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Evaluation of current fertilizer practice and soil fertility in vegetable production in the Beijing region

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Abstract

A survey on current fertilizer practices and their effects on soil fertility and soil salinity was conducted from 1996 to 2000 in Beijing Province, a major vegetable production area in the North China Plain. Inputs of the major nutrients (NPK) and fertilizer application methods and sources for different vegetable species and field conditions were evaluated. Excessive N and P fertilizer application, often up to about 5 times the crop requirement in the case of N, was very common, especially for high-value crops. Potassium supply may have been inadequate for some crops such as leafy vegetables. Urea, diammonium orthophosphate ($(NH_4)_2HPO_4$) and chicken manure were the major nutrient sources for vegetable production in the region. Over 50% of N, 60% of P and nearly 90% of K applied originated from organic manure. Total N application rate for open-field Chinese cabbage from organic manure and inorganic fertilizers ranged from 300 to 900 kg N ha^{-1} on 78% of the farms surveyed. More than 35% of the surveyed greenhouse-grown tomato crops received $>$ 1000 kg N ha^{-1} from organic and inorganic sources. A negative K balance (applied K minus K removed by the crop) was found in two-thirds of the surveyed fields of open-field Chinese cabbage and half of the surveyed fields of greenhouse-grown tomato. Plant-available N, P and K increased with increasing length of the period the greenhouse soils had been used for vegetable production. Similarly, soil salinity increased more in greenhouse soils than in open-field soils. The results indicate that balanced NPK fertilizer use and maintenance of soil quality are important for the development of sustainable vegetable production systems in this region.

Introduction

Beijing is located on the northern border of the North China Plain (39°56′ N, 118°20′ E). Vegetable cropping has become more popular in the region over the last 10 years, reaching an area of 107,800 ha in 2001, and is one of the most important sources of income for local farmers. Fertilization and irrigation are important management tools to optimize crop production. Current management practices in vegetable production are based largely on intensive fertilizer use and irrigation. Although information is available on N requirements of vegetable crops in other countries (Lorenz et al. 1989; Fageria 2002), it was poorly developed by local extension services in China and many farmers still determine fertilizer application rates by 'rule of thumb', which is a cause of concern regarding agricultural resources and food quality.

With vegetable production exceeding demand, emphasis is shifting to good quality and healthy products. However, insufficient information and institutional support are available for implementation of sustainable vegetable production. Reliable data on current farm management are needed for the design of balanced fertilizer regimes, including information on the characteristics of crop nutrient uptake.

Survey work was therefore conducted to collect information on current fertilizer practices for selected vegetable species in open fields and greenhouses in the Beijing region. In addition, nutrient balances were calculated and soil analyses conducted to estimate the potential risk of soil salinization and to develop balanced nutrient management strategies.

Materials and methods

Seven suburban districts and counties (Shunyi, Tongzhou, Daxing, Pinggu, Yanqing, Miyun and Changping) in Beijing Province were selected for the survey, with the number of farms surveyed proportional to the vegetable cultivation area in each county (proportional stratified sampling). Field selection changed from year to year to include cereal fields that in recent years had been converted into vegetable fields. Approximately 10% of the farms surveyed had been growing vegetables for under 5 years, about 40% for 5 years, 25% for 5 to 10 years, and the remainder for 10 to 15 years. Over 50% of fields surveyed produced non-leafy vegetables such as cucumber and tomato.

A total of 1286 questionnaires on crop management for open-field production and 543 for greenhouse production were collected from 1996 to 2000. Nutrient (NPK) compositions of different types of organic manure and of different vegetable crops were obtained from agricultural advisory centers (Extension Service Center, MOA 1989). Nutrient balances for N, P, and K were calculated for some major crop species, based on nutrient inputs from chemical fertilizers and organic manures and crop removal.

Soil surveys in greenhouses and open fields in these counties and districts were carried out to monitor soil fertility and soil secondary salinization. Soils, selected according to the same criteria as the surveyed fields, were analyzed using standard methods. Soil pH was determined in water (1:5 soil/water ratio) using a pH meter. Organic matter was determined using the Schollenberger method in which organic matter is oxidized in concentrated H_2SO_4 containing $K_2Cr_2O_7$ at 175 °C for 90 s and the excess $Cr_2O_7^{2-}$ is titrated with standard $FeSO_4$ solution. The factor used to convert organic C to organic matter was 1.724 (Tinsley 1950). 'Total' N was determined using semi-micro Kjeldahl digestion without reduction of nitrate. Plant-available P was estimated using bicarbonate extraction (the Olsen method) and plant-available K by ammonium acetate extraction. Electrical conductivity (EC) was determined in water (1:5 soil/water ratio), as were soluble salts. Atomic absorption spectrophotometry was used to determine Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} in the water extracts. Cl^{-} was determined by electrometric titration with silver, NO_3^{-} using a specific ion electrode, SO_4^{2-} using a turbidimetric method in which sulfate is converted into $BaSO_4$ suspension under controlled conditions and the turbidity measured spectrophotometrically, and HCO_3^{-} and CO_3^{2-} by potentiometric titration of the extract with HCl to pH 8.4 and 4.4, respectively.

