Spatial Variability and SSNM of Spring Wheat Production under Collective Contract Cropping

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Spatial variability of soil fertility (soil OM and available P, K, S, and Zn) and water in different parts of the study area were main factors influencing spatial variability of grain yield. Site-specific nutrient management (SSNM) treatments applied significantly more N and less P for relatively high soil fertility plots, and more N and K for low soil fertility plots than with collective contract cropping practice. SSNM for NPK increased yields by 8 to 19% and improved income by 455 to 520 RMB Yuan/ha.

Unbalanced fertilization along with a poor understanding of soil nutrient variability within fields can seriously affect crop yield and quality, economic returns, and environmental quality in China. During the last 10 years, data obtained from GPS/GIS technology and geo-statistics has played an important role in SSNM and the study of soil nutrient spatial variability (Jin, 1998). Recent examples of this type of research exist for traditional, smaller-scale family-operated crop production systems within China (Huang et al., 2003; Huang et al., 2006). However, spatial variability in China's collective contract crop production system and its corresponding management approaches have not been studied systematically.

China's collective contract crop production system generally uses the same amount of fertilizer for the same crop grown over several hectares to several hundred hectares, irrespective of the soil nutrient variability within these fields. This practice undoubtedly results in some areas of the field receiving too much fertilizer, whereas other areas receive too little. In this research, Keshan Farm of the northeastern China province of Heilongjiang was selected as an experimental area to analyze the spatial variability of soil nutrients as a basis for SSNM strategies for high quality and high yield spring wheat production as compared to the established collective contract system.

Table 1. Soil OM (%), available nutrient contents (mg/L), and pH in study area.

Item	Minimum value	Maximum value	Mean	Standard deviation	C.V., %	Soil samples below critical value, %
pH	5.3	6.4	5.7	0.2	2.7	-
OM	3.9	7.5	6.0	0.7	11.7	-
NH_4^+-N + NO_3^--N	17	90	34	10.6	30.9	100
P	9	23	14	2.9	21.3	32
K	64	143	84	13.3	15.9	38
S	5	44	11	8.4	73.7	75
Zn	0.7	2.5	1.4	0.3	25.1	94
Ca	2,600	4,915	4,373	296.9	6.8	0
Mg	345	903	791	73.8	9.3	0
Fe	47	121	85	13.5	15.9	0
Cu	1	3	2	0.3	15.7	0
Mn	16	47	24	5.9	24.3	0
B	0.1	2	0.7	0.3	46.7	2

Critical values of soil nutrient fertility evaluation were 110 for NH_4 + NO_3, 12 for P, 80 for K, 2 for Zn, 5 for Mn, 10 for Fe, 12 for S, 401 for Ca, 122 for Mg, 1 for Cu, and 0.2 for B (44 sampling sites).

The spring wheat production field under study was a black soil (Phaeozem) site of 156 ha, with an east longitude of 125°50´5˝ to 125°50´48˝ and north latitude of 48°18´16˝ to 48°19´15˝. The region has a cold, temperate continental climate, with average annual rainfall of 500 mm, average annual temperature of 1.9° C (ranging between -30 and 30 °C) and a frost-free period of about 120 days annually. The region's main crops are spring wheat and soybean.

A total of 44 soil samples were collected on a 200 m x 200 m grid from 0 to 20 cm depth prior to the plots being sown for spring wheat in the study area **(Figure 1)**. Each sample was a composite of 10 sub-samples (7 cm core size) taken within a 5 m radius of the grid point. 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 was measured by spectrophotometer (Huang et al., 2004). Soil water was determined gravimetrically. Results showed that the major soil nutrient limiting factors identified were N, P, K, S, and Zn, with the percentage of soil samples below the critical value being 100, 32, 38, 75, and 94 in the experimental area, respectively **(Table 1)**. Significant differences in variations of different soil nutrients were observed, with larger values for NO_3^--N and available S (C.V. 49.9% to 73.7%), lower values for P, K, and Zn (C.V. 15.9% to 25.1%), and relatively smaller values for pH and OM (C.V. 2.7% to 11.7%).

A patchy distribution of soil OM and available nutrient contents was generally observed, and contents of available soil P, K, S, and Zn in most areas were within one evaluation class **(Figure 1)**. Soil OM contents were negatively correlated with the altitude in this study area (r = -0.50), with relatively higher contents of soil OM being generally in lower altitude areas, and vice versa. Soil NO_3^--N contents were positively correlated with soil water contents (r = 0.62), indicating that soil water may be beneficial in accumulation of NO_3^--N in soils under rainfed condition.

