12 Managing Soil Fertility for Sustainable Agriculture in Taihang Mountain Piedmont, North China

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Abstract

Soil fertility—the ability of soil reserves to supply adequate levels of essential nutrients needed for plant growth—affects agricultural productivity and sustainability as well as environmental health. For nearly 50 years, there have been great improvements in the balance of nutrient input and output in farmland in the piedmont of Mount Taihang. Soil surveys carried out in 1978, 1989 and 1998 showed that the levels of soil organic matter, total nitrogen (N), total phosphorus (P), available P and other trace elements have increased, but that available potassium (K) levels have not. These results are similar to those obtained by estimating the nutrient balance, which indicate that the characteristics of nutrient cycling depend on the system of fertiliser application in farmland. Soil chemical fertility according to the Chinese classification Standard for Soil Nutrients is good on the whole. In the piedmont of Mount Taihang, nutrient management should focus on reducing the N input and increasing K levels in order to ensure sustainable productivity and good environmental health.

土壤肥力是土壤供应作物生长所须养分的能力。土壤肥力影响农业的生产力、持续性及区域环境健康。近 50 年来，太行山前平原农田养分平衡有了极大的改善。除了钾素外，农田中氮素、磷素等投入量超过作物产品携出量，有机物投入量超过土壤有机质分解量，且盈余量越来越大，特别是肥料氮。1978 年、1989 年、1998 年在栾城县进行的三次土壤调查结果也表明，除了土壤速效钾外，土壤有机质、土壤全氮、土壤全磷、土壤速效磷及微量元素都有明显的提高，这与农田养分平衡估算的趋势是一致的。由此说明，农田施肥制度决定了农田养分循环格局，农田养分循环格局决定了土壤肥力的演替。根据中国土壤养分分级标准，从整体来看，栾城县土壤肥力较好、且向高肥力方向发展，但化肥氮投入过多及污染物的排放对农田环境健康构成潜在的影响。为了农业生产的持续性与区域环境安全，太行山前平原农田应减少氮素的投入、增加钾的投入。

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Introduction

SOIL fertility is a measure of soil productivity. It can be broadly defined in terms of physical, chemical and biological factors: nutrient levels, water, air, heat, soil chemistry, soil physics and characteristics of the biome. More narrowly, it can be defined as the ability of soil to supply adequate levels of the nutrients that are essential for plant growth. The natural levels of these nutrients depend on factors associated with soil formation: parent materials, climate, vegetation, topography, time and other external forces such as erosion, deposition, accumulation and groundwater. Human activities also affect soil fertility in cultivated areas. We have known for 1000 years that applying animal and vegetable manure to the soil can restore its fertility (Tisdale and Nelson 1966). Conversely, unwise land use may lead to decreases in soil fertility and productivity. This paper focuses on the concept of soil fertility that is confined to nutrients — that is, the ability of the soil to supply adequate levels of essential nutrients for plant growth.

Since the 1960s, there has been a 20-fold increase in the amount of chemical fertiliser applied each year in China; the amount per area of farmland is now near that of developed countries. This has contributed to a threefold increase in grain production in 30 years. However, there are emerging problems in protecting the agricultural environment. Soil fertility acts as an indicator of both environment and soil quality.

We now know that applying fertiliser has ecological risks, especially when resources are not used carefully. Consequently, managing soil fertility for crop growth now focuses on the sustainable use of resources and protection of the environment rather on maximising yields and profits. For example, people now expect that manure and other nutrients from organic waste will be recycled rather than being allowed to seep into groundwater or other parts of the environment; people also expect that measures will be taken to prevent the degradation of soil fertility through over-consumption or a lack of balance of crop nutrients.

The management of soil fertility requires the rational application of fertiliser. This depends on the type of soil and the pattern of nutrient cycling in a particular agroecosystem. This chapter focuses on changes in the soils of the Taihang Mountain piedmont of North China over the past 50 years. It assesses nutrient input and output, and describes patterns of nutrient cycling and evolving soil fertility. It then draws some conclusions about the sustainable management of soil fertility in the region.

