# Effect of long term fertilization on soil fertility and crop yield in a Udic Mollisol

Xiao zeng Han[A,C], Chun Song[A], Feng xian Wang[A,B], Feng ju Wang[A,B], Wen xiu Zou [A]

[A]Northeast Institute of Geography and Agricultural Ecology, Chinese Academy of Sciences, Harbin, China 150081.
[B]Northeast Agricultural University, Harbin,China 150030.
[C]Corresponding author, Email xzhan@neigaehrb.ac.cn

**Abstract**
A six-year field trial was conducted to study the effects of fertilization on fertility characteristics and crop yield in a Udic Mollisol. Maize and soybean grown in a rotation, and which had received no fertilizer (CK), chemical N, P and K fertilizers (NPK), chemical N, P and K fertilizers plus a low quantity of pig manure (NPM+LOM), and chemical N, P and K fertilizers plus a high quantity of pig manure (NPM+HOM).Results indicated that soil fertility characteristics after six years cultivation, including the content of soil organic matter, the concentrations of soil total N, total P, available N, available P and available K, the percentage of soil water stable aggregates of more than 0.25mm, and the yields of maize and soybean during rotation were in the order of NPK+HOM> NPK+LOM> NPK> CK. The study concluded that annual organic manure and chemical fertilizer combined application could improve Mollisol fertility characteristics and increase crop yields.

**Key Words**
Northeast China, maize-soybean rotation, organic manure, soil fertility characteristic.

**Introduction**
The black soils, classified as Mollisols, in China are primarily distributed in Heilongjiang and Jilin provinces, Northeast of China, and are one of the three largest Mollisol areas in the world. The original black soils are commonly thought to be fertile and productive, with the soil organic matter content between 5%–8%. Parts of these black soils have degraded over time owing to intensive farming practices (Han *et al*. 2006; Zhu *et al*. 2007). In order to study the fertility of the agricultural black soil, several long-term experimental designs involving agronomic practices have been established in this region, and extensive studies demonstrated that crop yields and some soil physiochemistry or biochemisty characteristics changed with different soil managements (e.g. Xing *et al*. 2005; Liu *et al*. 2005; Wang *et al*. 2006; Song *et al*. 2007). The purpose of this study is to better describe changes of comprehensive fertility characteristics of Mollisols of Northeast China under different fertilization managements according to an accurate agricultural plot experiment.

**Materials and methods**
*Field experimental site and soil*
The study was conducted in Hailun Agro-Ecological Experimental Station (N 47°26', E 126°38'), Chinese Academy of Sciences. This research site is in the north temperate zone and continental monsoon area with a mean annual temperature of about 1.5℃ and a frost-free period of 120–130 days. The annual precipitation is about 500–600 mm with 65% distributed in June–August. The soil in the area is a typical black soil (Mollisol) with the texture of silty clay. The original vegetation is meadow grass, but when it is converted to farmland, the dominating crops are soybean and maize. Before the experiment was established, the properties of the soil to a depth 0–20 cm were as follows: organic matter, 46.4g/kg; total N, 2.24 g/kg; total P, 0.727 g/kg ; total K, 22.5g/kg; alkali-hydrolysable N 229.7mg/kg; available P, 22.4 mg/kg; available K, 204.5 mg/kg; and pH 6.3.

*Fertilization treatments and crop rotation*
A six years field experiment (2003 to 2008) was involved in this study. The experiment consisted of four fertilization treatments, being no fertilizer (control; CK), continuous application of chemical N, P and K fertilizers in the forms of urea, $(NH_4)_2HPO_4$ and $K_2SO_4$ (NPK), chemical N, P and K fertilizers plus low quantity of pig manure (NPM+LOM), and chemical N, P and K fertilizers plus high quantity of pig manure (NPM+HOM). The experiment was a randomised block design with four replicates. The amounts of fertilizer applied in treatment NPK, NPK+LOM and NPK+HOM are summarised in Table 1. The average organic carbon content of the pig manure was 253 g/kg, total N, P and K concentrations were 37.3, 14.7 and 8.3 g/kg, respectively, and available N and available P concentrations were 1212 and 848 mg/kg, respectively.