Results

Nutrient application and crop yield

Chinese cabbage (*Brassica campestris* L. ssp. *Pekinensis* (Lour) Olsson), cucumber, tomato, cabbage (*Brassica oleracea* L. var. *capitata* L.), radish and eggplant were identified as the main vegetable crops, accounting for almost 50% of the regional vegetable area. Survey results show (Table 1) that marketable crop yield and presumably NPK uptake varied twofold among crop species and fields. Chinese cabbage, tomato and cucumber removed relatively large quantities of nutrients because of their high yields. Greenhouse sweet pepper and eggplant removed more nutrients than those in open fields because of higher yields.

Nutrient inputs in organic manures and inorganic fertilizers far exceeded crop removals (Tables 1 and 2), especially for non-leafy vegetables. Most of the nutrient input was in the form of organic manure, averaging 55% for N, 77% for P and 90% for K in open fields, and comparable values in greenhouses (Table 2). Average application rates of organic manure increased in the course of the survey period (Table 3), as did its contribution to total N and P inputs, i.e., for N from 39 to 58% and for P from 55 to 95% over the period 1996–-2000. Over half of the applied organic manure was in the form of chicken manure, which

Table 1. Average marketable yields of selected vegetable species cultivated in open fields and greenhouses of the surveyed farms in the Beijing suburbs from 1996 to 2000.

Species	Number of farms		Marketable yield (tonnes ha^{-1})	
	O[1]	G	O	G
Cabbage	64	14	50.0 27–90[2]	51.6 13–83
Chinese cabbage	590	65	83.1 22–147	82.8 22–105
Cucumber	107	94	66.8 22–97	70.4 18–155
Eggplant	36	19	48.4 30–105	61.3 37–90
Sweet pepper	20	5	37.6 22–60	55.8 26–78
Tomato	149	132	70.8 30–179	63.3 19–150

[1]O, open field; G, greenhouse; [2]Range.

may be explained by the rapid expansion of the poultry sector and farmers' perception that chicken manure can increase soil fertility more quickly than other forms of organic manure because of its relatively high concentrations of N and P.

Urea, which rapidly hydrolyzes in soil to ammoniacal N, and diammonium orthophosphate, which recently replaced calcium phosphate, were common chemical N and P fertilizers, while nitrate fertilizers, generally more expensive than urea or ammonium fertilizers, were not common. Potassium sulfate and potassium chloride were the main K fertilizers used, but they represented only about 1% of the total K input. Of this, 58% was applied before seeding and 42% as a top-dressing in open fields. Almost all potassium sulfate used in greenhouses was applied as basal fertilizer, but most of the N fertilizers were applied as top-dressing in furrow irrigation.

The dominant vegetable species were Chinese cabbage in open fields and tomato in greenhouses. Of the farms in the survey growing Chinese cabbage, about 35% did not apply organic manure and 61% applied N fertilizers at rates from 200 to 400 kg N ha^{-1}. Total N supply from organic manure and chemical fertilizers ranged from 300 to 900 kg ha^{-1} on 78% of the farms (Figure 1). In greenhouse-grown tomato, only 11% of the farms did not use organic manure, and 30% applied $>$ 800 kg N ha^{-1} in organic manure. Consequently, 35% of the greenhouse tomatoes received $>$ 1000 kg N ha^{-1} in both organic and inorganic forms (Figure 1).

