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Current Soil Nutrient Status of Intensively Managed Greenhouses*[1]

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ABSTRACT

Nine districts covering the main greenhouse vegetable areas in Tianjin Municipality of the North China Plain were selected for the soil investigation in 2010 to survey the current soil nutrient status (soil available N, P and K), acidification and salinization due to excessive input of fertilizers in greenhouses in Tianjin. The study showed that, in particular, soil available P content increased with the age of greenhouses. In contrast, our results did not reveal higher K accumulation and lowered pH in the greenhouse soils compared with cultivation in open fields. Over-fertilization, causing high NO_3^- accumulation, most likely resulted in salinity problems in the greenhouses. Ninety percent of the investigated greenhouse soils had electrical conductivity values of saturated paste extracts of 2–10 d S m^{-1}, which might affect the yields of vegetable crops like green bean, pepper, cabbage, carrot, eggplant, lettuce, spinach, celery, cucumber and tomato. The findings of our survey of the current fertility and salinity problems in greenhouse soils suggest that there is an urgent need to improve the farmers' practices and strategies in fertilization management in greenhouses of China. Because education and the agricultural technical extension services may play a more important role in avoiding overuse of fertilizers, we suggest that current nutrient management practices should be improved in the near future through training of local farmers in farmers' schools and through strengthening the agricultural extension services with practical techniques.

Key Words: electrical conductivity, greenhouse vegetables, over-fertilization, soil pH, soil survey

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INTRODUCTION

The total area of vegetable crops planted under greenhouses or plastic-film houses in China was more than 2 500 000 ha in 2008, and China has become the country that produces the most vegetable crops under greenhouses or plastic-film houses (Yang *et al.*, 2011) of the world. To obtain high production, shallow-rooted vegetable crops in greenhouses are intensively managed with high inputs of water and nutrients, leading to an increase in salt accumulation, soil acidification, nutrient imbalances and a high risk of nutrient losses to the environment; thus, efficient management for nutrients is crucially important for sustainable vegetable production (Guo *et al.*, 2010). Recent investigations have revealed that excessive nitrogen (N) fertilizer applications ($> 1\,000$ kg N ha^{-1}) with less than 10% of fertilizer N being recovered are commonly found in the intensive greenhouse vegetable planting systems (Chen *et al.*, 2004; Zhu *et al.*, 2005). Consequently, high proportions of unused N are lost to the environment by nitrate leaching, denitrification and NH_3 volatilization (Cabrera and Chiang, 1994; Fox *et al.*, 1996; Ramos *et al.*, 2002; He *et al.*, 2007). For example, the NO_3^--N concentrations in shallow wells (< 15 m) around greenhouses in Humin, Shandong Province, ranged from 9–274 mg N L^{-1}, with 99% of surveyed wells exceeding 10 mg N L^{-1}, more than half of the samples (53%) exceeding 50 mg N L^{-1} and 26% exceeding 100 mg N L^{-1} (Ju *et al.*, 2006). Furthermore, because P is generally retained to a higher extent, P accumulation in the soil corresponds with greenhouse age. The high rates or repeated applications of phosphate fertilizer and organic manure induce a significant accumulation of P (Chen *et al.*, 2004; Yang *et al.*, 2011), eventually leading to water pollution through runoff (Edmeades, 2003).

To develop sustainable nutrient management practices suitable for China in the 21st century, since 2005, China has launched national programs of soil testing and fertilizer recommendations. To bridge the gaps in knowledge and technology transfer between research institutions and extension agencies, Chinese universities and research institutions set up the "Agricultural Extension Professor System" and the "Professional

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Master Degree Program for Agricultural Extension" in 2006 (Miao *et al.*, 2011). Our hypothesis is that an investigation of the actual status of soil fertility in the intensive greenhouses may critically evaluate the progress of these current practices and strategies for nutrient management in greenhouses. Furthermore, this investigation could help farmers to improve their practices and enable stakeholders to develop future strategies for nutrient management and sustainable agriculture through saving inputs and preventing environmental damages resulting from nutrient losses.

