# Long-term Changes in Soil Fertility and Fertilizer Efficiency under Different Fertilizer Practices

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**This 12-year study was conducted under the direction of the Soil and Fertilizer Institute, Chinese Academy of Agricultural Sciences (CAAS). Its objective was to monitor long-term changes in soil fertility, fertilizer use efficiency, crop yield, and grain quality under various fertilizer management schemes. The study was conducted in Harbin on black soil, the most important soil type in Heilongjiang province, covering approximately five million ha.**

## Experimental Procedures

This long-term trial was initiated in 1980 at the Soil and Fertilizer Institute of the Heilongjiang Academy of Agricultural Sciences. Mean annual temperature for the area is 3.5º C, mean annual precipitation is 535 mm, and the frost-free period is about 135 days. From samples collected in 1979, soil pH was 7.2 and organic matter was 2.7 percent. Total nitrogen (N), phosphorus (P), and potassium (K) contents were 0.15 percent, 0.17 percent, and 2.5 percent, respectively. Available N, P and K contents were 151, 51 and 200 mg/kg, respectively.

Data in this paper span four cycles of a three-year wheat-soybean-corn crop rotation. Inorganic fertilizer was applied at 150-75-75 kg N-$P_2O_5$-$K_2O$/ha for wheat and corn and 75-150-75 kg/ha for soybean. Farmyard manure (FYM) was applied at a rate of 18.6 t/ha with every corn crop. All fertilizers were applied in the fall after harvest. Plots were 168 $m^2$ in size and were not replicated.

## Long-term Changes in Crop Yield

**Zero Fertilization** – In the plot receiving no fertilizer, the cumulative yields of wheat, soybean and corn consistently declined over 12 years (**Table 1**). The average change in the cumulative yield ($\Delta Y$) between the three-year cycles was -8.1 percent, or -880 kg/ha. Wheat yields continually declined through the second, third, and fourth crop cycle, dropping 1,260 kg/ha from 1980 to 1989. Soybean and corn yields fluctuated, but both crops showed a negative trend. The second cycle soybean yield showed a slight increase over the first cycle, but this was followed by lower yield levels in the third and fourth cycles. Corn production was highly variable and followed an alternating yield pattern throughout the study.

| Table 1. Crop yields as affected by no fertilizer application. | | | | |
|---|---|---|---|---|
| | Yield, kg/ha | | | |
| Crop cycles | Wheat | Soybean | Corn | Cumulative yield, kg/ha |
| 1980 | 2,535 | | | |
| 1981 (I) | | 2,070 | | |
| 1982 | | | 6,990 | 11,595 |
| 1983 | 2,385 | | | |
| 1984 (II) | | 2,265 | | |
| 1985 | | | 5,850 | 10,500 |
| 1986 | 1,830 | | | |
| 1987 (III) | | 1,365 | | |
| 1988 | | | 7,170 | 10,365 |
| 1989 | 1,275 | | | |
| 1990 (IV) | | 1,935 | | |
| 1991 | | | 5,745 | 8,955 |
| Overall production, kg/ha | | | | 41,415 |
| Average yield change (ΔY) | | | | -8.1% |

| Table 2. Crop yields as affected by FYM application. | | | | |
|---|---|---|---|---|
| | Yield, kg/ha | | | |
| Crop cycle | Wheat | Soybean | Corn | Cumulative yield, kg/ha |
| I | 2,745 | 2,010 | 7,350 | 12,105 |
| II | 3,495 | 2,055 | 6,885 | 12,435 |
| III | 2,445 | 1,290 | 6,900 | 10,635 |
| IV | 1,635 | 1,890 | 8,250 | 11,775 |
| Overall production, kg/ha | | | | 46,950 |
| Average yield change (ΔY) | | | | -0.4% |

**Applying Manure** – The plot receiving only FYM also showed a tendency for lower yields over time (**Table 2**). The cumulative yield for wheat, soybean and corn was highest in the second cycle. However, this was followed by lower cumulative yield levels in the third and fourth cycles. The ΔY between the three-year cycles was -0.4 percent, or -110 kg/ha. Wheat production showed an initial increase in the second cycle, followed by two successive cycles of declining yield. Soybean yields followed an alternating yield pattern throughout the study. Corn production was lowest in the second and third crop cycles, but was highest in the fourth crop cycle.