Spring wheat was planted in all areas of the study area in 2007, but field history indicates that this is not always the case. The area has often been split between wheat and soybean

Abbreviations: 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; GPS = global positioning system; GIS = geographic information system; OM = organic matter. Note: USD1 is equal to approximately 6.82 RMB Yuan.

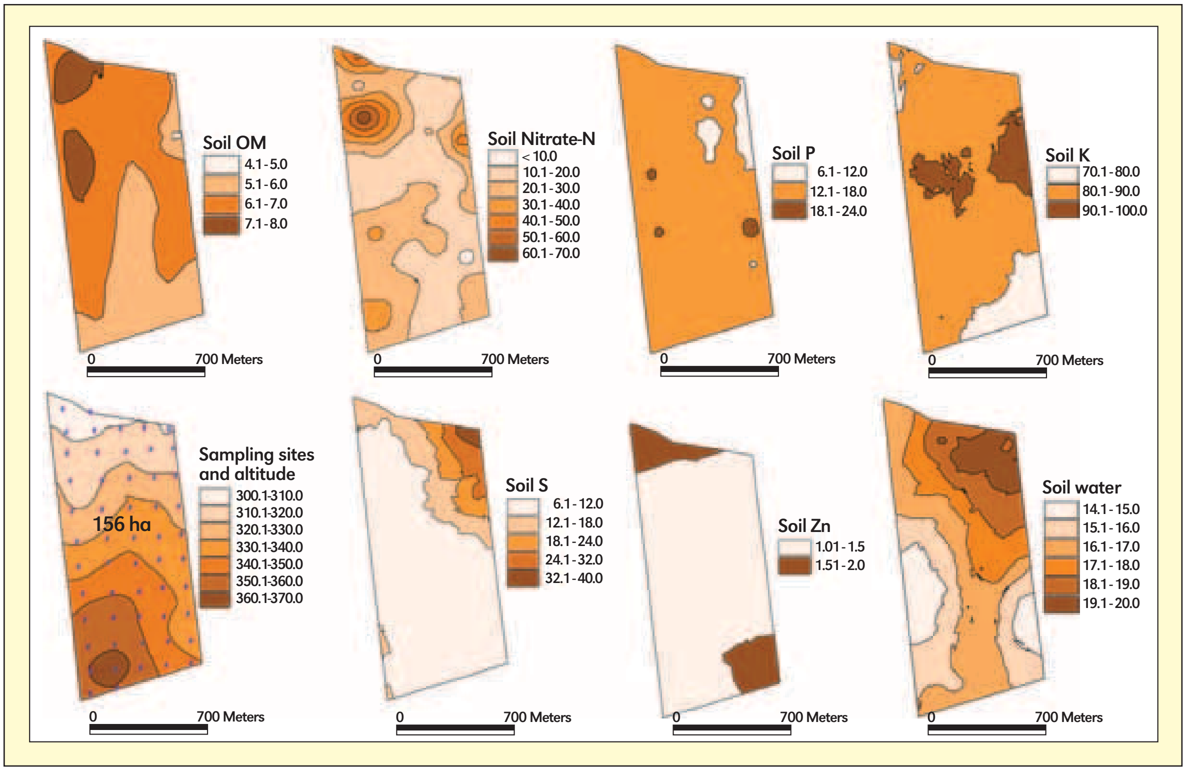

Figure 1. Spatial distribution of soil OM (%), available nutrients (mg/L), soil water (%), altitude (meters), and location of sampling sites in the study area.

Table 2. Response of site-specific balanced fertilization in spring wheat in the study area.

Fertility category	Treatment[1]	Yield, kg/ha	Yield increase, %	Income[3], RMB Yuan/ha	Income increase, RMB Yuan/ha
Relatively high soil fertility	NPKZnS	3,340	6.4	4,896	17
	NPKZn	3,344	6.5	5,175	296
	NPKS	3,288	4.7	4,870	-9
	NPK	3,396	8.1	5,334	455
	Collective[2] Contract Cropping	3,140	-	4,879	-
	No fertilizers	2,796		5,032	
Relatively low soil fertility	NPKZnS	3,076	21.3	4,083	291
	NPKZn	3,129	23.4	4,449	658
	NPKS	2,938	15.9	3,902	111
	NPK	3,014	18.9	4,311	520
	Collective Contract Cropping	2,536	-	3,791	-
	No fertilizers	1,817		3,270	