To support this goal and to deliver a database describing the current situation, our objective was to investigate the actual status of nutrient levels, acidification and salinization of soils in greenhouses of Tianjin Municipality in the North China Plain (NCP). Tianjin represents the typical intensively managed cultivation of greenhouse vegetables in the NCP. The survey was, therefore, conducted in Tianjin to obtain information on current fertilizer practices in open fields and greenhouses.

MATERIALS AND METHODS

Sample site description

The NCP is a major area for vegetable production in China. Tianjin (38° 95′–40° 05′ N, 116° 92′–117° 83′ E) is located in the northeast of the NCP and reached a vegetable growing area of 107 000 ha from a total of 420 000 ha arable land in 2010. Nine districts of Tianjin Municipality, Beichen (BC), Baodi (BD), Dongli (DL), Hangu (HG), Jinghai (JH), Jixian (JX), Ninghe (NH), Wuqin (WQ) and Xiqin (XQ), which cover all the vegetable growing areas in the Tianjin region, were selected for soil investigations of greenhouses and open fields as references in the distinct surrounding of the greenhouses in 2010 (Table I). A total of 144 questionnaires concerning fertilizer amounts applied in greenhouses and information about farmers' education, ages and genders were conducted by interviewing the individual farmers. The major vegetable crops in greenhouses are cucumber, tomato, green bean, celery and spinach and in open fields are winter wheat and maize. The main soil type is loamy, silty alluvial soil (FAO system). Tianjin has a semi-humid, continental monsoon climate. The annual average temperature is approximately 12.3 °C. The hottest month is July, with an average temperature of 26 °C, and the coldest month is January, with an average temperature of 4 °C. The average annual precipitation is approximately 550–680 mm. However, approximately 80% of the precipitation occurs in the summer.

TABLE I

Number of soil samples in different ages of greenhouses and in open fields of nine districts of Tianjin Municipality

District	Open fields	Greenhouses			
		1–3 years	4–9 years	10–20 years	$>$ 20 years
Beichen	4	6	-	3	5
Baodi	4	4	4	4	-
Dongli	5	4	-	2	6
Hangu	4	1	4	3	4
Jinghai	4	4	6	4	4
Jixian	4	4	4	4	4
Ninghe	4	3	4	4	-
Wuqin	4	3	6	5	4
Xiqin	4	4	4	4	-

Soil sample analyses

One-hundred and sixty-three air-dried soil samples were collected from a depth of 30 cm, extracted with a 30 g:60 mL soil-to-CaCl$_2$ solution (0.01 mol L^{-1}) and analyzed for NO$_3^-$-N content with a Kontron high performance liquid chromatography system (Goebe ElektroTechnik GmbH, Halletau, Germany). Soil samples were taken at the given greenhouse shortly after the vegetable crops were harvested and before the new fertilizers were applied between June and August of 2010. To determine soil NO$_3^-$-N contents at different soil depths, additional moist soil samples from 56 greenhouses cultivated in the last 10–20 years were taken at depths of 0–30, 30–60 and 60–90 cm. Fresh soil samples were frozen before the analysis. Soil samples were taken at the given greenhouse shortly after the vegetable crops were harvested and before the new fertilizers were applied in September of 2010 and were extracted with 0.005 mol L^{-1} CaCl$_2$ (30 g:60 mL) and the extracted solution was analyzed with a reflectometer (RQeasy®, Merck KGaA, Darmstadt, Germany) (Schmidhalter, 2005).

For the analyses of plant available P and easily exchangeable K, the air-dried soil samples were extracted with the calcium acetate lactate (CAL) method recommended by Schüller (1969). To compare with plant available P extracted by the CAL method (CAL-P), the Olsen extraction with 0.5 mol L^{-1} NaHCO$_3$ (Olsen *et al.*, 1954) was applied to 20 selected soil samples, including the soils with low and high P contents. After extraction, the phosphate was determined by a spectral photometer (LC 75, Perkin Elmer, Norwalk, USA), and K extracted by the CAL method (CAL-K) was analyzed with a flame photometer (Elex 6361, Eppendorf AG, Hamburg, Germany) in the solutions.

