Spatial Variability and Site-Specific Nutrient Management in a Vegetable Production Area

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Soil nutrients showed similar spatial distribution patterns across the study site in Hebei Province and were correlated with vegetable production history and fertilizer application rates. Vegetable crop type and history of fertilizer use were important factors in the development of a regional nutrient management program.

A long-term reliance on high rates of N and P fertilizer along with a poor understanding of soil nutrient variability within fields can seriously affect vegetable yield and quality, economic income, and environmental quality in China. During the last 10 years, data obtained from GPS/GIS and geo-statistics has played an important role in the study of soil nutrient spatial variability and SSNM (Jin, 1998). Recent examples of this type of research exist for grain production systems within China (Huang et al., 2003; Huang et al., 2004).

However, spatial variability in China's vegetable fields and corresponding management approaches have not been studied systematically. China's vegetable production system is more intensive and farmers generally use higher rates of fertilizer compared to grains. The objective of this study was to analyze the spatial variability of soil nutrients as a basis for SSNM strategies for high quality and high yield vegetable production.

The study was located in the northwestern vegetable production area of Taizhang Village, Hongqiao Town, Yutian County. The soil at the site is classified as Fluvo-aquic—a floodplain soil. The most limiting soil nutrients included N, K, and Zn (**Table 1**). Only 5% of the soils had P contents below the critical value, but emphasis on P fertility was still recommended due to high crop P requirements and the need to maintain high soil P fertility. The local climate was semiarid monsoon, with an average annual rainfall of 693 mm, average annual temperature of 11 °C, and a frost-free period of about 190 days annually. In recent years, cabbage has generally been grown as the first crop in this area from March to May, with many other kinds of vegetables being grown as the second crop each year. The most common rotation systems included cabbage/welsh onion, cabbage/Chinese cabbage, cabbage/Chinese celery, and cabbage/leaf mustard.

The study area consisted of 182 farmer plots belonging to six production groups. These are denoted further in this report as Groups 1, 2, 3, 4, 7, and 8, respectively (**Figure 1**). Groups 1, 2, 3, 4, 7, and 8 consisted of 29, 35, 27, 31, 37, and 23 farmer plots, respectively. A total of 217 soil samples were collected on a 50 m × 50 m grid at depths of 0 to 20 cm prior to the plots being sown for cabbage. Vegetable production history was surveyed at each sampling site, including crop types sown, rotation systems, and fertilizer use. Soil pH, OM, and available P, K, Cu, Fe, Mn, Zn, Ca, Mg, S, and B were analyzed according to the Agro Services International (ASI) soil test procedure (PPIC Beijing Office, 1992). Soil NO_3^--N and particle size were also measured (Huang et al., 2004). Cabbage response to site-specific balanced fertilization under different soil fertilizer levels was determined. Descriptive statistics and geo-statistics were used to analyze the data.

Results showed significant similarity in the spatial distribution of soil NO_3^--N, P, K, and Zn in the study area (**Figure 2**). Correlation coefficients between soil NO_3^--N content and soil P, K, and Zn contents were 0.47, 0.46, and 0.24 ($p<0.01$), respectively. Correlation coefficients between soil P and soil K and Zn contents were 0.76 and 0.52 ($p<0.01$), respectively. The correlation coefficient between soil K content and soil Zn content was 0.49 ($p<0.01$).

Significant differences in soil fertility existed between production groups (**Table 2**).

Table 1. Soil OM, available nutrient, sand, and clay contents, and pH in the vegetable production area.

Item	Minimum	Maximum value	Mean	Standard deviation	C.V., %	Critical value	Soil samples below critical value, %
pH	5.1	7.9	6.7	0.64	10		
OM, %	1.0	2.3	1.8	0.2	10	1.5	2
NO_3^--N, mg/L	20	156	63	28	44	60	53
P, mg/L	4	94	35	16	47	12	5
K, mg/L	44	147	75	20	27	80	67
Zn, mg/L	0.6	3.9	1.43	0.43	30	2	93
Mn, mg/L	3	71	18	12	70	5	8
Fe, mg/L	3	65	16	11	69	10	36
Cu, mg/L	1.0	3.3	1.86	0.42	23	1	0
S, mg/L	7	75	36	13	37	12	4
Ca, mg/L	2,796	5,753	4,429	499	11	401	0
Mg, mg/L	393	934	721	109	15	122	0
B, mg/L	0.3	8.0	2.35	1.35	57	0.2	0
Sand, %							
0.02-2 mm	24	35	28	2	6		
Clay, %							
<0.002 mm	23	35	28	2	8		

217 sampling sites were evaluated

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium; Zn = zinc; Cu = copper; Fe = iron; Mn = manganese; B = boron; NO_3^--N = nitrate-N; NH_4^+ = ammonium; GPS = global positioning system; GIS = geographic information system; OM = organic matter; SSNM = site-specific nutrient management; CV = coefficient of variation; FP = farm practice.