Nutrient balances

Average N and P balances are positive for all species, as are K balances, except for Chinese cabbage. For most surveyed vegetable species, the N and P balances (fertilizer input minus crop removal) showed very large surpluses, especially the high-value non-leafy species, i.e., cucumber, tomato, eggplant and sweet pepper (Table 4). In contrast, a negative K balance was commonly found in Chinese cabbage, a species with a relatively low economic value. However, these simple nutrient balances do not take account of soil nutrient supply, no visible K deficiency symptoms in this area of alluvial calcareous Cambisols. From Table 4 it can be derived that the average input ratio of N:P:K was 1:0.29:0.28 in surveyed open fields and 1:0.30:0.30 in the protected fields. Thus, current fertilizer practice does not balance crop requirements. However, this simple input–output approach does not take into account nutrient supply from indigenous soil sources, and further work is required to develop that aspect. It would be especially useful to develop a suitable procedure for determining soil mineral N supply (N_{min}) so that this source of available N could be incorporated in the formulation of balanced fertilizer strategies. It could also be argued that nutrients in organic manure cannot be compared to inorganic sources, because only a small proportion is readily available and the remainder becomes only slowly available. However, in the longer term, a proportion of organic N (that can be estimated following detailed field experiments), similar to P and K supply from organic manure, will become available for crop uptake.

The relationships between marketable yields and N balances for field-grown Chinese cabbage and greenhouse tomatoes (Figure 2) show the low frequency of negative N balances. However, nearly two-thirds of the farms with Chinese cabbage production showed negative K balances compared to about half for the greenhouse-grown tomatoes.

Nutrient accumulation in vegetable fields

Multiple vegetable cropping is common in open fields and greenhouses in the suburbs of Beijing. Potential annual nutrient accumulation is therefore likely to be higher than the values given in Table 4, and accumulation increasing with increasing length of the period of vegetable production. However, this effect can only

Table 2. Average nutrient inputs for selected vegetable species cultivated in open fields and greenhouses of surveyed farms in the Beijing suburbs from 1996 to 2000.

Species	n[1]	N input (kg ha^{-1})			P input (kg ha^{-1})			K input (kg ha^{-1})		
		Total	OM[2]	TD[3]	Total	OM	TD	Total	OM	TD
Open fields										
Cabbage	64	679	421	61	191	160	39	251	229	17
		0–2093[4]	0–1956		0–836	0–813		0–909	0–847	
Chinese cabbage	590	607	262	584	166	108	535	143	124	137
		27–1584	0–1223		0–554	0–508		0–610	0–529	
Cucumber	107	882	487	107	259	191	88	251	235	28
		52–2073	0–1467		0–686	0–610		0–635	0–635	
Eggplant	36	776	434	36	227	172	28	222	212	6
		253–1377	0–978		33–508	0–462		0–510	0–510	
Sweet pepper	20	833	508	20	258	201	18	248	244	2
		45–2064	0–1712		16–711	0–711		16–741	0–741	
Tomato	149	862	450	149	257	180	133	254	232	41
		302–2078	0–1467		0–759	0–610		0–715	0–635	
Greenhouses										
Cabbage	14	440	234	14	110	84	8	132	129	1
		75–1272	12–1086		5–451	5–451		5–470	6–470	
Chinese cabbage	65	624	339	65	188	139	57	173	153	19
		228–1008	0–733		0–381	0–305		0–442	0–318	
Cucumber	94	1012	539	91	279	213	73	261	250	14
		0–2887	0–2301		0–1101	0–950		0–992	0–992	
Eggplant	19	1070	668	19	373	276	18	339	291	9
		270–2356	122–1711		53–863	51–711		53–741	53–741	
Sweet pepper	5	1068	568	5	334	231	5	283	258	1
		660–1558	273–734		162–457	86–305		179–442	178–318	
Tomato	132	787	464	126	231	179	90	232	209	29
		0–2880	0–2445		0–1016	0–1016		0–1058	0–1058	

[1]n, number of surveyed farms; [2]OM, organic manure; [3]TD, number of farms with topdressing of chemical fertilizer; [4]Range.

Table 3. Average rate of organic manure application and fraction of total nutrient application on vegetable farms in the Beijing suburbs from 1996 to 2000.

Year	Average input of organic manure (tonnes fresh weight ha^{-1})	Proportion of total nutrient applied (%)			Number of farms surveyed
		N	P	K	
1996	36.5	38.9	54.9	90.5	275
1997	38.2	41.5	54.7	84.2	463
1998	43.7	49.1	65.7	89.0	478
1999	34.6	47.0	64.4	76.1	17
2000	54.0	58.7	94.8	97.1	51

be quantified through repeated soil analysis for total and available nutrients in long-term field experiments.

As a first approximation, greenhouses and open fields of different ages were selected to examine changes in soil fertility over time. Values of indicators of soil fertility such as total N, organic matter and available P and K in the surface soil layers of greenhouses were higher in greenhouses that had been in use for a longer period of time (Table 5).