For soil pH, air-dried soil samples were suspended with 1:2.5 soil-to-CaCl$_2$ solution (0.01 mol L^{-1}). The pH in the suspension was measured with a pH meter (Ecoscan pH 5, Eutech Instruments, Singapore). The soil electrical conductivity (EC) from a 1:1 soil-to-water extract was measured with an electrical conductivity meter (LF 340, WTW GmbH, Weiheim, Germany) and converted into EC of a saturated paste extract (ECe) according to ECe = 1.94EC − 0.17 for loamy silty soils (Zhang *et al.*, 2005).

To estimate the contribution of soil nitrate to ECe (dS m^{-1}), the following two formulas (Hu and Schmidhalter, 2004 and Nobel, 2009, respectively) were used:

$$\mathrm{ECe} = -27.8\varPsi_{\mathrm{s}} \qquad (1)$$

$$\varPsi_{\mathrm{s}} = -iCRT \qquad (2)$$

where $\varPsi_{\mathrm{s}}$ is the solution potential (MPa); i is the ionization constant (for non-electrolytes, $i = 1$); C is the molar concentration (mol L^{-1}) of soil solution in the saturated paste; Soil water content at the saturated paste was 50% on dry soil basis. R is the universal gas constant (0.008 314 MPa L mol^{-1} K^{-1}); and T is the absolute temperature (293 K).

Statistical analyses

The data were analyzed with an analysis of variance (ANOVA) using IBM SPSS Statistics 19.0 (IBM, New York, USA). Multiple comparisons using Duncan's multiple range test were performed whenever the ANOVA indicated significant differences at $P < 0.05$.

RESULTS

The results of our questionnaire survey showed that the annual nutrient rates for greenhouse vegetable crops were approximately 660–4 320 kg N ha^{-1}, 240–1 830 kg P ha^{-1} and 210–2 100 kg K ha^{-1}. The organic manure/compost accounted for about 82% of total nutrients applied. Among the 143 interviewed farmers for vegetable crop cultivation, 56% was at the ages of 46–60 years old. The female farmers accounted for 29% and the male farmers were 71%. Eighty six percent of the interviewed farmers had received their education either from only elementary school or from high school.

Soil NO_3^--N content

Table II showed that soil $\mathrm{NO_3^-}$-N content at 0–30 cm was mostly higher under greenhouse conditions than in open fields. The $\mathrm{NO_3^-}$-N concentrations in the open fields ranged between 100 and 240 kg N ha^{-1}, while in the greenhouses, soil $\mathrm{NO_3^-}$-N ranged between 160 and 1 270 kg N ha^{-1}. Although the results demonstrated a trend of increasing soil $\mathrm{NO_3^-}$-N with increasing greenhouse age for the regions of BC, BD and XQ (Table II), these results did not apply for the other regions, which showed the opposite tendency of soil $\mathrm{NO_3^-}$-N with greenhouse age. The average values of soil $\mathrm{NO_3^-}$-N contents from open fields and greenhouses varied with region (Table II).

However, the results in Table III showed that soil $\mathrm{NO_3^-}$-N also accumulated in lower layers.

Soil available P

The soil CAL-P content is shown in Table IV. The results showed higher CAL-P content in greenhouses than that in open fields and much higher P accumulation in the greenhouses greater than 10 years old than that in the greenhouses less than 10 years old. In the open fields, CAL-P content was between 80 and 700 mg P kg^{-1}, whereas it ranged between 80 and 1 300 mg P kg^{-1} in greenhouses. CAL-P content in 10–20 year-old

TABLE II

Soil $\mathrm{NO_3^-}$-N contents (0–30 cm) at different ages of greenhouses and in open fields of nine districts of Tianjin Municipality

District	Open fields	Greenhouses			
		1–3 years	4–9 years	10–20 years	> 20 years
	kg N ha^{-1}				
Beichen	234±67$^{a)}$b$^{b)}$	204±34b	-	752±231a	893±192a
Baodi	236±33b	568±163ab	824±176a	825±68a	-
Dongli	178±69b	1 272±471a	-	160±45b	199±49b
Hangu	239±91b	433±0a	258±33b	234±46b	291±41b
Jinghai	190±46a	369±140a	239±42a	322±110a	289±84a
Jixian	99±61b	318±68ab	164±73b	648±199a	742±24a
Ninghe	230±75ab	302±170ab	163±19b	696±239a	-
Wuqin	208±65b	1 008±342a	352±62b	274±28b	229±25b
Xiqin	109±37b	288±88ab	515±127a	467±58a	-

a) Means±standard errors ($n = 2$–6).

b) Means followed by the same letter(s) within each row are not significantly different at $P \leq 0.05$ by Duncan's multiple range test.