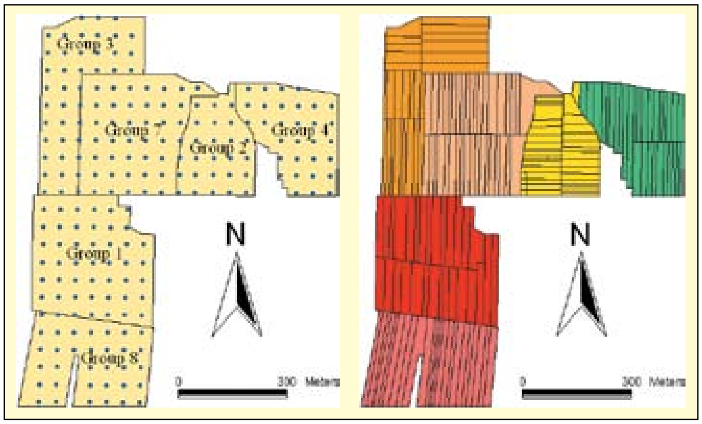

Figure 1. Diagram of sampling sites within production groups (left) and farmers' plots (right) in the vegetable production study area.

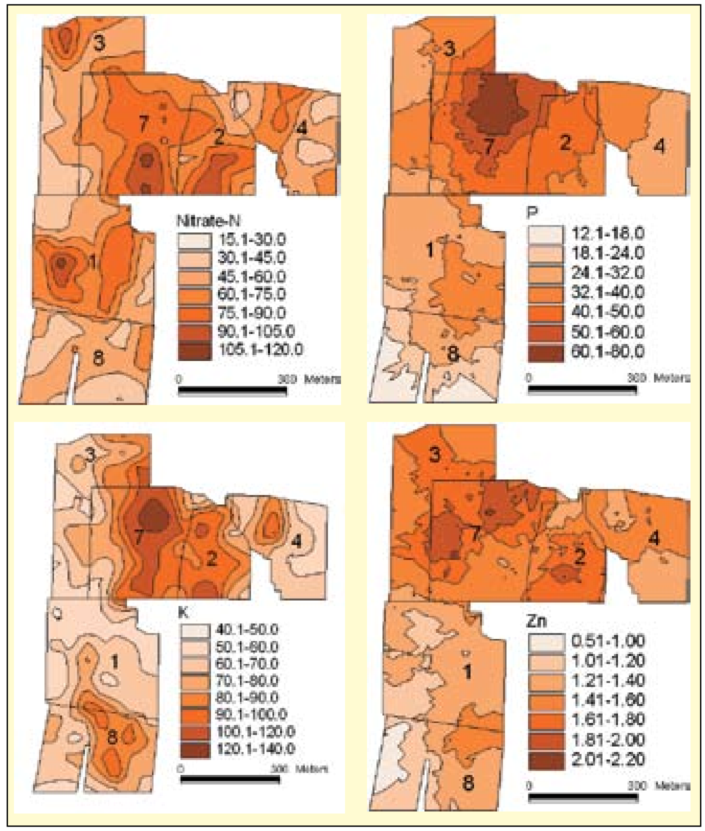

Figure 2. Overlay between the map of the production groups and the contour map of soil-available nutrients (mg/L) in this study area (1, 2, 3, 4, 7, and 8 indicate the respective production group). The boundary for each group can be seen from Figure 1.

