Classifying Spatial Variability in Corn Yield Response to Nitrogen Fertilization by Using Soil and Terrain Attributes

Peter Kyveryga[1], Petrutza Caragea[2], and Tracy Blackmer[1]

[1]On-Farm Network™, Iowa Soybean Association and [2]Department of Statistics, Iowa State University

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IOWA STATE UNIVERSITY — COLLEGE OF AGRICULTURE

Introduction

Nitrogen (N) fertilizer is one of the most expensive inputs in corn production, and managing N spatially within fields is important for both economic and environmental reasons. Varying application of N that gives the maximum profit has been of interest during the last two decades. While spatial variability in yield response (YR) to N and variability in economic optimal rates within fields are well documented, there is no acceptable methodology for testing whether variable rate N fertilization is feasible and which factors to consider when prescribing this fertilization.

Many factors can potentially affect YR to N within fields. Soil moisture and amount of rainfall dominate in some years, while amounts of N mineralized from soil organic matter become important in others years. Establishing relationship between YR and site-specific factors within fields is often complicated by effects of additional factors such as losses of soil N applied as commercial fertilizer or animal manure. In addition, only a handful of studies had enough data and large spatial resolution of N fertilizer treatments to classify YRs within fields. With the advent of on-the-go sensors collecting soil and terrain attributes has become less expensive and allowing for correlation of site-specific information with YRs within fields.

The objective of this study was to explore a new method for relating spatial variability in YR to available soil and terrain attributes.

Treatment Application: Seven fields with no-till practices were planted to corn after soybean and received two N rates (112 and 140 kg N ha^{-1}) applied in alternate strips in many replications (Fig. 1A) within each field during three years. The fertilizer strips were 12-rows wide with urea-ammonium N solution injected into the soil at V3-V5 corn growth stage.

Data Collection and Processing: The strips were harvested by using a six-row combine equipped with yield monitor and GPS . The yield data were screened for outliers and individual yield observations were aggregated within each fertilizer rate at grid cells ranging from 25 to 30 m. YRs were calculated as differences between the aggregated yield values at the high and low N fertilizer rates in each grid cell. Because yield monitor data could include some errors, the YRs were classified as two categories: profitable and non-profitable based on corn and fertilizer prices at which 0.20 Mg corn grain was enough to cover the cost of additional 28 kg N ha^{-1} (Fig. 1B).

Apparent soil electrical conductivity (ECa) was collected by using an EM-38 or Veris 3100 sensor and elevation was collected by an RTK system (Fig. 1E). The elevation data were used to derive slope maps and to calculate topographic wetness index (TWI), which shows the ability of water to accumulate in certain places within fields (Fig. 1C and D). All soil and terrain attributes were aggregated at the same grid cell size as for the yield observations.

Statistical Analysis: Autologistic models were used to model spatial structure in YR expressed as a binary response variable: profitable and non-profitable and to incorporate available spatial covariates (ECa, elevation, slope, TWI, and soil map units). The models determined the probability of receiving profitable YR to additional fertilizer. The parameter values for the autologistic models were calculated by maximizing the log pseudo-likelihood (Caragea and Kaizer, 2007), and neighborhood matrices were based on distance with the radius 35 m.

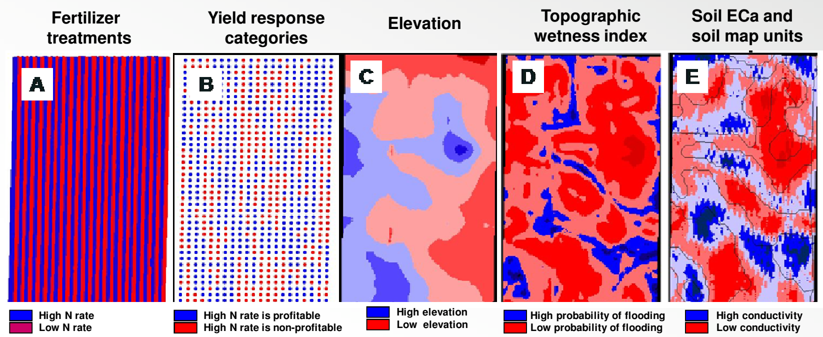

Fig. 1. An example of a 25-ha field with N fertilizer treatments (A), yield responses to additional N expressed as profitable and non-profitable categories (B), and soil and terrain attribute maps (C, D, and E).