The study focuses on the balance between nutrient inputs and outputs. Inputs include chemical fertiliser, manure and straw, bionitrogen fixation and irrigation. Outputs include crop uptake, leaching from the soil, runoff on the soil surface, drainage, and nitrogen (N) loss through processes such as denitrification and ammonia emission. It is difficult to quantify some of these items. For example, the amount of N lost through leaching and denitrification depends on the net superfluous amount of inorganic N. Consequently, we use the constants of N loss after fertiliser application and N fixation.[1]

Changes in Applied Nutrient Levels

We selected Luancheng County as a typical study case for the Taihang Mountain piedmont, which is part of the North China Plain (NCP). The Overview provides further details of the NCP region. Over the past 50 years, nutrient inputs have increased very quickly, as shown in Figures 1–3 (Hu Chunsheng and Wang Zhiping 1999). For example, inorganic N increased from 0 kg/ha/year to 420.5 kg/ha/year; organic N increased at a slightly slower rate, from 36.0 kg/ha/year to 101.3 kg/ha/year over the past 50 years. In the past, N has been applied mainly as

[1] In other words, we assume that the nitrogen loss rate does not change as conditions change.

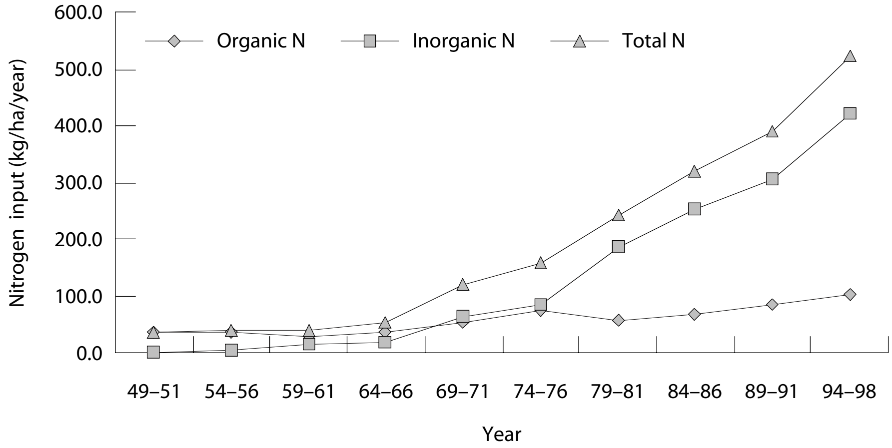

Figure 1. Nitrogen (N) input in farmland in Luancheng, 1949–98.

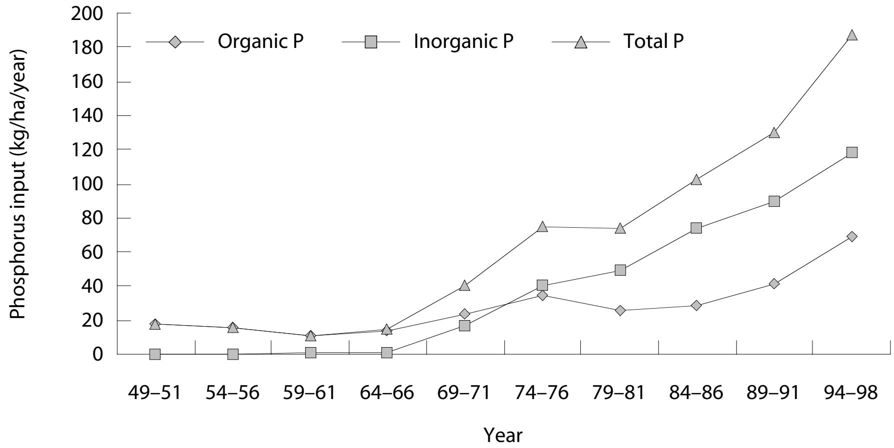

Figure 2. Phosphorus (P) input in farmland in Luancheng, 1949–98.

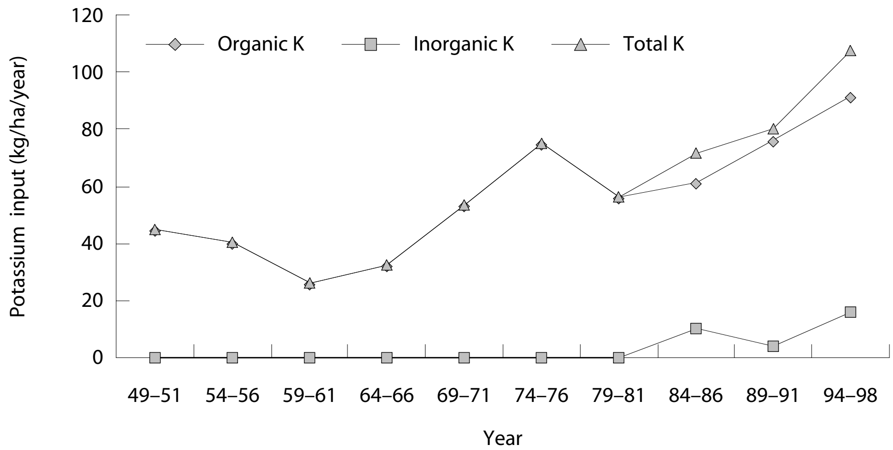

Figure 3. Potassium (K) input in farmland in Luancheng, 1949–98.