Soil NO_3^--N, P, K, and Zn within Groups 2 and 7 were significantly higher than in Group 8. Nutrient levels within most areas of Groups 1, 3, and 4 were also lower compared to Groups 2 and 7. Our farm surveys indicated that a close relationship existed between the spatial variability of soil nutrients and the vegetable production history and fertilizer application. Statistical analysis found a close, positive correlation for soil NO_3^--N, P, and K contents and N, P_2O_5, and K_2O fertilizer application rates, with the corresponding correlation coefficients as high as 0.50, 0.47, and 0.45 ($p<0.01$), respectively. Nitrogen application rate was negatively correlated with soil pH ($r = -0.31$, $p<0.01$). The hydrolysis of applied N forms, such as urea, produces NH_4^+ which is subject to nitrification and the release of hydrogen ions (H^+) (Fisk and Schmidt, 1996). Thus the lower pH for Groups 2 and 7 compared to Group 8 is one other characteristic developed from longer vegetable production history and higher and larger N fertilizer applications. A decline in soil pH can also increase soil Zn availability, a relationship which is supported by the map and statistical data for this study area.

The higher contents of soil NO_3^--N, P, and K for Groups 2 and 7 compared to Group 8 corresponded with longer vegetable production histories and higher and more frequent fertilizer applications (**Table 3**). Groups 2 and 7 had grown vegetables for 18 to 19 years, while vegetables had been grown for only 7 years within Group 8. Prior to this time, wheat and corn were the main crops, with relatively smaller annual application rates (Huang et al., 2002). Higher soil fertility for plots within Groups 2 and 7 versus Groups 1, 3, and 4 is most likely a result of higher planting frequencies for welsh onion or Chinese celery as second crops after the primary cabbage crop. Welsh onion and Chinese celery both require higher nutrient inputs than other vegetables grown in the region (**Table 4**).

Fertilizer use, soil nutrient status, vegetable production history, vegetable variety, and soil texture were found to be important factors in establishing a regionalized system for managing soil nutrients. Of these, the first three in the list showed

Table 2. Average soil OM, available nutrient, sand, and clay contents, and soil pH in the six production groups of the vegetable production area.

Item	Group 1 N = 45	Group 2 N = 25	Group 3 N = 42	Group 4 N = 31	Group 7 N = 40	Group 8 N = 34
pH	6.9±0.3 d	6.6±0.4 c	6.3±0.5 b	6.4±0.4 bc	6.1±0.4 a	7.6±0.2 e
OM, %	2.0±0.1 c	1.7±0.2 a	1.8±0.2 b	1.6±0.1 a	1.8±0.1 b	2.0±0.2 c
NO_3-N, mg/L	66±31 bc	72±28 cd	55±24 a	56±24 ab	80±24 d	45±19 a
P, mg/L	30±9 b	42±15 c	33±12 b	31±10 b	52±17 d	20±12 a
K, mg/L	63±13 a	92±16 c	69±15 ab	67±15 ab	93±23 c	74±15 b
Zn, mg/L	1.2±0.3 ab	1.6±0.4 d	1.5±0.4 cd	1.4±0.4 bc	1.6±0.5 d	1.2±0.3 a
Mn, mg/L	14±7 b	18±9 bc	22±12 cd	20±10 c	26±16 d	5±2 a
Fe, mg/L	11±3 b	14±8 b	20±9 c	19±9 c	25±14 d	5±3 a
S, mg/L	37±13 b	40±13 bc	26±13 a	44±11 c	38±7 b	35±15 b
Sand, % 0.02-2 mm	27.1±1.4 a	28.3±2.0 b	27.1±1.2 a	28.8±1.2 b	27.2±1.6 a	27.3±1.5 a
Clay, % <0.002 mm	28.3±1.6 de	27.0±2.0 bc	28.6±2.0 e	25.7±1.1 a	27.6±1.9 cd	26.7±2.9 ab

* Means with the same letter are not significantly different at $p<0.05$ (lower case letter). ± = standard deviation.

significant differences between production groups. However, no obvious differences in vegetable production history, first and second vegetable crop selection, fertilizer use, soil nutrient status, and soil texture were found within production groups. Thus, it was technically feasible to develop SSNM strategies for balanced N, P, K, and Zn application at the production group-scale.