Maize and soybean were grown in a rotation, with one crop per year. Maize (Zea mays L. cv. Haiyu 6) was sown in 2003, 2005 and 2007; soybean (Glycine max (Merrill.) L. cv. Heinong 35) was grown in 2004, 2006 and 2008.

**Table 1. Amounts of fertilizer applied in treatments with N, P and K fertilization (NPK), NPK fertilizers plus low quantity of organic manure (NPK+LOM), and NPK fertilizers plus high quantity of organic manure (NPK+HOM)**

| *Treatments* | *N (kg/ha/yr)* | | *$P_2O_5$ (kg/ha/yr)* | | *$K_2O$ (kg/ha/yr)* | | Pig manure (kg/ha/yr) | |
|---|---|---|---|---|---|---|---|---|
| | Maize | Soybean | Maize | Soybean | Maize | Soybean | Maize | Soybean |
| NPK | 60 | 15 | 24 | 24 | 60 | 60 | 0 | 0 |
| NPK+LOM | 60 | 15 | 24 | 24 | 60 | 60 | 10000 | 10000 |
| NPK+HOM | 60 | 15 | 24 | 24 | 60 | 60 | 20000 | 20000 |

*Soil sampling and analysis*

At least six soil cores were taken randomly from each plot (0–20 cm topsoil) after the crop was harvested. The soil cores were then bulked, air-dried and sieved through 2 mm before analysis. Soil organic C and total N were determined by an elemental analyzer (Elementa, Germany). Soil available N was analysed through quantifying alkali-hydrolysable N in the Conway diffusion unit with Devarda's alloy in the outer chamber and boric acid-indicator solution in the inner chamber (Shen *et al*. 2004). Total P in the soil was determined using the molybdenum-blue method after digestion with concentrated $HClO_4$–$H_2SO_4$ while available P was determined with the Olsen method (Kuo 1996). Total K was determined in 0.02 M HCl solution after the soil was fused with NaOH at 720°C for 15 min, while available K was extracted in 1 M $CH_3COONH_4$ (pH 7; soil:solution=1:10) for 30 min. Soil pH was measured in water extracts at a $H_2O$:soil ratio of 2.5:1. Soil water stable aggregate content was determined according the method of Six (1998) and Puget (2000).

*Statistical analysis*

Experimental data were analysed using one-way ANOVA appropriate to a factorial randomized block design. Wherever appropriate, the treatment means were compared at the 5% level of significance using the shortest significant ranges (SSR) test using the computational programs of SAS 9.0(SAS Institute. 2002) .

## Results and discussion

*Soil organic matter and nitrogen*

Soil organic matter (SOM) is an important indicator for soil quality and sustainable agriculture, and agricultural practices may strongly affect SOM content and chemistry. After 6 years maize-soybean rotation, soil organic matter content of treatments CK and NPK changed insignificantly compare with 2002 soil sample, whereas it increased 1.6 g/kg and 5.5 g/kg in treatments NPK+LOM and NPK+HOM, respectively (Table 2). Previous research indicated that the total carbon (C) content in black soil of northeast China was stable without any significant changes under 13 years maize and soybean cultivation (Wang *et al.* 2006). But chemical fertilizer combined with the recycled organic manure application increased soil organic carbon content (Han *et al*. 2006). These results are consistent with this study.

As the similar trend of soil organic matter, total N content of treatments CK and NPK changed insignificantly after 6 years cultivation, whereas increased by 9.8% and 18.8% for treatments NPK+LOM and NPK+HOM, respectively (Table 2). Therefore soil C/N ratio kept stable after 6 years rotation, which favors crops assimilating soil nitrogen. After 6 years maize-soybean rotation, soil available N content of treatment CK decreased by 13% compared with 2002 soil sample, whereas treatment NPK retained soil available N content (Table 2). With further added organic manure, soil available N content of treatments NPK+LOM and NPK+HOM increased by 17% and 30%, respectively.