organic N, but inorganic N is now more important: applied inorganic N accounted for half of the total N applied in the 1960s, up to 60% in the 1970s, and is now 80%. Phosphorus (P) has followed a similar trend, but 5–10 years later: applied inorganic P accounted for half of the total applied P in the 1970s but up to 70% in the 1990s. Potassium (K) was applied as organic K until the late 1980s, since when the application of inorganic K has gradually increased.

The ratio of artificial nutrient input to product output[2] could be an indication of whether excess nutrients are being added to the soil. If the ratio is less than 1, the nutrient budget is negative; if the ratio is larger than 1, the nutrient budget is positive. The bigger the ratio, the greater the level in the soil of superfluous nutrients that could be lost to the environment.

Fertiliser is added to the soil to promote grain yield. For example, Table 1 shows that from 1949–51 to 1994–98 output N increased from 58.8 kg/ha/year to 519.8 kg/ha/year and input N increased from 58.9 kg/ha/year to 123.5 kg/ha/year. The ratio of N input to output increased from 0.88 to 1.74 over the same period. The N balance started to change from negative to positive in the early 1980s. From 1949–51 to 1994–98, output P increased from 15.8 kg/ha/year to 122.8 kg/ha/year and input P from 17.4 kg/ha/year to 187.0 kg/ha/year; the ratio of P input to output increased from 0.7 to 1.52. The P balance did not change from negative to positive until the 1970s. Nutrient K was abundant in the early 1950s, but there has subsequently been a deficit, with the ratio of input to output less than 1. Thus, fertiliser efficiency has gradually decreased with increasing crop yield. Increasing levels of nutrient input have been required, and inorganic nutrients have had to be applied at increasing rates as productivity increased.

The added nutrients have improved crop yield but have also accumulated in the soil. It is evident that fertiliser input is close to a maximum.

Soil Nutrient Content

Table 2 shows that soil fertility has improved with increased fertiliser input and better nutrient balance (Hu Chunsheng 1999). The data in the table represent the average of 32 soil samples from Luancheng County. Available K has obviously decreased rapidly as less K fertiliser has been added to soil during the past three decades; it will be essential to apply K to farmland in future if soil fertility is to be sustained in the Taihang Mountain piedmont.

Evaluating Soil Fertility

Crop production is based on the use of plant nutrients and on the physical characteristics of the soil. More plant nutrients have been added since 1960, but most crops continue to depend on 'mining' the soil for some or most nutrients. Soil diagnosis helps to determine when additions are needed. Both chemical and physical properties can be used as diagnostic indicators for soil fertility.

Classification of soil fertility

Table 3 shows the classification of soil fertility according to the Chinese standard classification (Shanmin Shen 1998). This is a general standard for the whole of China, discussing most crops and soil types. It is based on the effect of fertiliser application on yield at particular levels of soil nutrients. There are six grades. Grade 1 soil has excellent fertility; applying additional fertiliser to soil of this grade will not increase crop yield. Grade 6 soil has very poor fertility; applying additional fertiliser is likely to have a significant effect on crop yield. Grade 4 is the threshold level at which fertiliser must be applied to increase the yield.

[2] For example, straw and grain—that is, above-ground biomass.

Table 1. The structure and balance of nutrients in farmland, Luancheng county, 1949–98 (kg/ha/year).