TABLE III

Soil NO_3^--N contents at different soil depths in different greenhouses of four districts of Tianjin Municipality

District	Soil depth			
	0–30 cm	30–60 cm	60–90 cm	0–90 cm
	kg N ha^{-1}			
Beichen	190±61[a]	165±46	147±56	502±155
Jinghai	288±25	234±28	176±18	698±63
Jixian	456±77	404±62	360±50	1 229±181
Wuqin	321±61	321±73	289±68	931±197

[a] Means±standard errors ($n = 6$–22).

TABLE IV

Soil available P contents (0–30 cm), extracted with calcium acetate lactate, at different ages of greenhouses and in open fields of nine districts of Tianjin Municipality

District	Open fields	Greenhouses			
		1–3 years	4–9 years	10–20 years	> 20 years
	mg P kg^{-1}				
Beichen	375±190[a]b[b]	139±30b	-	1 261±160a	1 039±160a
Baodi	225±110b	722±320ab	983±210a	676±120ab	-
Dongli	288±80b	603±100a	-	372±20ab	592±60a
Hangu	703±10a	166±0b	716±320a	738±390a	1 320±460a
Jinghai	83±20b	192±40b	352±70ab	857±150ab	1 301±80a
Jixian	75±40c	686±30b	716±320b	896±70b	1 234±140a
Ninghe	86±10c	369±120b	568±90b	1 065±70a	-
Wuqin	708±240a	77±40b	737±100a	489±110ab	668±160a
Xiqin	225±80c	337±150bc	990±260a	760±50ab	-

[a] Means±standard errors ($n = 2$–6).

[b] Means followed by the same letter(s) within each row are not significantly different at $P \leq 0.05$ by Duncan's multiple range test.

greenhouses was 9 times higher than that in 1–3 year-old greenhouses. Duncan's multiple range test demonstrated a significant difference ($P \leq 0.05$) in CAL-P content among the different ages of greenhouses. Although there was a difference in CAL-P content among the regions (Table IV), the variation of the CAL-P content in the top soils (0–30 cm) among the regions was lower for older greenhouses compared to younger ones.

Fig. 1 showed that there was a close correlation between soil available P contents measured by CAL and Olsen methods. Soil P content measured by CAL extraction was approximately 3–4 times higher than that by Olsen extraction.

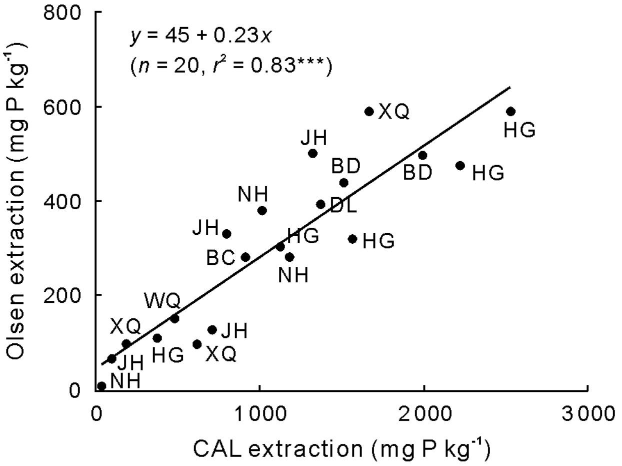

Fig. 1 Correlations between soil available P contents determined by calcium acetate lactate (CAL) and Olsen extractions in some districts of Tianjin Municipality, including Beichen (BC), Baodi (BD), Dongli (DL), Hangu (HG), Jinghai, (JH) Ninghe (NH), Wuqin (WQ) and Xiqin (XQ).

