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# Long-term effects of different organic and inorganic fertilizer treatments on soil organic carbon sequestration and crop yields on the North China Plain

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ABSTRACT

The aim of the study is to analyze the effects of different fertilization of organic and inorganic fertilizers on soil organic carbon (SOC) sequestration and crop yields after a 22 years long-term field experiment. The crop yields and SOC were investigated from 1981 to 2003 in Dry-Land Farming Research Institute of Hebei Academy of Agricultural and Forestry Sciences, Hebei Province, China. The dominant cropping systems are winter wheat–summer corn rotation. There were totally sixteen treatments applied to both wheat and corn seasons: inorganic fertilizers as main plots and corn stalks as subplots and the main plots and subplots all have four levels. The results revealed: after 22 years, mixed application of inorganic fertilizers and crop residuals, the SOC and crop yields substantially increased. Higher fertilizer application rates resulted in greater crop yields improvement. In 2002–2003, wheat and corn for the highest fertilizer inputs had the highest yield level, 6400 kg $ha^{-1}$ and 8600 kg $ha^{-1}$, respectively. However, the SOC decreased as the excessive inorganic fertilizer input and increased with the rising application of corn stalks. The treatment of the second-highest inorganic fertilizer and the highest corn stalks had the highest SOC concentration (8.64 g C $kg^{-1}$). Pearson correlation analysis shows that corn and winter wheat yields and the mineralization amount of SOC have significant correlation with SOC at $p < 0.05$ level.



## 1. Introduction

The food security in China is very important because the large population and the better living standard need more food. The North China Plain (NCP) is one of the most important agricultural regions, where about 35 million ha of croplands are located and at least 14 million ha of land area is dominated by the cropping system of winter wheat–summer corn rotation (Liu et al., 2003). Winter wheat and summer corn cultivated on the NCP account for 48% and 59% of the country's total, respectively (Liu and Mu, 1993). Therefore, the soil quality and crop yields of NCP have great implications for China's food supply.

Manure application to soil had been a common practice adopted at NCP for many centuries. It can enrich soil and hence ensure crop yields. But recently organic manure application has almost disappeared because the application of organic manure in arable cropping system is both labor-demanding and cost-inefficient. Another factor may be due to the increased use of inorganic fertilizers and biocides and consequential considerable increase of soil productivity in a relatively short time (Ellis and Wang, 1997). However, the application of inorganic fertilizer could reduce soil fertility and crop productivity in the long run (Yaduvanshi, 2001; Khan et al., 1986). Soil degradation is threatening food security (Oldeman et al., 1990), and will increase the emission of $CO_2$. The rising level of carbon dioxide in the atmosphere is highly correlated with global warming. Therefore soil quality and its importance for sustainable agricultural development has received growing attention in recent years (Dumanski and Pieri, 2000; Zhang et al., 2003).

Many researchers are concerned with the ways of addressing soil degradation to achieve a sustainable agriculture and $CO_2$ abatement. Numerous researches had shown that manure applications can increase crop yields and soil organic matter (SOM), and improve the soil quality as well (Blair et al., 2006).

As the rapid development of agricultural machinery, the practice of returning crop stalks to farm field has become one of the main sources of organic fertility required by cropland. Returning crop stalks like green manure can reduce soil erosion

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and ameliorate soil physical properties (MacRae and Mehuys, 1985; Smith et al., 1987), enhance SOM and fertility (Doran and Smith, 1987; Power, 1990), increase capacity of nutrient retention (Drinkwater et al., 1998; Dinnes et al., 2002), and decrease global warming potential (Robertson et al., 2000). This study was carried out based on the results of a long-term winter wheat–summer corn field experiment conducted from 1981 to 2003. The objectives of the study were (1) to assess effects of inorganic and corn stalks on yields and yield trends of both winter wheat and corn, (2) to monitor the changes in soil organic carbon (SOC) content under continuous winter wheat–corn cropping with different soil fertility management practices, and (3) to identify reasons for yields and SOC trends.

## 2. Methods and materials

### 2.1. Description of the long-term experiment

The experiment was carried out at the Dry-Land Farming Research Institute of Hebei Academy of Agricultural and Forestry Sciences, Hengshui (37°42′ N, 115°42′ E, altitude of 31 m above sea level), Hebei Province, China from 1981 to 2003. The soil is alluvial soil (Soil taxonomy of USDA, 1999) with particle composition of sand 27.2%, silt 55.1%, and clay 17.7%. Selected soil properties were measured at the start of the experiment (in Table 1). The annual average precipitation was 411 mm with nearly all occurring between June and September (Fig. 1 in Supplementary data) and the annual average temperature was 12.5 °C.