[1]N, P, K, Zn, and S denote N, P_2O_5, K_2O, Zn, and S, respectively. Application rate of N, P_2O_5, K_2O, Zn, and S is 67.5, 52.5, 37.5, 4.5, and 31.1 kg/ha, respectively, for relatively high soil fertility, and 90, 75, 60, 4.5, and 31.1 kg/ha for relatively low soil fertility.
[2]Application rate of N, P_2O_5, and K_2O is 47.3, 72.5, and 31.5 kg/ha for collective contract cropping.
[3]Price of N, P_2O_5, K_2O, Zn, S, and spring wheat (grain) is 4.35, 5.65, 5.00, 15.00, 8.70, and 1.80 RMB Yuan/kg, respectively.

during the same year, each crop with different fertilization practices.

Significant spatial variability of grain yield was found within the study area **(Figure 2)**. Grain yields ranged from 3,201 to 7,104 kg/ha (averaged 4,977 kg/ha; C.V. = 15.5%). Collective contract farming traditionally uses a blanket approach to its crop management, thus differences in soil fertility and water in different parts of the study area might be main factors influencing the spatial variability of grain yield. Significant spatial correlation relationships were found between grain yield and contents of soil nutrients and soil water. Correlation coefficients between grain yield and contents of soil OM, and available P, K, S, and Zn were 0.33, 0.51, 0.37, 0.53, and 0.32, respectively. The correlation coefficient between grain yield and soil water content was 0.37. Weight of 1,000 kernels is an important component factor influencing grain yield, as the correlation coefficient between them was 0.44. Spatial variability of 1,000 kernel weight was affected by soil available P content as the correlation coefficient between them was 0.32.

Spatial variability of grain yield was correlated closely and positively with total nutrient uptake (accumulation rates of nutrients in crop grain and straw) during the growth period in the study area **(Figure 3)**. Notable similarities in spatial distribution of total uptake of nutrients and corresponding contents of available soil nutrient were observed in the study area **(Figure 1 and Figure 3)**. Correlation coefficients between total N uptake and soil OM, between total P uptake and available soil P, and between total K uptake and available soil K were 0.44, 0.46, and 0.51 (n = 44, $r_{0.05}$ = 0.30, $r_{0.01}$ = 0.39), respectively **(Figure 4)**.

The SSNM techniques for high-yield spring wheat production in the study area were developed based on the regionalized soil nutrient GIS maps and a computerized fertilizer recommendation system based on soil test levels, yield goals, soil and climatic conditions, among other factors (Huang et al., 2007). SSNM treatments applied significantly more N and less P for relatively high soil fertility plots, and more N and K for relatively low soil fertility plots than collective contract cropping. Yield and profitability for collective contract cropping and SSNM are compared within

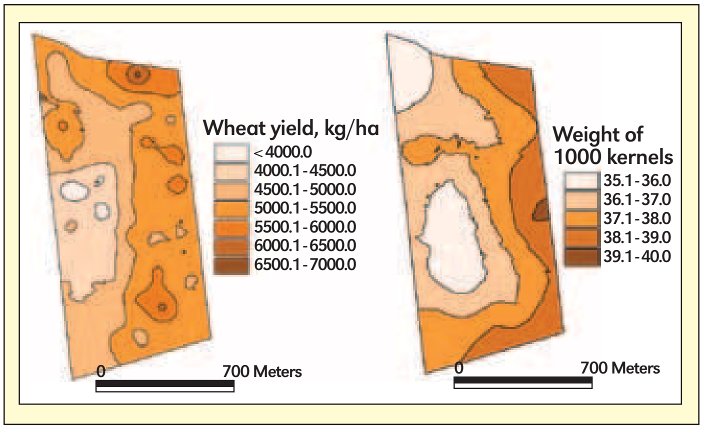

Figure 2. Spatial distribution of grain yield (kg/ha) of spring wheat and 1000 kernel weight (g) in the study area.