**Table 2. Soil organic mater (SOM), total N, available N contents and C/N ratio measured in 2002 and in 2008 in treatments without fertilizer application since 2003 (CK), with N, P and K fertilization (NPK), with NPK fertilizers plus low quantity of organic manure (NPK+LOM), and NPK fertilizers plus high quantity of organic manure (NPK+HOM)**

| Treatments | SOM (g/kg) | Total N (g/kg) | C/N | Available N (mg/kg) |
|---|---|---|---|---|
| Soil sample (2002) | 46.4±0.44c | 2.24±0.44c | 12.02±0.34a | 229.7±3.50c |
| CK (2008) | 46.5±0.35c | 2.25±0.10c | 12.01±0.61a | 200.5±14.62d |
| NPK (2008) | 46.6±0.83c | 2.32±0.07c | 11.66±0.40ab | 230.8±16.46c |
| NPK+LOM (2008) | 48.0±0.78b | 2.46±0.05b | 11.32±0.35b | 269.5±12.48b |
| NPK+HOM (2008) | 51.9±1.36a | 2.66±0.07a | 11.34±0.26b | 299.0±7.62a |

*Soil phosphorus, potassium and pH*
Compared with 2002 soil sample, total phosphorus content of 2008 soil sample from treatments CK and NPK changed insignificantly, whereas it increased significantly in treatments NPK+LOM and NPK+HOM (Table 3). Soil available phosphorus data showed that 6 years maize-soybean rotation without fertilizer decreased soil available phosphorus content by 16%, whereas applied NPK fertilizer retained soil available phosphorus, with further added low and high quantity of pig manure increased soil available phosphorus content by 95% and 216%, respectively. This change trend was consistent with previous report (Song *et al*. 2007). Soil total potassium and available potassium content of different treatments changed insignificantly after 6 years. Soil pH data showed that 6 years rotation without fertilizer didn't change soil pH significantly, whereas chemical fertilizer application decreased soil pH, change it from 6.3 of 2002 soil sample into 5.8 of 2008 soil sample. This indicated long term chemical fertilizer application caused black soil acidification. By contrary, added organic manure alleviated soil acidification (Table 3).

**Table 3. Soil total P, available P, total K, available K and pH measured in 2002 and in 2008 in treatments without fertilizer application since 2003 (CK), with N, P and K fertilization (NPK), with NPK fertilizers plus low quantity of organic manure (NPK+LOM), and NPK fertilizers plus high quantity of organic manure (NPK+HOM)**

| Treatments | Total P(g/kg) | Available P(mg/kg) | Total K(g/kg) | Available K(mg/kg) | pH |
|---|---|---|---|---|---|
| Soil sample (2002) | 0.73±0.05c | 22.35±0.64c | 22.53±0.95a | 204.5±1041ab | 6.3±0.17ab |
| CK (2008) | 0.68±0.08c | 18.70±0.76d | 23.20±1.85a | 187.3±9.03b | 6.2±0.10ab |
| NPK (2008) | 0.76±0.08c | 23.00±1.13c | 22.38±0.70a | 202.50±11.03ab | 5.8±0.22b |
| NPK+LOM (2008) | 1.04±0.10b | 43.63±1.30b | 22.68±0.51a | 205.25±15.56a | 6.2±0.10a |
| NPK+HOM (2008) | 1.34±0.12a | 70.60±2.77a | 22.25±1.43a | 212.75±18.52a | 6.2±0.17a |