Salts have accumulated in the topsoil layer of greenhouses (Table 6) because of the upward movement of soil water as evapotranspiration exceeds water input (precipitation + irrigation). Average soluble salt content and EC in the 0–5 cm layer were 2.69 g kg^{-1} and 0.56 ms cm^{-1} in greenhouses following ex-

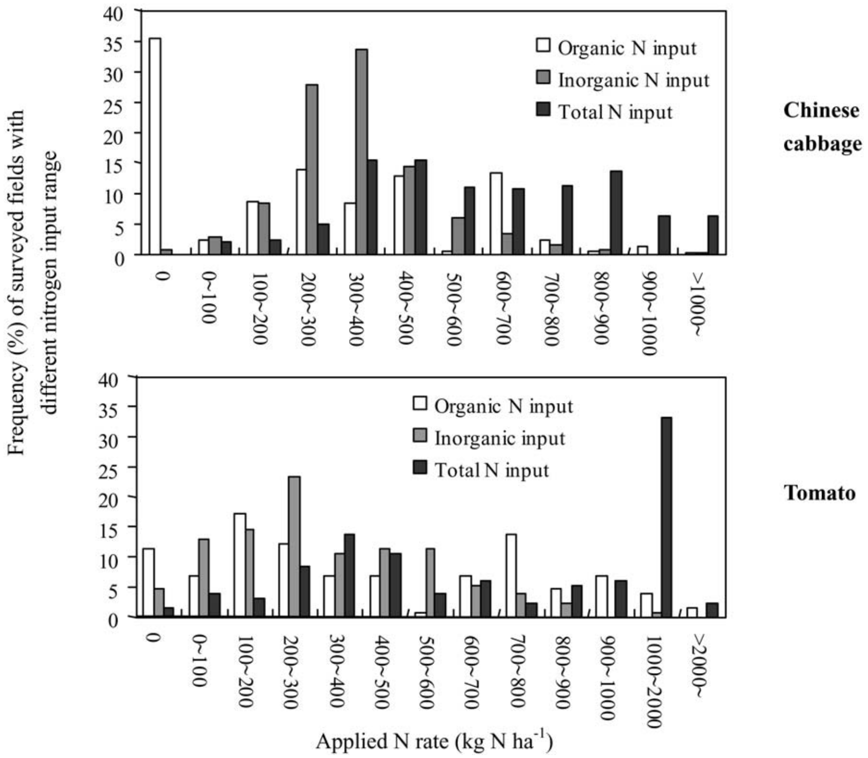

Figure 1. Frequencies of applied N rates in organic manures and chemical fertilizers in field-grown Chinese cabbage (n = 590) and greenhouse-grown tomato (n = 132) in the Beijing suburbs from 1996 to 2000.

Table 4. Average nutrient balances calculated by subtracting crop offtakes from fertilizer inputs for selected vegetable crop species of surveyed farms in the Beijing suburbs from 1996 to 2000.

Species	Nitrogen (kg ha^{-1})		Phosphorus (kg ha^{-1})		Potassium (kg ha^{-1})	
	Open fields	Greenhouses	Open fields	Greenhouses	Open fields	Greenhouses
Cabbage	529	286	169	88	159	36
	–89–1980[1]	–5–1233	–16–820	–11–446	–97–839	–69–446
Chinese cabbage	448	467	134	156	–93	–62
	–201–1413	41–833	–40–531	–21–344	–340–396	–276–173
Cucumber	699	820	220	238	58	58
	–99–1909	–93–2621	–32–652	–19–1069	–178–481	–281–828
Eggplant	619	871	208	347	41	110
	–32–1221	151–2065	15–492	38–826	–345–331	–198–405
Sweet pepper	639	781	240	307	47	–17
	–109–1871	363–1266	2–695	149–430	–193–540	–99–37
Tomato	611	563	227	204	25	27
	92–1812	–206–2558	–24–731	–38–976	–184–412	–291–744

[1]Range.

tensive periods of vegetable cultivation, approximately 40% higher than in open fields nearby. No significant differences in soluble salt content were found in open fields for different durations of vegetable cultivation. Average proportions of soluble cations in the 0–25 cm layer in greenhouses were: Ca^{2+} 53, Mg^{2+} 22, Na^{+} 18 and K^{+} 7%, and of anions: SO_4^{2-} 50, NO_3^{-} 14 and Cl^{-} 6%. Soil pH values in greenhouses (Table 6) were slightly lower than in