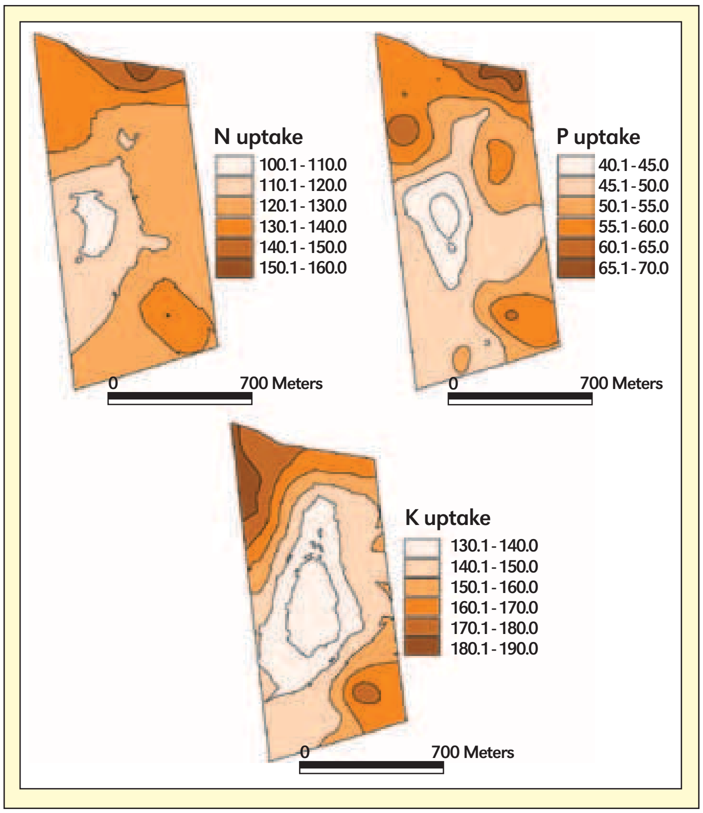

Figure 3. Spatial distribution of total nutrient uptake (kg/ha) during growth period of spring wheat in the study area.

relatively high and low soil fertility plots in **Table 2**. No yield response to Zn fertilizer or S fertilizer was found in these experiments. SSNM (NPK) increased spring wheat yield by 8.1% and 18.9%, respectively, within relatively high and low soil fertility plots, and also improved income by 455 and 520 RMB Yuan/ha, respectively. BC

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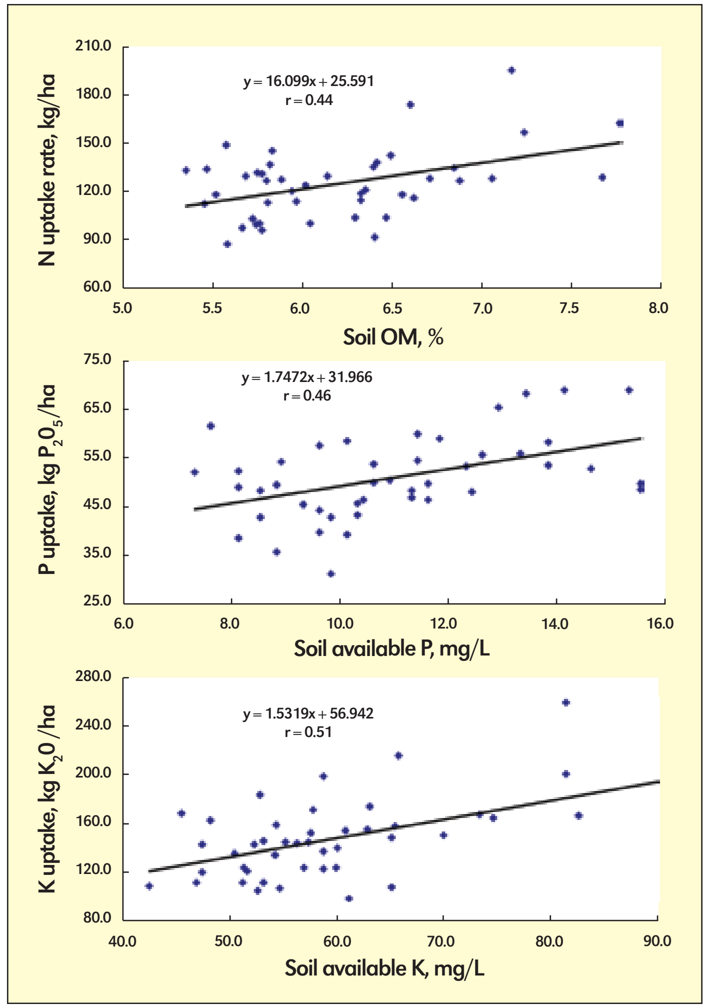

Figure 4. Relationship between total nutrient uptake during growth period of spring wheat and contents of soil available nutrients prior to spring wheat seeding in the study area. Significant at the 1% probability level.

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