Year	Nutrients[a]	Artificial inputs		Natural input	Output		Balance ratio[b]	Grain yield
		Organic	Inorganic		Product	Loss		
1949–51	N	36.0	0	22.9	44.4	14.4	0.81	2108
	P_2O_5	17.4	0	0	15.8	0	1.10	
	K_2O	44.8	0	0	36.8	0	1.22	
1954–56	N	34.5	3.3	23.1	53.4	15.5	0.71	2528
	P_2O_5	15.8	0	0	18.8	0	0.84	
	K_2O	40.1	0	0	41.5	0	0.97	
1959–61	N	27.5	12.3	22.8	43.0	15.9	0.93	2070
	P_2O_5	10.6	0.7	0	15.0	0	0.75	
	K_2O	26.2	0	0	34.4	0	0.76	
1964–66	N	34.6	18.8	22.3	60.5	21.3	0.88	2828
	P_2O_5	13.5	1.3	0	21.2	0	0.70	
	K_2O	32.7	0	0	48.8	0	0.67	
1969–71	N	54.3	64.4	21.5	101.3	47.5	1.17	4568
	P_2O_5	24.1	16.5	0	34.8	0	1.17	
	K_2O	53.6	0	0	76.3	0	0.70	
1974–76	N	73.2	83.8	21.2	137.6	62.8	1.14	7410
	P_2O_5	34.0	40.7	0	48.6	0	1.54	
	K_2O	74.8	0	0	91.5	0	0.82	
1979–81	N	55.9	186.2	21.6	160.6	96.9	1.51	8348
	P_2O_5	25.3	48.9	0	54.6	0	1.36	
	K_2O	56.5	0	0	108.7	0	0.52	
1984–86	N	65.6	252.0	21.9	202.0	127.0	1.57	9 690
	P_2O_5	28.6	74.3	0	68.3	15.6	1.23	
	K_2O	61.4	10.4	0	139.5	0	0.51	
1989–91	N	84.8	304.2	22.2	240.9	181.8	1.61	10,995
	P_2O_5	40.9	89.3	0	80.4	0	1.62	
	K_2O	76.4	4	0	166.6	0	0.49	
1994–98	N	101.3	420.5	22.2	300.3	219.5	1.74	13,650
	P_2O_5	68.6	118.4	0	122.8	0	1.52	
	K_2O	91.3	16	0	202.7	0	0.49	

[a] N = nitrogen; P_2O_5 = phosphorus oxide; K_2O = potassium oxide
[b] Balance ratio = artificial input divided by product output

Physical and chemical properties of the soil

We analysed soil fertility using the threshold guidelines for soil chemical indicators shown in Table 2 and the Australian standard soil physical indicators described by Walker and Reuter (1996). Soil fertility was evaluated according to the following criteria:

Physical factors

- soil consistency
- soil texture
- soil colour
- status of any roots
- presence of slaking and dispersion
- field capacity
- available water
- wilting point
- bulk density
- total porosity
- air-filled porosity

Table 2. Soil nutrient content in Luancheng, 1978–98.

	Total nutrient content (g/kg)								Available nutrient content (mg/kg)					
Year	OM	N	P	K	Zn	Cu	Pb	Cd	P	K	Fe	Cu	Zn	Mn
1978	11.5	0.78	1.5	22.8	–	–	–	–	7.77	141	8.27	1.03	0.67	8.20
1989	14.6	0.91	–	–	54.8	16	23.6	0.11	8.9	106.2	8.25	0.87	1.16	7.51
1998	15.0	1.03	0.8	12.2	58	19.4	12.8	0.63	16.0	88.1	9.0	2.03	1.67	9.0

Cd = cadmium; Cu = copper; Fe = iron; K = potassium; Mn = manganese; N = nitrogen; OM = organic matter; P = phosphorus; Pb = lead; Zn = zinc

Table 3. Classification of soil fertility (Chinese standard classification).

	Grade					
Soil component[a]	1	2	3	4	5	6
Organic matter (g/kg)	4	3–4	2–3	1–2	0.6–1	0.6
Total N (g/kg)	0.2	02–0.15	0.15–0.10	0.10–0.075	0.075–0.05	0.05
Total P (g/kg)	0.1	0.081–0.1	0.061–0.08	0.041–0.06	0.02–0.04	0.02
Olsen-P (mg/kg)[b]	40	40–20	20–10	10–5	5–3	3
Available K (mg/kg)	200	200–150	150–100	100–50	50–30	30
Available Zn (mg/kg)	3	1.1–3	0.51–1.0	0.31–0.5	0.3	
Available Fe (mg/kg)	20	10.01–20	4.51–10	2.51–4.5	2.5	
Available Mn (mg/kg)	30	15.1–30	5.1–15	1.1–5	1.0	
Available Cu (mg/kg)	1.8	1.01–1.8	0.21–1.00	0.11–0.2	0.11	
Available B (mg/kg)	2	1.01–2	0.5–1.0	0.26–0.5	0.25	
Available Mo (mg/kg)	0.3	0.21–0.3	0.16–0.2	0.11–0.15	0.10	
Indicators	Excellent	Very good	Good	Fair	Poor	Very poor