Soil available K

Similar to CAL-P content in the soils, the accumulation of K was almost always higher under greenhouse conditions than in open fields (Table V). In the open fields, CAL-K content was between 60 and 230 mg K kg^{-1}, while it ranged between 50 and 330 mg K kg^{-1} in greenhouses. In contrast to CAL-P content in the soils, CAL-K content was not significantly related to the differences in greenhouse age. The data showed that there were greater variations in CAL-K content among the different regions under the open field and greenhouse conditions (Table V).

TABLE V

Soil K contents (0–30 cm), extracted with the calcium acetate lactate, at different ages of greenhouses and in open fields of nine districts of Tianjin Municipality

District	Open fields	Greenhouses			
		1–3 years	4–9 years	10–20 years	$>$ 20 years
			mg K ha^{-1}		
Beichen	109±26[a]b[b]	181±42b	-	317±41a	180±27b
Baodi	72±10b	157±36b	322±54a	320±78a	-
Dongli	107±27b	331±26a	-	47±3b	88±12b
Hangu	238±64a	254±0a	314±37a	330±53a	306±54a
Jinghai	148±40b	323±36a	301±37ab	121±26b	190±38b
Jixian	58±29b	267±57a	275±18a	252±51a	104±16b
Ninghe	184±45a	222±32a	254±67a	310±83a	-
Wuqin	90±31a	261±146a	119±22a	196±44a	161±16a
Xiqin	76±22a	180±48a	183±35a	144±34a	-

[a] Means±standard errors ($n = 2$–6).

[b] Means followed by the same letter(s) within each row are not significantly different at $P \leq 0.05$ by Duncan's multiple range test.

Soil pH and ECe

Table VI showed that the pH values of the soils were between 6.6 and 7.7. There were only limited differences among the different ages of greenhouses and open fields with the maximum range of 0.5 pH units (one case 0.7). Soil pH values slightly decreased with the greenhouse age. Significant differences in pH between greenhouse ages were observed in seven of the nine districts.

In contrast to soil pH, there were greater variations among the ECe values (Table VII) ranging between 9.9 and 1.9 dS m^{-1}. For most regions, there was no significant difference in ECe when comparing the greenhouses of different ages. Compared with open field conditions, the ECe was slightly higher under greenhouse conditions and was closely correlated to the soil NO_3^--N content ($r^2 = 0.69^{**}$). The contribution of NO_3^- accumulation in the soil to the ECe varied with the location and age of greenhouses and ranged from 0.3 to 3 dS m^{-1}, which was approximately 10%–40% of total ECe (Table VIII).

DISCUSSION

This study demonstrated that the residual soil NO_3^--N after harvest was approximately 500–1 230 kg N ha^{-1} at 0–90 cm soil depths for the vegetable crops cultivated in greenhouses in Tianjin (Table III). The result is in agreement with a study showing approximately 1 173 kg N ha^{-1} at the same soil depth for greenhouse vegetable crops in Shandong of the NCP (Ju *et al.*, 2006). High soil NO_3^--N accumulation is due to high annual N inputs from mineral fertilizers, manures and irrigation water. Several reports have shown annual application of N to greenhouse vegetable crops has reached more than 1 000 kg N ha^{-1}, leading to an N recovery efficiency as low as 10% of the applied N fertilizer and an N surplus of $>$ 500 kg N ha^{-1} (Chen *et al.*, 2004; Zhu *et al.*, 2005; Ju *et al.*, 2006, 2007, 2009). In addition, the average values of soil NO_3^--N

TABLE VI

Soil pH (1:2.5 soil to 0.01 mol L^{-1} $CaCl_2$) at different ages of greenhouses and in open fields of nine districts of Tianjin Municipality

