Spatial Variability of Indigenous Nitrogen Supply: Implications for Precision Nitrogen Management in Intensive Agricultural Regions of North China Plain

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Abstract

A better understanding of spatial variability in indigenous nitrogen (N) supply is needed for implementing precision N management strategies. The objectives of this study were to 1) determine the magnitude and spatial structures of field-to-field and within-field variability of indigenous N supply in farmer's fields of North China Plain (NCP); and, 2) evaluate the potential of using chlorophyll meter and crop canopy sensor for in-season N management in the intensive agricultural regions of NCP. Winter wheat (*Triticum aestivum* L.) plant samples were collected on 25 x 25 m grids at jointing stage and harvesting stage from seven farmer's fields receiving no fertilizers in Quzhou County, Hebei Province in 2007 and analyzed for aboveground biomass, N concentration and N uptake. At jointing stage, chlorophyll meter readings and canopy reflectance index NDVI were also collected using SPAD 502 chlorophyll meter and GreenSeeker canopy sensor, respectively. The results indicated that indigenous nitrogen supply varied significantly both from field to field and within field, with winter wheat N uptake ranging from 26 kg ha^{-1} to 235 kg ha^{-1} at jointing stage, and from 33 to 320 kg ha^{-1} at harvest, and the spatial variability had either weak or moderate spatial structure. Both N sufficiency index (NSI) based on chlorophyll meter readings and N response index (NRI) based on GreenSeeker NDVI can be used to estimate N deficiency and responsiveness to N application.

Media summary

Understanding the spatial variability of indigenous nitrogen supply will result in development of better crop nitrogen management strategies.

Key Words

Within-field variability, field-to-field variability, nitrogen uptake, crop sensor, precision agriculture.

Introduction

Over-application of nitrogen (N) fertilizers is commonly reported in North China Plains, resulting in low nitrogen use efficiency, and high risk of environmental pollution (Ju et al., 2006; Zhao et al., 2007). Precision nitrogen management is a promising approach to solve this over-application problem, by taking both spatial and temporal variability in soil N supply and crop demand into consideration. Several questions need to be answered before appropriate precision N management strategies can be successfully implemented: 1). How large is the within-field and field-to-field variability in soil N supply? 2). Is the variability spatially structured within a field and/or across different fields? 3). Can chlorophyll meter and active canopy crop sensor be used to monitor winter wheat N status variability for potential application in precision N management in North China Plain? This study was conducted to answer these questions.

Materials and Methods

Seven fields next to each other were selected for this study in Quzhou Experimental Station of China Agricultural University in North China Plain. The total area is about 20 ha. The fields had different management history. In the fall of 2006, winter wheat was planted in all the fields, and no fertilizers were applied. In April 2007 when the crop was at jointing stage, aboveground plant samples were collected at 25 x 25 m grids and analyzed for biomass, N concentration (Fig. 1). At the same time, chlorophyll meter (SPAD 502) was used measure the relative leaf chlorophyll concentration, and GreenSeeker canopy crop sensor was used to collect NDVI and RVI data on the same grids. At harvest, crop yield and biomass were determined as well, and N concentrations in grain and straw were analyzed.

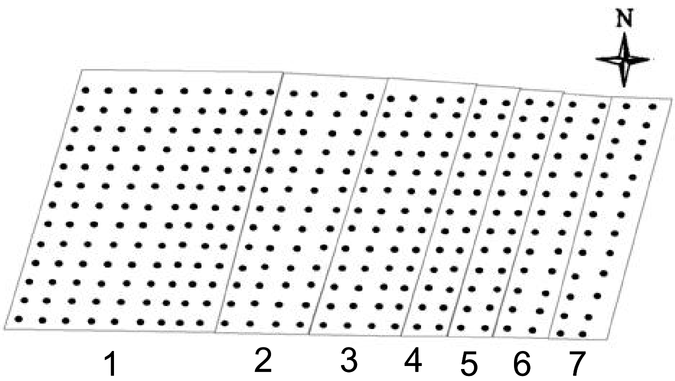

Fig. 1. Sampling locations in the seven research fields.

Results

Across all the seven fields, average above-ground plant N uptake varied from 25.96 to 164.36 kg ha-1 (mean=96.08 kg ha^{-1}; CV=41.52%) and from 33.38 to 319.54 kg ha-1 (mean =143.54 kg ha^{-1}; CV=34.79%) at jointing and harvest stages, respectively (Table 1). Field 1 and Field 4 had the highest (180.68 kg ha^{-1}) and lowest (96.45 kg ha^{-1}) average soil N supply, respectively. Within a field, the CV varied from 17.97 to 33.48%.

Wheat N uptake showed either weak or moderate spatial structure either across the several different fields or within individual field (Table 2), and the range of spatial dependence within a field varied from 48 – 112 m, but the mean correlation distance was all less than 21 m. Across different fields, however, the spatial dependence was stronger than within a field.