[a] Mo = molybdenum; B = boron; see Table 2 for explanation of other chemical abbreviations
[b] Olsen-P refers to the level of phosphorus measured using the Olsen analytical method

Chemical factors

- organic matter
- total N
- total P
- available P
- available K
- trace elements

Luancheng County typically has cinnamon soil with a thin humus layer and thick middle solum. Tables 4 and 5 show the main morphological and physical properties of the soil. In summary, soils are grey–yellow in morphology, sandy, loose, and good for storing water, but have a high bulk density and a plough pan. They have fair levels of total organic matter, total N, total P and available K, with good levels of trace elements; this suggests that soil fertility in Luancheng is in the middle range and that applying fertiliser every year is necessary to maintain soil fertility and sustain crop production. The results showed a potential deficiency in K; although current levels are not causing reduced crop yields, it is essential to start applying K fertiliser immediately.

Overall, soil fertility is judged to be fair to near good. Over the past 50 years, there has generally been a trend towards improved soil fertility, particularly for total organic matter, total N, available P and trace elements. Only in the total and available K content has there been a sharp reduction in levels: the average K content was at the lower end of the range (grade 3–4), suggesting the start of a trend to K deficiency. A serious problem is an increase in total cadmium (Cd), indicating probable soil pollution.

Conclusions for Sustainable Management

Successful management of soil fertility must meet the objectives of increasing production, being economically profitable and protecting the environment to enable the sustainable development of agriculture. The rational input of chemical fertiliser and manure must be emphasised for high-yield regions such as the Taihang Mountain piedmont. The basic approach should be to increase control over chemical fertiliser input, to increase the input of K fertiliser and to increase the level of manure returned to the soil.

The input of chemical N fertiliser is up to 420.5 kg/ha/year and there is a trend to continuously increase the amount for higher yields. The entry of superfluous N into the soil poses a serious ecological risk. In many places, the nitrate content

Table 4. Main morphological indicators of grey-yellow soil in Luancheng County.

Layer[a]	Thickness (cm)	Consistency	Colour	Texture	Root density (cm/cm^3)	
					Wheat	Corn
A_1	0–17	Soft	Grey–brown	Sandy loam	3.49	1.12
A_1B	17–30	Very hard	Light brown	Sandy loam	1.63	0.48
B_1	30–65	Firm	Dark brown	Loam	0.51	0.26
B_2	65–90	Firm	Dark brown	Loam	0.34	0.25
BK	90–145	Very hard	Light yellow	Light clay	0.16	0.12
B_3	145–170	Very hard	Grey yellow	Light clay	0.18	
BC	170–190	Very hard	Light yellow	Medium clay		

[a] Capital letters refer to soil horizons
Source: Report of the Luancheng County Natural Resources Survey and Agricultural Division, 1979.

Table 5. Main physical indicators of soil in Luancheng County.

Layer[a]	Thickness (cm)	Field capacity (%)	Wilting point (%)	Plant available water (%)	Bulk density (g/cm^3)	Total porosity (%)	Air-filled porosity (%)
A_1	0–17	36.35	9.63	26.73	1.41	46.42	10.07
A_1B	17–30	34.86	11.37	23.49	1.51	42.62	7.76
B_1	30–65	33.25	13.92	19.33	1.47	44.14	10.89
B_2	65–90	34.28	13.91	20.37	1.51	42.62	8.34
BK	90–145	34.36	12.95	21.41	1.54	41.48	7.12
B_3	145–170	38.98	13.87	25.11	1.64	37.68	1.42
BC	170–190	38.05	16.44	21.61	1.59	39.58	1.53

[a] Capital letters refer to soil horizons
Source: Report of the Luancheng County Natural Resources Survey and Agricultural Division, 1979.

of groundwater and vegetables is already more than prescribed by the National Hygienic Standard of Drinking Water and Food. Increasing levels of Cd in the soil may be due to the application of phosphate accompanied by Cd. Cadmium accumulation in the soil may lead to Cd pollution, a serious environmental issue. The ability of the soil to supply adequate levels of K for plant growth has decreased, as little K fertiliser has been applied in the past 50 years. K deficiency in the soil can reduce yields and reduce the efficiency of other fertilisers.

Farmers in the Taihang Mountain piedmont should emphasise the balanced application of fertilisers. In particular, policy makers should encourage the collection of manure and its return to soil.

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