Table 1. Summary statistics and bootstrap confidence intervals for mean yield responses to additional N fertilizer on the field scale.

Field	Number of grid cells[a]	Median	Mean	Bootstrap 95% confidence interval	
				Lower	Upper
		----------Mg ha^{-1}----------			
2004-1	281	-0.01	0.07	-0.09	0.26
2004-2	276	0.48	0.60	0.47	0.71
2004-3	445	0.15	0.29	0.17	0.40
2005-1	345	0.38	0.38	0.27	0.48
2006-1	478	0.33	0.30	0.24	0.36
2006-2	437	-0.16	-0.21	-0.28	-0.15
2006-3	305	0.24	0.31	0.24	0.38

[a]Grid cell size was 20x30 m.

Exploratory Analysis

The high N rate increased yield in five of seven fields as shown by confidence intervals for the mean YRs calculated on the field scale (Table 1). Although on average the high N rate was not profitable to apply in three fields, the exploratory analysis showed that some areas within these fields had YR large enough to cover the cost of fertilization. The analysis also showed high spatial dependency in YR expressed as profitable and non-profitable categories within all fields (Fig. 1B).

Modeling Spatial Variability in YR

Table 2 shows parameter estimates for autologistic models when incorporating spatial covariates. Because we observed strong spatial dependency in YR in directions at which the fields were planted and harvested, we used autologistic models that had spatial parameters calculated for the directions along and across corn rows.

None of the spatial covariate was significant in predicting the probability of profitable YR to additional N in two fields. Soil map units were found to have little effect on YR in all fields. Elevation was a significant factor in one field and applying additional N was profitable in areas with higher elevation. Soil ECa was significant in two fields where it was not profitable to increase N rate within the areas with high ECa (i.e., high clay and soil organic matter contents). The same trend was observed in two fields where extra N had effect only in areas with lower TWI values and lower capacity to accumulate water. As a factor, slope was significant only in one field where it was profitable to apply additional N in areas that had lower slope values.

Table 2. Parameter estimates for autologistic models that were used to identify the probability of receiving profitable yield response to additional N within each field.

Spatial covariate[a]	Field						
	2004-1	2004-2	2004-3	2005-1	2006-1	2006-2	2006-3
Intercept	2.32	7.94*	-0.64	4.99*	3.42	-1.73	3.24
Elevation	-0.23		0.062*				-0.13
ECa	-0.07				-0.057*		-0.079*
Slope	0.68				-0.81*		0.011
TWI		-0.79*		-0.59*			
Soil Map Unit							
Spatial parameter							
along rows	4.28***	3.05***	2.21***	2.67***	2.72***	4.08***	2.19**
across rows	0.03	-0.25	-0.57	-0.36	0.56	0.87	0.74

*,**, *** Significant at *P*=0.10, *P*=0.01, and *P*=0.001 levels, respectively.
[a] Covariates were initially selected by performing stepwise multiple logistic regressions without considering spatial dependency.

Conclusions

We observed strong spatial dependency in YRs within the fields, but no single factor could predict well the probability of profitable YR to additional N in all fields. In some fields, the areas with lower ECa, higher elevation, and lower ability to accumulate water, and therefore, with lower potential to mineralize soil organic matter tended to respond to additional N.

The effects of soil and terrain attributes were found to be small and did not substantially decrease spatial dependency in the direction along corn rows. It is possible, however, that another factor such as distribution of crop residues from the previous crop in these no-till fields could have changed the immobilization-mineralization patterns of soil organic N, and thus, influenced YR within the fields. Additional observations are being collected to study temporal variability in YR.

The proposed method uses simple economic analysis and provides enough data to have high spatial resolution. The method should be well suited for situations when growers already applying variable N rates by simply increasing or decreasing N rates by small increments and their decision is based on whether applying additional fertilizer.