SSNM techniques for high-yield and high-quality vegetable production were developed based on GIS maps and a computerized fertilizer recommendation system (IPNI China Program, 2007). Fertilizer recommendations for a production group or farmer's plot were accomplished via information transmission, long-distance diagnosis, and online consultation. A nutrient fertility class for each production group or each farmer's plot could be obtained by overlaying the contour map of soil nutrients with either the map of the production groups (**Figure 1**, left) or farmer plots (**Figure 1**, right) in the GIS. If soil nutrient contents in most areas of a production group or plot were within one evaluation class, soil nutrient contents for all areas of that group or plot were considered to fall within that one evaluation class. A fertilizer recommendation was made according to production group or plot, and variable fertilization was performed by farmers through hand application. SSNM treatments applied significantly less N and P than FP, and utilized Zn which was omitted under FP.

Table 3. Vegetable production history and average fertilizer application rates for the period 2000-2002 for each production group of the vegetable production area.

Production group	Number of plots surveyed	Production history in years	Fertilizer application rate, kg/ha/year					
			Chemical fertilizer			Organic manure		
			N	P_2O_5	K_2O	N	P_2O_5	K_2O
Group 1	29	15.5±0.7	957 ±217	275 ±90	276 ±90	16 ±30	12 ±23	11 ±21
Group 2	35	18.6±1.0	1019 ±220	358 ±88	358 ±87	0.0 ±0.0	0.0 ±0.0	0.0 ±0.0
Group 3	27	16.0±1.1	946 ±190	288 ±87	288 ±87	26 ±74	19 ±56	21 ±62
Group 4	31	17.6±0.5	909 ±220	345 ±146	309 ±93	4 ±24	3 ±18	4 ±20
Group 7	37	19.4±0.9	1124 ±228	420 ±95	420 ±95	14 ±41	10 ±31	11 ±34
Group 8	23	7.1±1.3	813 ±218	267 ±93	315 ±112	21 ±38	16 ±28	16 ±31

* Correlation coefficients between soil NO_3^--N, P, and K contents and total application rates of N, P_2O_5, and K_2O in chemical fertilizer and organic manure were 0.50, 0.47, and 0.45 ($p<0.01$, $n = 217$), respectively. ± = standard deviation.

Table 4. Average fertilizer input in main vegetables for the period 2000-2002.

Vegetable varieties	Number of plots surveyed	Average fertilizer application rate, kg/ha/year		
		N	P_2O_5	K_2O
Cabbage	182	412±74	123±33	123±34
Welsh onion	64	640±210	244±92	238±81
Chinese cabbage	41	318±122	74±52	74±52
Chinese celery	41	688±219	214±147	222±154
Leaf mustard	36	210±93	52±16	52±16

Cabbage was grown as the first crop in this study area consisting of 182 farmer plots. Other kinds of vegetables were grown as the second crop each year.
± = standard deviation.

Table 5. Response of site-specific balanced fertilization in cabbage in 2004.

Fertility category	Treatment	Yield (fresh weight), t/ha	Yield increase, %	Fertilizer input, RMB yuan/ha	Fertilizer input decrease, %	Income, RMB yuan/ha	Income increase, %
Relatively high soil fertility	Farm practice $N_{365.7}P_{135.0}K_{135.0}Zn_{0.0}$	64±2.7	–	2,052	–	18,412	–
	Balanced fertilization $N_{300.0}P_{45.0}K_{105.0}Zn_{30.0}$	69.7±1.5	9.0±2.4	1,485	27.6	20,827	13.1
Medium soil fertility	Farm practice $N_{465.0}P_{157.7}K_{148.4}Zn_{0.0}$	68.4±1.6	–	2,493	–	19,406	–
	Balanced fertilization $N_{330.0}P_{75.0}K_{135.0}Zn_{30.0}$	77.3±2.5	13.0±3.3	1,780	28.6	22,969	18.4
Relatively low soil fertility	Farm practice $N_{473.8}P_{157.6}K_{158.0}Zn_{0.0}$	64.1±2.7	–	2,545	–	17,958	–
	Balanced fertilization $N_{375.0}P_{105.0}K_{165.0}Zn_{30.0}$	74.2±3.0	16.0±2.0	2,122	16.6	21,654	20.6

N, P, K, and Zn, respectively denote N, P_2O_5, K_2O, and $ZnSO_4 \cdot 7H_2O$, with subscript numbers being application rate of nutrient or fertilizer (kg/ha). Price of N, P_2O_5, K_2O, $ZnSO_4 \cdot 7H_2O$, and cabbage is 3.15, 4.17, 2.50, 3.00, and 0.32 RMB Yuan/kg, respectively. ± = standard deviation. 1 US$ = 7.7 RMB.