District	Open fields	Greenhouses			
		1–3 years	4–9 years	10–20 years	$>$ 20 years
Beichen	7.5±0.1[a]a[b]	7.6±0a	-	7.0±0.1b	6.9±0.1b
Baodi	7.4±0.1a	7.2±0.1ab	7.0±0.1b	7.0±0.1b	-
Dongli	7.6±0.1ab	7.7±0a	-	7.7±0.1a	7.4±0.1b
Hangu	7.4±0.1a	7.4±0a	7.0±0.1b	7.2±0.2ab	7.3±0.1ab
Jinghai	7.5±0a	7.5±0a	7.5±0.1a	7.1±0.2b	7.2±0.1b
Jixian	7.0±0.3a	7.1±0.1a	7.0±0.1a	7.0±0.2a	6.6±0.1a
Ninghe	7.4±0.1a	7.2±0b	7.2±0.1b	7.2±0.1b	-
Wuqin	7.6±0.1a	7.5±0a	7.2±0.1b	7.1±0.1b	7.0±0.1b
Xiqin	7.6±0.1ab	7.7±0a	7.3±0.1b	7.3±0.1b	-

[a] Means±standard errors ($n = 2$–6).

[b] Means followed by the same letter(s) within each row are not significantly different at $P \leq 0.05$ by Duncan's multiple range test.

TABLE VII

Electrical conductivity (EC) measured in a 1:1 soil-to-water extract and converted to EC of a saturation paste extract (ECe) at different ages of greenhouses and in open fields of nine districts of Tianjin Municipality

District	Open fields	Greenhouses			
		1–3 years	4–9 years	10–20 years	> 20 years
	dS m^{-1}				
Beichen	6.0±1.9[a]a[b]	3.6±0.5a	-	5.2±0.6a	5.5±0.8a
Baodi	2.2±0.6b	4.7±1.1a	4.9±1.0a	5.9±0.4a	-
Dongli	3.4±0.4b	9.9±2.5a	-	2.8±1.0b	3.8±0.4b
Hangu	5.7±3.2a	4.3±0.0a	3.4±0.2a	2.9±0.4a	3.8±0.3a
Jinghai	3.0±0.6b	2.9±0.6b	6.0±0.7a	3.5±0.4b	3.5±0.3b
Jixian	2.1±1.2a	2.2±0.4a	1.1±0.2a	3.6±1.0a	3.8±1.0a
Ninghe	2.1±0.3b	2.8±0.8b	2.0±0.3b	6.3±1.4a	-
Wuqin	1.9±0.3b	7.2±2.0a	3.2±0.7b	2.4±0.5b	2.4±1.1b
Xiqin	2.3±0.7b	6.3±0.5a	4.3±0.6b	3.9±0.6b	-

[a] Means±standard errors ($n = 2$–6).

[b] Means followed by the same letter(s) within each row are not significantly different at $P \leq 0.05$ by Duncan's multiple range test.

TABLE VIII

Contributions of NO_3^- accumulation in soil to electrical conductivity of a saturation paste extract (ECe) at different ages of greenhouses and in open fields of nine districts of Tianjin Municipality

District	Open fields		Greenhouses							
	Content	Percent	1–3 years		4–9 years		10–20 years		> 20 years	
			Content	Percent	Content	Percent	Content	Percent	Content	Percent
	dS m^{-1}	%	dS m^{-1}	%	dS m^{-1}	%	dS m^{-1}	%	dS m^{-1}	%
Beichen	0.5	9.0	0.5	13.2	-	-	1.7	30.2	2.1	33.9
Baodi	0.5	24.9	1.3	24.6	1.9	36.2	1.9	30.7	-	-
Dongli	0.4	11.1	3.0	26.8	-	-	0.4	12.6	0.5	10.9
Hangu	0.6	13.6	1.0	21.8	0.6	16.6	0.5	17.0	0.7	16.4
Jinghai	0.5	14.9	0.9	25.0	0.6	9.0	0.8	18.7	0.7	17.5
Jixian	0.3	14.9	0.8	29.5	0.4	24.8	1.5	33.7	1.7	39.5
Ninghe	0.5	20.7	0.7	19.5	0.4	17.1	1.6	22.7	-	-
Wuqin	0.5	23.0	2.3	29.0	0.8	28.2	0.6	27.2	0.5	26.9
Xiqin	0.3	11.7	0.7	9.7	1.2	25.1	1.1	26.1	-	-