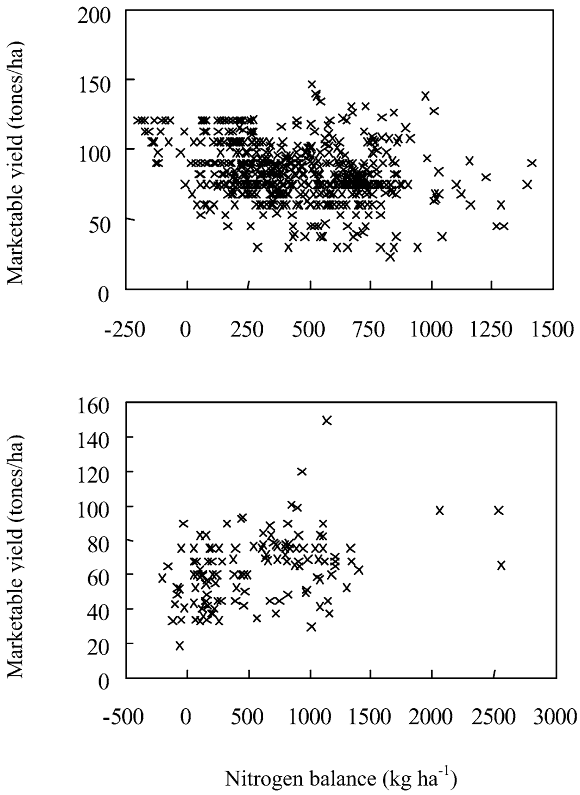

Figure 2. Relationship between marketable yield and N balance for field-grown Chinese cabbage (upper graph, n = 590) and greenhouse-grown tomato (lower graph, n = 132) in the Beijing suburbs from 1996 to 2000.

open fields and the difference increased with duration of vegetable cultivation.

Discussion

Excessive nutrient application is an economic loss for vegetable growers, and may also result in greater pest management problems (Neeteson et al. 1999). Average N and P inputs in open fields were 682 and 195 kg ha^{-1}, respectively, equivalent to 3 and 5 times crop demand. Soil nutrient accumulation was high in greenhouses because farmers always use very high rates of chemical fertilizer on 'high-value' crops, in combination with large amounts of organic materials such as chicken manure. Secondary soil salinization might increase in greenhouses with increasing length of periods of vegetable production.

In general, recently converted cereal fields show relatively low soil fertility, the main reason for farmers to apply large amounts of inorganic fertilizers and organic manures to improve soil fertility. From an environmental perspective, overuse of chemical N fertilizer has been associated with increased levels of NO_3-N in groundwater and surface waters (Wehrman and Scharpf 1989). In agricultural areas with intensive farming practices, excessive application of P has led to increased incidence of soils with a high P concentration, increasing the risk of P enrichment of surface runoff and P losses during drainage (Stanley et al. 1995).

Urea and diammonium orthophosphate were the dominant N fertilizers. Farmers perceive N fertilizer as one of the most important factors contributing to crop production. In recent years, diammonium orthophosphate has become a popular fertilizer for top-dressing of N and this might be one of the reasons for the large amounts of P applied. Chicken manure, with its rapid release of nutrients in soils, was the major type of organic manure used in the Beijing suburbs.

Fertilizer application methods used in the North China Plain include broadcasting, followed by soil incorporation before planting and application during furrow irrigation. Late broadcasting or soil incorporation during topdressing is often not possible because the plants are too large and would suffer salinity damage if the fertilizer remained on the leaves and incorporation would result in mechanical damage to the plants. It is well known that good contact between roots and nutrients with low mobility in the soil such as PO_4^{3-} and NH_4^+ is essential (Sørensen 1996), because their diffusion rates are very low (Nye and Tinker 1977). Nutrient use efficiency of vegetable crops in this region has been found to be low and this has been associated with excessive irrigation (Chen et al. 2002). Specific fertilizer and irrigation management systems such as drip irrigation systems may need to be developed to improve nutrient use efficiency.

Simple methods for farmers to estimate soil N_{min} content at preplanting are also required so that this N contribution to crop nutrition can be taken into account in fertilizer strategies for vegetable crops. Semi-quantitative methods have been developed for use by farmers in Germany, and although inferior to laboratory analyses, they are much better than using 'rules of thumb', which always seems to lead to over-fertilization of crops (Weier et al. 2001). Growers and advisors do not perform site-specific measurements but use fertilizer recommendations based on

Table 5. Average soil NPK status in the surface soil layer (0–20 cm) of greenhouses of varying age (period of vegetable production) for surveyed farms in the Beijing suburbs from 1997 to 1999.