Yield, profitability, and N recovery rate data for FP and SSNM are compared within the high, medium, and low soil fertility plots in **Table 5** and **Table 6**. SSNM increased cabbage yield by 9, 13, and 16% within high, medium, and low fertility plots, respectively. SSNM also lowered fertilizer input costs by 27.6, 28.6, and 16.6% (high, medium, and low), and improved income per hectare by 13.1, 18.4, and 20.6% (high, medium, and low).

Plant N uptake was enhanced under SSNM at all three soil fertility classifications. SSNM employed lower N application rates, and the contribution from other soil N pools was relatively equal between plots receiving SSNM and FP. Thus, significant improvements in N recovery rate, ranging between 9.8 to 11 percentage points, were achieved across soil fertility classifications. BC

Table 6. Recovery rate of the applied N for site-specific balanced fertilization in cabbage in 2004.

Fertility category	Treatment	N uptake, kg/ha	N contribution from soil, kg/ha	Recovery rate for applied N, %
Relatively high soil fertility	Farm practice $N_{365.7}P_{135.0}K_{135.0}Zn_{0.0}$	129±6	100±4	7.9±0.9
	Balanced fertilization $N_{300.0}P_{45.0}K_{105.0}Zn_{30.0}$	149±3	95±4	18.0±2.2
Medium soil fertility	Farm practice $N_{465.0}P_{157.7}K_{148.4}Zn_{0.0}$	139±3	114±4	5.4±1.2
	Balanced fertilization $N_{330.0}P_{75.0}K_{135.0}Zn_{30.0}$	155±5	101±4	16.4±2.0
Relatively low soil fertility	Farm practice $N_{473.8}P_{157.6}K_{158.0}Zn_{0.0}$	140±6	107±4	7.0±1.8
	Balanced fertilization $N_{375.0}P_{105.0}K_{165.0}Zn_{30.0}$	170±7	107±4	16.8±3.0

The contributed N from soil denotes plant N uptake from no N treatment (FP - N for FP, BF - N for BF).
± = standard deviation.

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InfoAg 2007 Set for July 10-12 in Springfield, Illinois

The popular national/international version of the Information Agriculture Conference, InfoAg 2007, is scheduled for July 10, 11, and 12. The location is the Crowne Plaza in Springfield, Illinois, the same as for InfoAg 2005.

InfoAg 2007 is organized by the Foundation for Agronomic Research (FAR) in cooperation with IPNI. CropLife Media Group is also a partner in the Information Agriculture Conference, particularly with managing the exhibit area.

"The Information Agriculture Conference has come a long way since the first conference in 1995," notes FAR President Dr. Harold Reetz, of Monticello, Illinois. "Many of the precision ag technologies that were considered to be in early development stages then are becoming generally adopted by farmers, dealers, and industry today."

Opportunities and effects of shifting corn production to meet the grain and biomass ethanol market demands is a hot topic in agricultural circles today, and will be part of the discussion at InfoAg 2007. The detailed records and natural resource (soil, water, etc.) inventories that are part of farm databases, and the other technologies of precision ag might be useful in decisions on shifting crop acreage. Many farmers and their advisers are also dealing with questions regarding how to manage continuous corn, or how to manage corn where they have not grown it before.

Another important question regards the issues of productivity: "How can we use these technologies to increase corn yields on our best fields and thus reduce the need to convert acreage from other crops, or from CRP?" That is the longer-term solution that will be addressed.

Conservation of natural resources will also be a major theme at InfoAg 2007. The Natural Resources Conservation Service (NRCS) will bring a large soil survey exhibit that was originally prepared for the 2006 World Congress of Soil Science in Philadelphia. The program will also feature a series of USDA-NRCS Conservation Innovation Grant projects that FAR and IPNI are coordinating to develop fertilizer best management practices guides for six major cropping systems.

A pre-conference tour and demonstration program will again be a feature of InfoAg 2007. Potential attendees and exhibitors for the Information Agriculture Conference are encouraged to plan ahead now in making arrangements. For more information about InfoAg 2007, please visit the website: **>www.infoag.org<**, or contact Dr. Harold Reetz: phone 217-762-2074, e-mail: hreetz@farmresearch.org. BC