contents from open fields and greenhouses varied with region (Table II), indicating that soil NO_3^--N accumulations may be influenced by the cultivations of crops and the personal management practices of individual farmers. Consequently, high proportions of unused nitrogen are lost to the environment by NO_3^- leaching, denitrification and NH_3 volatilization (Cabrera and Chiang, 1994; Fox *et al.*, 1996; Ramos *et al.*, 2002; He *et al.*, 2007). The excessive nutrient application represents not only an economic loss for vegetable growers but also poses an environmental problem. Furthermore, it is known that high NO_3^--N accumulation in soil also results in salinization problems. Our results suggest that higher EC values under greenhouse conditions were closely correlated with the soil NO_3^--N content, contributing to 10%–40% of ECe, which has been shown in other studies as well (Shi, W. M. *et al.*, 2009; Shi, Y. C. *et al.*, 2009). In contrast to the studies showing an increase in soil NO_3^--N accumulation with increasing greenhouse age (Chen *et al.*, 2004), our results in Table II did not show a tendency of increasing soil NO_3^--N with greenhouse age in the Tianjin region. However, the results of our study clearly demonstrated that high NO_3^--N also accumulated in the lower layer of soil, indicating a high potential for NO_3^- leaching.

Furthermore, the excessive N application in greenhouses causes high NO_3^- concentrations in leafy vegetables, which may be harmful to human health. Numerous studies have shown that high NO_3^- contents in soils stimulate plants, especially vegetables, to absorb and accumulate excessive NO_3^- (Petrovic *et al.*, 1992; Santamaria *et al.*, 1998). Humans consume the soft green parts of leaves and stems, which are the plant parts that accumulate large amounts of NO_3^- (Walker, 1990). Nitrate accumulation in plants has been regarded as harmful to the human body, and this has been of great concern to scientists and consumers (Rockman and Granli, 1991; Powlson *et al.*, 2008).

In other studies, plant available P (Olsen-P) in soils was significantly higher in greenhouses (an average of 83.5 mg kg^{-1}) than that in cereal crop fields (12.5–636 mg kg^{-1}) (Xie and Tan, 2001). According to Sun *et al.* (2009), the optimum level of soil Olsen-P content under Chinese condition is 10–30 mg kg^{-1}, and > 50 mg kg^{-1} is high. A large number of reports have shown that longer periods of greenhouse cropping cause soil available P enrichment in Chinese greenhouses (Chen *et al.*, 2004; Yang *et al.*, 2011), which is confirmed by our study (Table IV). However, high soil P accumulation under current greenhouse vegetable cultivation may suggest that there is a need to develop technologies and strategies for optimal nutrient management in greenhouse vegetables. In agricultural areas with intensive farming practices, excessive application of P has led to an increased incidence of soils with high P concentrations, increasing the risk of P surface runoff by erosion and P losses during drainage (Stanley *et al.*, 1995). Studies at the Rothamsted Research Station in SE England have shown a marked increase in P concentration in drainage water to more than 2 mg L^{-1} as soon as soil Olsen-P exceeded 60 mg kg^{-1} (Heckrath *et al.*, 1995), while Olsen-P in the greenhouse vegetable soils in the NCP reached 160 mg P kg^{-1} (Chen *et al.*, 2004). The questionnaire survey showed that the reason for this may be that farmers excessively applied organic manure, P and compound fertilizers to obtain higher yields.

Although available P, as shown in Table IV, was extracted by CAL method, which was approximately 3–4 times higher than that by the Olsen extraction, there was a close relationship of available P content in Chinese soils between the two methods (Fig. 1). A similar relationship between CAL-P and Olsen-P was derived from a study of Chinese paddy soils (Hu *et al.*, 2003). Accordingly, Neyroud and Lischer (2003) concluded that there was a close relationship between soil P contents extracted by CAL and Olsen in a comparison of different methods of measuring soil P availability in European soils. The CAL method is commonly used for fertilizer recommendation in Germany. According to Kerschberger *et al.* (1997), 45–90 mg P kg^{-1} soil is the optimal level for all soil types in Germany. However, the data in Table IV showed that soil CAL-P contents in most of the greenhouses were greater than 300 mg P kg^{-1}. Excessive nutrient application is an economic loss for vegetable growers and may also result in greater pest management problems (Neeteson *et al.*, 1999). In addition, the excessive available P in soils may even induce micronutrient deficiency (e.g., Zn deficiency).