Table 1. Descriptive statistics of above-ground winter wheat plant nitrogen uptake at jointing and harvest stages.

	Jointing Stage					At Harvest				
Field	N	Mean	Min	Max	CV	N	Mean	Min	Max	CV
		---------g kg^{-1}--------			--%--		----------gkg^{-1}-------			--%--
1	116	129.00	58.37	235.05	27.17	101	180.68	84.93	319.54	23.34
2	52	94.49	25.96	161.67	35.88	52	142.00	46.27	261.58	28.87
3	52	57.91	32.03	137.93	31.30	52	97.08	33.38	177.67	33.48
4	26	56.15	28.76	97.05	28.00	26	96.45	41.04	147.40	27.04
5	26	82.16	54.87	114.46	18.09	26	139.26	89.26	192.43	17.97
6	26	85.33	43.02	150.96	29.26	26	131.12	55.47	202.05	29.46
7	26	93.41	48.46	164.36	29.33	26	159.10	99.13	244.69	30.93
All	324	96.08	25.96	235.05	41.52	309	143.54	33.38	319.54	34.79

Table 2. Descriptive statistics of above-ground winter wheat plant nitrogen uptake at jointing and harvest stages.

	Jointing Stage					At Harvest				
Field	N	Ratio†	A‡	MCD§	Model¶	N	Ratio	A	MCD	Model
		--%--	-----m-------				--%--	------m------		
1	116	24.00	68	6.12	G	101	20.90	49.3	3.86	G
2	52	30.00	47.6	5.36	G	52	63.65	85	20.29	S
3	52	25.76	115.6	11.17	G	52	47.17	90	15.92	S
All	324	72.41	387	105.08	S	309	66.93	368	92.36	S

† Ratio: The ratio of structural variance C over sill (C0+C), where C0 is nugget
‡ A: effective range of spatial dependence
§ MCD: mean correlation distance, calculated by 3/8*(C/(C0+C)*A (Han et al., 1994).
¶Semi-variogram model: S=Spherical; G=Gaussian

The N Sufficiency Index (NSI) (Peterson, 1993) based on SPAD meter readings (Fig. 2, left) and N Response Index (Mullen et al., 2003) based on GreenSeeker NDVI (Fig. 2, right) at jointing stage all indicated that Field 3 and 4 would be most responsive to N application, and the winter wheat yield and N uptake at harvest indicated these two fields had the lowest yield and N uptake.

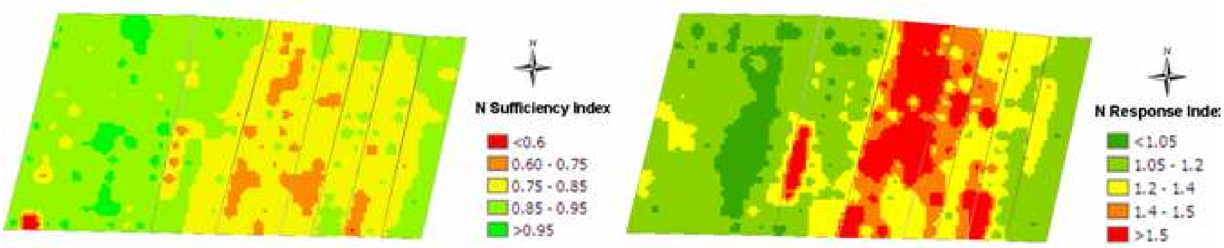

Fig. 2. N sufficiency index (NSI) based on SPAD meter readings (left) and N response index (RI) based on GreenSeeker NDVI (right) at jointing stage.

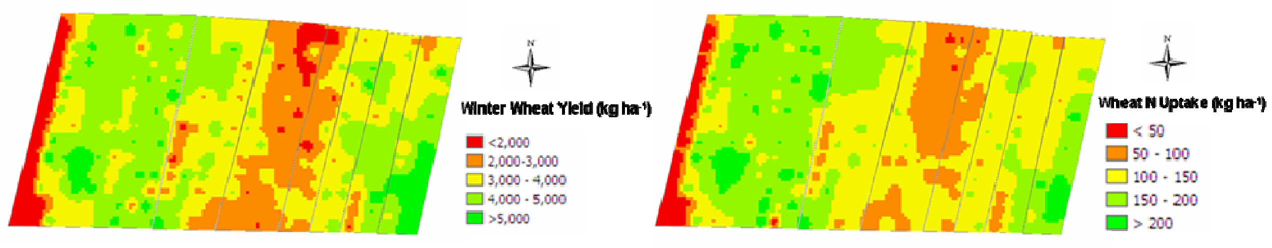

Fig. 3. Winter wheat yield (left) and wheat N uptake at harvest time (right).

Conclusion

Indigenous N supply varied significantly both within individual field and across different fields, the spatial dependence, however, was not strong. Both chlorophyll meter (SPAD meter) and crop canopy sensor (GreenSeeker) showed good potential in estimating N deficiency and response at jointing stage, and application in precision crop N management.

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