**Applying Commercial Fertilizer** – Evidence for sustained yield improvement was found with all four treatments supplying N (**Table 3**). The NPK, NP, and NK treatments provided the highest overall production totals and positive ΔY values of 1.4, 3.6, and 3.4 percent, respectively. Reliance on N alone also sustained a positive ΔY of 3.3 percent. However, this practice produced a grain production level only slightly above the level achieved with FYM alone. Reliance on mineral P and K, alone or in combination, resulted in declining yields over time. The ΔY values for the P, K, and PK treatments were -5.5, -4.0, and -1.8 percent, respectively.

| Table 3. Crop yields as affected by mineral fertilizer application. | | | | | | |
|---|---|---|---|---|---|---|
| | Cumulative yield per crop cycle, kg/ha | | | | Total production, | (ΔY), |
| Treatment | I | II | III | IV | kg/ha | % |
| N | 11,280 | 12,285 | 11,775 | 12,390 | 47,730 | 3.3 |
| P | 12,060 | 11,295 | 11,190 | 10,155 | 44,700 | -5.5 |
| K | 11,490 | 11,340 | 10,965 | 10,140 | 43,935 | -4.0 |
| NP | 11,955 | 11,655 | 12,180 | 13,245 | 49,035 | 3.6 |
| NK | 11,910 | 12,960 | 11,250 | 12,900 | 49,020 | 3.4 |
| PK | 11,685 | 13,275 | 11,445 | 10,845 | 47,250 | -1.8 |
| NPK | 12,705 | 12,255 | 11,220 | 13,020 | 49,200 | 1.4 |

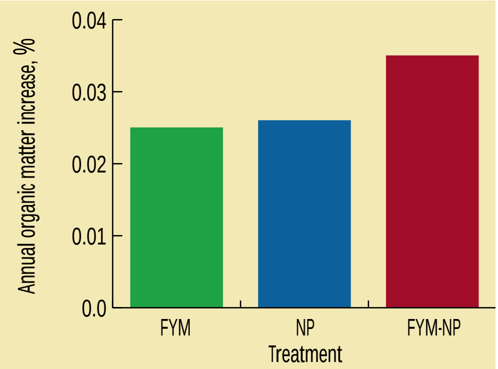


Figure 1. Increases in soil organic matter content in a black soil over 12 years, Heilongjiang province.

**Combining FYM with Inorganic Fertilizer** – Compared to inorganic fertilizer treatments (**Table 3**), FYM raised the yield levels for FYM-P, FYM-K, FYM-PK, and FYM-NP (**Table 4**). The FYM-NP combination resulted in the study's highest overall production and a positive ΔY of 4.8 percent. The beneficial effects of combining FYM with P, K and PK treatments are evident. These treatments are obviously taking advantage of N being added to the system from the FYM. However, respective ΔY values of -5.2, -1.9 and 0.6 percent still question the sustainability of these treatments. The FYM-N treatment had a high yield in the final crop cycle, resulting in a ΔY of 5.4 percent, but it failed to improve overall grain production relative to inorganic N alone. No yield benefit was apparent with the combination of FYM with NPK despite a positive ΔY of 2.1 percent.

## Long-term Changes in Soil Properties

**Soil Organic Matter** – Soils receiving no fertilizer or FYM showed no consistent changes in organic matter (0 to 20 cm depth) as they fluctuated within the range of 2.37 to 2.79 percent. Application of FYM once in every cycle increased organic matter content by 0.29 percent in 12 years (**Figure 1**). The NP fertilizer treatment was equally as effective and increased soil organic matter content by 0.30 percent in 12 years. In comparison, the FYM-NP combination increased soil organic matter content by 0.42 percent in 12 years.