Our study found that soil K content (Table V) was generally in the optimal range and was not affected by the age of the greenhouses but varied with region. A slight decrease in soil pH with age of greenhouses was found here (Table VI). This result contrasts with the findings of a soil survey in Beijing from 1996 to 2000 by Chen *et al.* (2004) and other studies in greenhouses in the NCP (Ju *et al.*, 2006, 2007; Yang *et al.*, 2011), who found that soil K content increased and soil pH decreased with the increasing age of greenhouses. The findings from this study indicate to greenhouse vegetable growers that soil EC in greenhouses may result in severe salinity stress to most vegetable crops. According to Tanji and Kielen (2002), ECe levels between 2 and 4 dS m^{-1} may affect the yields of sensitive and moderately sensitive crops, while the yields of many crops were restricted by ECe between 4 and 8 dS m^{-1}. Only tolerant crops can cope with an ECe above 8 dS m^{-1}. The frequency analysis of the data in Table VII showed that, among the 40 means of ECe, 70% of the investigated soils had an ECe between 2–4 dS m^{-1} and 30% between 4–10 dS m^{-1}. These results indicate that the yields of most crops under greenhouse conditions will be affected by salinity. Among the vegetable crops in the investigated areas, green bean and carrot are most sensitive to salinity, while Chinese cabbage, celery, cucumber, eggplant, lettuce, pepper, spinach and tomato are moderately sensitive to salinity (Shannon and Grieve, 1999; Tanji and Kielen, 2002). Salt tolerance can be adequately measured on the basis of two parameters: the threshold ECe, *i.e.*, the electrical conductivity that is expected to cause the initial significant reduction in the maximum expected yield, and the slope. The slope is simply the percentage of yield expected to be reduced for each unit of added salinity above the threshold value (Shannon and Grieve, 1999). The threshold of green bean and carrot is as low as at 1.0 dS m^{-1} (ECe) and thereafter, the yield was reduced by about 14%–19% per dS m^{-1}. For the moderately sensitive vegetables, the threshold ranges between 2 and 4 dS m^{-1} (ECe). Thereafter, their yields were reduced by about 6%–14% per dS m^{-1} (Shannon and Grieve, 1999).

Our findings on soil fertility and salinity in greenhouses in the NCP are similar to the reports from several years ago, which indicates that the progress to optimize or implement nutrient management in greenhouse vegetables is still slow in the investigated areas. Thus, we conclude that there is an urgent need to improve the farmers' current practices in fertilization management in greenhouses of China. Miao *et al.* (2011) summarized that possible reasons for the overuse of fertilizer in China are the following: i) high yield goal with high nutrient inputs; ii) small-scale farming; iii) farmers with a low education compared with other professions; and iv) the lack of well-established independent agricultural technical extension services. Among the above mentioned factors, we think that education and the agricultural technical extension services may play a more important role in overuse of fertilizers. Though more advanced fertilization management technologies are already available in China, they are not yet applied on farms.

Our questionnaire survey showed that most of the farmers in Tianjin region were approximately 40–50 years old with elementary and junior high school degrees. Most of them do not have any knowledge about nutrient balance. Thus, enhancing agricultural services to support fertilizer efficiency improvements will pose a great challenge for China. China's agricultural sector is very large, diverse, decentralized and disorganized, with limited extension support and little regulation. China's agricultural extension system has historically been an arm of the central government policy and it did never have an explicit environmental mandate. Thus, extension services need to improve their capacity to identify local environmental problems and to design local solutions, particularly through stronger linkages with research institutes. Currently, extension agents lack the initiative to provide technical guidance to farmers (especially on reducing the amount of fertilizers used) due to lack of updated knowledge, budgetary constraints and, increasingly, pressure to sell fertilizers and other agricultural inputs to make ends meet (Zhou *et al.*, 2010).

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