*Soil water stable aggregates*
Aggregates have profound effects on SOM dynamics and nutrient cycling physically protecting soil organic matter, influencing microbial community structure, limiting oxygen diffusion, regulating water flow, determining nutrient adsorption and desorption. Research demonstrated that agricultural management has considerable influences on macroaggregates stability (Elliott *et al.* 1986), and previous study indicated macroaggregates store more nutrients than microaggregates (Six *et al.* 1999). Soil water stable aggregates of more than 0.25mm ($WSA_{>0.25mm}$) percentage of control treatment (CK) decreased 15% after 6 years cultivation, whereas treatment NPK had no significant change (Table 4). After added organic manure, $WSA_{>0.25}$mm percentage increased 7.8% and 25.4% in treatments NPK+LOM and NPK+HOM, respectively.

**Table 4. Soil water stable aggregates composition measured in 2002 and in 2008 in treatments without fertilizer application since 2003 (CK), with N, P and K fertilization (NPK), with NPK fertilizers plus low quantity of organic manure (NPK+LOM), and NPK fertilizers plus high quantity of organic manure (NPK+HOM)**

| Treatments | Aggregate size (mm) (%) | | | | |
|---|---|---|---|---|---|
| | ≥2 | 0.25-2 | 0.053-0.25 | <0.053 | $WSA_{>0.25mm}$ |
| Soil sample (2002) | 17.8±1.18c | 46.4±0.68c | 21.1±1.27b | 10.5±1.14b | 64.2±1.59c |
| CK (2008) | 14.0±1.26d | 40.5±0.98d | 27.6±0.93a | 11.8±0.50a | 54.5±1.88d |
| NPK (2008) | 17.8±1.22c | 46.1±0.75c | 21.3±0.46b | 10.2±0.38bc | 63.9±0.85c |
| NPK+LOM (2008) | 20.2±1.04b | 49.0±0.72b | 16.5±1.11c | 9.5±0.28c | 69.2±0.52b |
| NPK+HOM (2008) | 25.4±0.91a | 55.1±2.33a | 9.1±1.10d | 4.7±0.45d | 80.5±3.14a |

Data are means ± standard error (n=4)

*Crop yields*
Maize yields followed an order of NPK+HOM> NPK+LOM> NPK> CK between treatments during rotation (Figure 1). However, the yields among treatments NPK, NPK+LOM and NPK+HOM had no significant difference. There was an increased trend of maize yields with time (Figure 1): yields in 2005 increased 41.3%, 8.0%, 9.9% and 7.3% in treatments CK, NPK, NPK+LOM and NPK+HOM, respectively, compared with yields in 2003; and yields in 2007 further increased 32.8%, 19.2%, 18.5% and 18.2%, respectively. According to the local meteorologic materials (data not shown), rainfall and temperature changed little during the experiment. Therefore, maize yields increased with time mainly due to soybean roots fixing considerable N from the atmosphere and soybean plant residue returned to soil during rotation. Soybean yields followed the same order (NPK+HOM> NPK+LOM> NPK> CK) as maize between treatments during rotation (Figure 1). These results indicated that added organic manure with chemical fertilizer improved the maize and soybean yields during this rotation in Mollisols of northeast China.

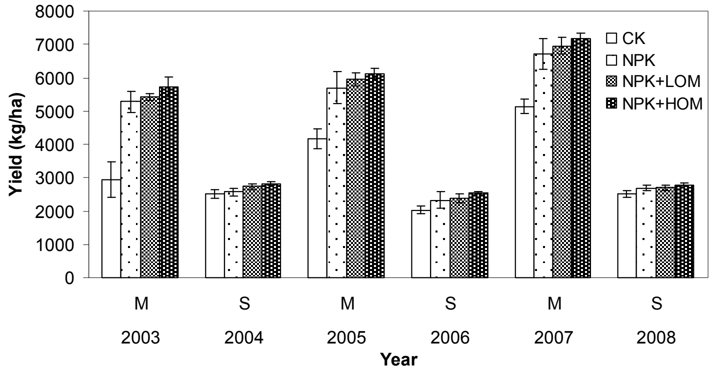


**Figure 1. Maize and soybean yields (kg/ha) in treatments without fertilizer application since 2003 (CK), with N, P and K fertilization (NPK), with NPK fertilizers plus low quantity of organic manure (NPK+LOM), and NPK fertilizers plus high quantity of organic manure (NPK+HOM)**