The experiment utilized the split-plot design with inorganic fertilizers as main plots and corn stalks as subplots. The main plots and subplots all had four levels of treatments, which were expressed as A and B, respectively. So there were totally sixteen treatments with three replicates each treatment, which were set as (A1, A2, A3, A4)*(B1, B2, B3, B4). The four levels of main plots were: A1 (no fertilizer), A2 (N 90 kg ha$^{-1}$ and $P_2O_5$ 60 kg ha$^{-1}$), A3 (N 180 kg ha$^{-1}$ and $P_2O_5$ 120 kg ha$^{-1}$), A4 (N 360 kg ha$^{-1}$ and $P_2O_5$ 240 kg ha$^{-1}$). The four levels of subplots were B1 (no fertilizer), B2 (corn stalks 2250 kg ha $^{-1}$), B3 (corn stalks 4500 kg ha $^{-1}$), B4 (corn stalks 9000 kg ha $^{-1}$). The larger the number attached to treatment appellations indicated a higher level of fertilizer input, either of inorganic or organic fertilizers. Phosphorous was applied as basal fertilizers once and for all prior to sowing of winter wheat in October. Nitrogen was divided into two halves, one for winter wheat and the other for summer corn. Half of the N that was allocated to winter wheat was applied as basal fertilizers just prior to its sowing, while the remaining half was top-dressed. All N-fertilizers that were allocated for corn were top-dressed. As for application method, basal fertilizers were applied before crop sowing and were mixed with soil by plowing, and top-dressing was applied to the soil surface before the tillage stage. Prior to the next round of planting, corn stalks were spread on the soil surface and incorporated into the soil through plowing with adequate irrigation that was applied during crop growth season.

Winter wheat was grown at the end of October and harvested in early June, followed immediately by the sowing of corn in mid-June, which was harvested in mid-October. Winter wheat and summer corn required irrigation according to their specific water-demanding stages. To control growth-reducing factors, hand weeding and other plant protection measures were applied as needed.

### 2.2. Soil sampling and chemical analyses

Soil samples were collected from the top soil layer (0–20 cm) of each plot once a year after the corn crop harvest, and then were air dried and subsequently ground to pass a 0.25 mm sieve. Soil organic matter was determined by a standard potassium dichromate digest method, and total N was measured with the Kjeldahl method. To determine the available P, soil samples were first extracted with $HClO_4$-$H_2SO_4$ solution and 0.5 mol L$^{-1}$ $NaHCO_3$ (pH 8.5), respectively. Subsequently, the Olsen P method was used. Available K was extracted with an ammonium acetate solution ($NH_4OAc$, 1 mol L$^{-1}$) and then determined with a flame photometer.

### 2.3. Incubation soil: C mineralization

The samples for incubation were taken in October each year after corn harvest. Samples (10 g) of whole soil were incubated in triplicate in 500 mL glass jars. During the incubation, soil samples were wetted to field capacity. Small glass bottles were fitted within the jars containing 10 mL of 0.25 M NaOH to trap the $CO_2$ evolved. Jars were sealed and stored in a dark room at 27 °C. C evolution was determined by pipetting 5 mL of the C-containing NaOH, and autotitrating with 0.15 M HCl after precipitation of carbonates with 8 mL of 3 M $BaCl_2$ (De Neve and Hofman, 2000).

### 2.4. Statistical analysis

All ANOVA, regression, and multivariate analyses were conducted in SPSS 13.0. Treatments were analyzed by one-way ANOVA and significant differences between means were judged by Turkey's post-hoc tests. To determine the key factor (*s*) affecting yields and the quantitative relationships between them, stepwise multiple regression analysis was applied using the criteria of probability of $p < 0.05$ to accept.

## 3. Results and discussion

### 3.1. Wheat and corn yields and soil organic carbon content

In order to assess the effects of inorganic and corn stalks organic nutrient sources on yields and yield trends of both winter wheat and corn, we selected the treatments of A1B1, A1B4, A2B1, A2B4, A3B1, A3B4, A4B1, A4B4 to analyze.

Yields in all treatments displayed similar changes, which increased overtime for A2B1, A2B4, A3B1, A3B4, A4B1, A4B4 treatments, remained fairly steady for A1B1, A1B4 treatments, and decreased in some years (Fig. 1). Yields fluctuations were largest for A4B4 and smallest for A1B1. In 2002–2003, some treatments of wheat yield increased again and A4B4 treatment had the highest yield, that is, about 6400 kg ha$^{-1}$. For corn yield, A4B4 treatment also had the highest yield, about 8600 kg ha$^{-1}$. In the long run, the decrease in yields of both wheat and corn was the strongest with the A1B1 and A1B4. In both wheat and corn, yields of A2B1, A2B4, A3B1, A3B4, A4B1, A4B4 were higher than those of A1B1, A1B4. The treatments of A2B1, A2B4, A3B1, A3B4, A4B1, A4B4 substantially increased the yields of wheat and corn, especially from 1999 to 2000. So the response of wheat and corn to inorganic and organic fertilizers was distinct in the long term. By comparing the yield

**Table 1**
Characteristics of the 0–20 cm layers of the soil at the beginning of the experiment plot, Hengshui, China.

| Soil layer (cm) | Organic matter (g kg$^{-1}$) | Available N (g kg$^{-1}$) | Available P (mg kg$^{-1}$) | Bulk density (g cm$^{-3}$) | Field capacity (%) | Wilting coefficient (%) | pH |
|---|---|---|---|---|---|---|---|
| 0–20 | 11.51 | 0.05 | 12 | 1.14 | 27.65 | 8.20 | 8.32 |