**Soil Nitrogen** – Over 12 years, soils that did not receive any nutrients showed no significant changes in N content (0 to 20 cm depth). Application of N fertilizer alone resulted in an average soil N accumulation of 0.03 percent in 12 years. The balanced treatment of NPK increased soil N by 0.046 percent in 12 years. Results suggested little difference in hydrolyzed N (0 to 20 cm depth) among treatments, but did show a slight tendency for higher values in treatments containing inorganic N (data not shown).

Table 4. Effect of combining FYM and mineral fertilizers on crop yield.

| Treatment | Cumulative yield, kg/ha I | II | III | IV | Overall production, kg/ha | (ΔY), % |
|---|---|---|---|---|---|---|
| FYM-N | 11,685 | 11,940 | 10,710 | 13,305 | 47,640 | 5.4 |
| FYM-P | 12,765 | 12,105 | 11,595 | 10,860 | 47,325 | -5.2 |
| FYM-K | 11,850 | 12,060 | 10,545 | 11,070 | 45,525 | -1.9 |
| FYM-NP | 12,420 | 12,390 | 12,465 | 14,220 | 51,495 | 4.8 |
| FYM-NK | 12,195 | 12,045 | 10,890 | 13,200 | 48,330 | 3.4 |
| FYM-PK | 12,105 | 12,915 | 11,340 | 12,165 | 48,525 | 0.6 |
| FYM-NPK | 12,780 | 12,120 | 10,710 | 13,200 | 48,810 | 2.1 |

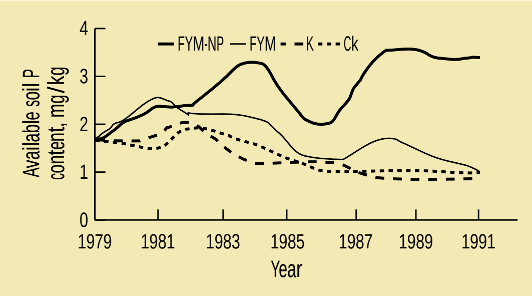

Figure 2. Changes in available P content in a black soil over 12 years, Heilongjiang province.

**Soil Phosphorus** – Soils that did not receive fertilizer or FYM showed an average decrease in available P equal to 0.17 percent annually. The 12-year duration of this study suggests a strong potential for the spread of P deficiency and lower crop production. Reliance on FYM alone resulted in a rapid decline of available P equal to 3.5 mg/kg annually. Application of NK also appeared to accelerate soil P depletion as the final P level for the treatment was lower than the unfertilized treatments (**Figure 2**). These results show how soil P mining accelerates with application of other plant nutrients when no P is applied. This is a good case for using balanced fertilization. Long-term inclusion of P fertilizer (FYM-NP) successfully raised available soil P above the level measured at the study's inception. Continued fertilizer additions would eventually lead to the establishment of an adequate soil P level and a switch to a soil P maintenance strategy.

**Soil Potassium** – After 12 years, no significant effect on total soil K (0 to 20 cm depth) was observed in any treatment. This is a result of adequate natural soil K levels. All fertilizer treatments maintained soil K between 200 to 300 mg/kg. However, observations indicate soil not receiving fertilizer was slightly below this range. It should be noted that without continuous application of K, soil K will eventually drop below the critical level and cause reduced yields. Thus, monitoring the K status is important, especially as higher crop yields are obtained.

## Conclusion

Continuous crop production over 12 years without the addition of either FYM or mineral fertilizer resulted in an average yield reduction of 8.1 percent. Reliance on FYM resulted in a lower rate of yield reduction of 0.4 percent. Such practices are detrimental to China's strategy for food security. The solution lies in the proper utilization of mineral fertilizers. Imbalanced fertilizer use resulted in lower crop production and plant nutrient losses capable of creating severe deficiencies and drastic yield reductions. In this study, N was the most yield-limiting macronutrient, followed by P. However, continued cropping without K fertilizer or FYM application could create another yield-limiting situation. A more intensive soil testing strategy is needed to monitor the soil fertility of Chinese soils. Such a strategy would ensure that all plant nutrients are built up and maintained at adequate levels. **BCI**

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