## Conclusion

In this work, we performed a comparative study of fertilization impacts on black soil (Mollisol) fertility and crop yield according to a 6 years maize-soybean rotation field experiment. Long term organic manure combined with chemical fertilizer application improved soil organic matter content, and increased soil total N, total P, available N, available P and available K content. Added organic manure kept soil pH relatively stable, and increased the percentage of soil macroaggregates larger than 0.25mm compared with single chemical fertilizer application. These data demonstrated that long term combined application organic manure and chemical fertilizer could improve Mollisol fertility characteristics as well as increase crop yields.

## References

Elliott ET (1986) Aggregate structure and carbon, nitrogen, and phosphorus in native and cultivated soils. *Soil Sci. Soc. Am. J.* **50**, 627–633.

Han XZ,Wang SY,Veneman PLM,Xing BS (2006) Change of organic carbon content and its fractions in black soil under long-term application of chemiacal fertilizers and recycled organic manure.*Communications in Soil Science and Plant Analysis* **37**, 1127-1137.

Kuo S (1996) Phosphorus. In 'Methods of soil analysis: chemical methodsPart 3'. (Ed DL Sparks) pp. 869–919. (Soil Science Society of America, Madison, WI).

Liu XB, Liu JD, Xing BS, Herbert SJ, Meng K, Han XZ, Zhang XY (2005) Effects of Long-Term Continuous Cropping, Tillage, and Fertilization on Soil Organic Carbon and Nitrogen of Black Soils in China. *Communications in Soil Science and Plant Analysis* **36**, 1229-1239.

Puget P,Chenu C,Balesdent J (2000) Dynamics of soil organic matter associated with particle-size fractions of water-stable aggregates.*European Journal of Soil Science* **51**,595–605.

SAS Institute (2002) SAS/STAT 9 user's guide. Vol. 1, 2, and 3. SAS Inst., Cary, NC.

Shen J, Li R, Zhang F, Tang C, Rengel Z (2004) Crop yields, soil fertility and phosphorus fractions in response to long-term fertilization under the rice monoculture system on a calcareous soil. *Field Crops Res* **86**, 225-238.

Six J, Elliott ET, Paustian K (1999) Aggregate and soil organic matter dynamics under conventional and no-tillage systems. *Soil Sci. Soc. Am. J.* **63**, 1350–1358.

Six J, Elliott ET,Paustian K, Doran JW (1998) Aggregation and soil organic matter accumulation in cultivated and native grassland soils. *Soil Science Society of America Journal* **62**, 1367-1377.

Song C, Han XZ, Tang C (2007) Changes in phosphorus fractions, sorption and release in Udic Mollisols under different ecosystems. *Biol. Fertil. Soils* **44**, 37-47.

Wang GH,Han XZ,Nakayama N (2006) Soil organic matter dynamics in continuously maize and soybean cultivated lands in Heilongjiang Province ,Northeast China: Estimation by natural $^{13}$Cabundance.*Soil Science and Plant Nutrition* **52**, 139-144.

Xing BS, Liu XB, Liu JD, Han XZ (2005) Physical and chemical characteristics of a typical Mollisol in China. *Communications in Soil Science and Plant Analysis* **35**, 1829-1838.

Zhu P, Ren J, Wang LC, Zhang XP, Yang XM, MacTavish D (2007) Long-term fertilization impacts on corn yields and soil organic matter on a clay-loam soil in Northeast China. *J. Plant Nutr. Soil Sci.* **170**, 219–223.