied without N (PK); organic compost was applied without inorganic fertilizers (ON); half N from inorganic fertilizer and another half from compost (1/2ON). The application rates of N, P and K, if it was applied, were the same in all the treatments at 150 kg N ha^{-1}, 32.7 kg P ha^{-1}, and 124 kg K ha^{-1} for winter wheat, and 150 kg N ha^{-1}, 26.2 kg P ha^{-1}, and 124 kg K ha^{-1} for maize. In the ON treatment compost was applied to provide the required amount of N to match the same rate of NPK. Compost was made of wheat straw mixed with soybean cake and cotton seed cake to enrich N content. N, P, and K contents were determined before application and then the amount needed for application was calculated based on the N content in the compost. Inorganic fertilizers complement the shortages of P and K from the applied compost. All compost, P as superphosphate, and K as $K_2(SO_4)$ were applied as basal fertilization. In the treatments without compost application, two thirds of N was applied as urea as basal fertilization and one third as topdressing for both wheat and maize. The experiment has four replicates with a random block design. Each 45.5 m^2 plot was isolated by cement banks, which were 60 cm depth and 10 cm above the soil surface.

The soil was calcareous (Fluvo-Aquic soil) with pH of 8.65. It is a typical soil in the region with a profile of sandy loam (about 9% clay, 21.8% silt) in the plough