Period of greenhouse vegetable cultivation (years)	Number of farms	Kjeldahl-N (g kg^{-1})	Organic matter (g kg^{-1})	Olsen-P (mg kg^{-1})	NH_4OAc-K (mg kg^{-1})
1–5	27	1.00	17.9	117	147
		0.11–2.59[1]	5.2–38.6	2–375	67–302
5–10	22	1.21	22.2	158	174
		0.57–2.30	3.5–35.8	18–349	69–484
11–15	16	1.43	22.9	118	191
		0.83–2.05	13.9–37.3	37–375	104–753
16–20	3	1.90	37.0	257	413
		1.17–2.63	28.8–43.8	171–338	154–611
Open fields	304	0.92	14.6	24	85
		0.43–1.98	7.3–33.6	2–139	45–397

[1]Range.

Table 6. Electrical conductivity (EC), pH and total soluble salt content in different soil layers of open fields and greenhouses of varying age (period of vegetable production) in the Beijing suburbs.

Soil layer	EC (ms cm^{-1})		pH (in water)		Total soluble salts[1] (g kg^{-1})	
(cm)	Greenhouse	Open field	Greenhouse	Open field	Greenhouse	Open field
1–5 years (n = 9)						
0– 5	0.44	0.37	7.97	8.13	1.57	1.48
	0.12–1.02[2]	0.11–0.66	7.13–8.51	7.50–8.56	0.57–4.48	0.70–2.01
5–10	0.35	0.20	7.82	8.29	1.56	0.98
	0.14–1.15	0.13–0.38	6.52–8.50	7.89–8.56	0.79–4.69	0.67–1.37
10–25	0.29	0.19	8.11	8.25	1.35	0.93
	0.09–0.29	0.09–0.42	7.23–8.76	6.99–8.75	0.67–4.56	0.54–1.84
25–40	0.30	0.16	8.17	8.44	1.48	0.74
	0.08–1.13	0.10–0.21	7.76–8.75	7.93–8.84	0.43–4.75	0.53–0.90
40–60	0.23	0.13	8.34	8.56	0.97	0.64
	0.08–0.51	0.08–0.19	7.80–8.83	8.01–8.96	0.47–1.98	0.22–0.90
60–80	0.19	0.13	8.33	8.59	0.91	0.75
	0.08–0.37	0.07–0.18	7.78–8.78	8.02–8.92	0.46–1.55	0.48–1.11
16–20 years (n = 4)						
0– 5	0.56	0.32	7.45	8.00	2.69	1.18
	0.36–0.87	0.22–0.49	7.28–7.52	7.60–8.43	1.81–3.18	0.75–1.32
5–10	0.43	0.25	7.53	8.24	1.96	0.96
	0.28–0.62	0.21–0.35	7.20–7.85	7.75–8.75	1.47–2.22	0.50–1.21
10–25	0.35	0.37	7.81	8.38	1.51	0.98
	0.21–0.53	0.15–0.85	7.35–8.08	7.88–8.94	1.03–1.76	0.57–1.47
25–40	0.23	0.15	8.08	8.43	1.16	0.84
	0.12–0.31	0.10–0.20	7.68–8.53	8.21–9.03	0.46–1.50	0.43–1.28
40–60	0.22	0.17	8.29	8.44	0.86	0.97
	0.11–0.30	0.10–0.24	7.98–8.71	8.20–8.98	0.48–1.24	0.56–1.33
60–80	0.23	0.16	8.19	8.55	1.03	0.83
	0.12–0.30	0.09–0.23	7.99–8.55	8.36–8.88	0.49–1.41	0.53–1.16

[1]Soluble salt ions include Ca^{2+} , Mg^{2+} , Na^{+} , K^{+}, NO_3^-, Cl^-, SO_4^{2-} and HCO_3^-; [2]Range.

estimates of crop yield, nutrient concentrations and crop offtakes (Lorenz et al. 1989). However, soil test laboratories and carefully designed field experiments are useful for fine-tuning of fertilizer recommendation systems (Motavalli et al. 2002). Our survey indicates that N and P inputs should be reduced and K inputs sometimes increased compared with the current commercial practice to match crop nutrient demand for optimum yields as a basis for development of sustainable vegetable production systems in the northern part of the North China Plain.

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