ZONE DELINEATION FOR NITROGEN MANAGEMENT

D.W. Franzen, T. Nanna, F. Casey, D. Ralston, J. Staricka, M. Halvorson, V. Hofman
North Dakota State University
J. Lamb and A. Sims
University of Minnesota

Abstract

Managing nitrogen through zone soil sampling has been shown effective in revealing residual soil nitrate patterns in North Dakota. Zone delineation has been constructed using several types of data, including yield maps, remote imagery, topography and soil EC sensor data. A study was conducted in North Dakota, Montana and Minnesota to evaluate zone delineation methods. Across the region, yield frequency maps, topography, remote imagery and soil EC data were effective in helping to construct zones. Use of simple classification techniques for delineating zones, such as a weighted, classified method, tended to be more effective in increasing yield or quality than more complicated clustering methods. Use of several tools together to construct zones was more effective than single tools.

Introduction

Zone management of nutrients has been generally accepted in the North Central region as a possible method for directing soil sampling (Rehm et al., 2001). Several data set tools have been used to construct zones that might be used for N management, including topography (Franzen et al, 1998), remote imagery (Sims et al., 2002), yield frequency maps (Diker et al., 2002), and soil EC (Fleming and Buchleiter, 2002). The objectives of this project were to evaluate different zone construction tools, methods to delineate zones, and the effects of variable-rate N fertilization compared with uniform application.

Methods

The experimental sites included locations in Montana, North Dakota and Minnesota, however, only the North Dakota and Minnesota sites will be discussed in this paper. In North Dakota, sites were located near Valley City, Oakes, Mandan, Minot and Williston. In Minnesota, sites were located near Crookston and Renville. Elevation data was obtained using a laser plane in a 0.25-acre grid. Soil EC was obtained using a Veris®* soil EC sensor. Satellite imagery was obtained from Landsat 5/7 NDVI at 30 m resolution. Aerial photography was obtained using Ektochrome film, flying at 5,000 ft.

Yield frequency maps were developed by selecting a desired grid size, usually similar to the soil sampling grid used on the field, within Fortner Noesys© Transform, then exporting the resulting yield averages for the grids into Excel©. After sorting the average yield grids, yields equal to the

*Mention of a trademark is not an endorsement of the product.

mean were given the value '0'. Those yields higher than the mean were given a value of +1. Those lower than the mean were given a value of –1. The same procedure was used for each year of yield data regardless of crop. The normalized values of +1, -1 or 0 for each grid were added together to obtain the yield frequency for each grid.

Imagery was imported into Microsoft Photodraw V2© and grey scale was selected. The image was imported into Transform© and image data was averaged for each sampling grid size. The resulting image grid data was exported as text and zones were developed in Surfer 8.0©.

To develop yield frequency zones, EC zones, and imagery zones the data was divided into five classes using quintiles. Elevation data was divided into the following five landscapes; ridge/shoulder slopes, convex slopes, concave slopes, foot slopes, and depressions. All zones were mapped in Surfer 8.0© for Windows.

When data were combined to form zones from multiple data sources, the data were ranked 1 to 5, with 1 corresponding to lowest nitrate levels and 5 corresponding to highest nitrate levels. Each grid was given its data rank value, and the grids were summed to form new values. These values were again mapped in quintiles to provide a new map with five zones.

At Valley City, Oakes, Williston, Renville and Crookston, variable-rate N applications were conducted in at least one year of the study. The variable-rate consisted of the researchers favorite zone tool and method for delineating the zones, a variable-rate based on a clustering or classification method with more than one zone development tool, and a uniform rate based on a field mean. The statistical analysis was conducted based on the field experimental design, usually an RCB. However, additional code was added within SAS in the mixed model, repeated measures, with spatial analysis considered. Yield data was geostatistically analyzed for variogram construction, and the sill and range components used within the SAS mixed, repeated measures procedure. The resulting statistics provided an ANOVA with considerable spatial component removed and the effects of the N treatments better expressed.

Geostatistical analysis of yield data was conducted using GS^+ 5.0 for Windows©. Default variogram construction was ignored and a best-fit variogram was constructed by hand using the least squares capacity of GS^+ 5.0.

Soil samples to 2-feet in depth were obtained from the experimental fields usually in a 0.25-acre grid (110-foot stratified systematic), accept in some parts of the Mandan field, where a 0.5-acre grid (150-foot) was used. The soil sample analysis served as the base grid for comparison with nitrate estimates from the delineated zones. After zones were developed, the sampling grid design was imposed over the zones and a mean nitrate value from 8-10 sampling grids was given to each grid node that corresponded to the zone area. Once the entire field grid network was estimated in this manner, the soil sample nitrate results were correlated with the zone estimates.

Results

Correlation of zone nitrate-N estimates compared with sampling grid N estimates were significant for all comparisons at Williston (Table 1). Correlation with soil EC was most consistently highest in correlation. The highest correlation was in 2003 with satellite image, however, the correlation coefficient for satellite imagery in 2002 and 2004 was much lower. Residual nitrate-N in the 0-2 foot depth was in a narrow range from 20-30 lb/acre in most years. This probably affected the degree of correlation.

Table 1. Williston, zone nitrate-N estimates compared with sampling grid nitrate-N, 2002-2004.

Year	Yield frequency, 2002-2004	Topography	Aerial photograph, 2002	Satellite image, 2002	EC
2002	0.27	0.28	0.16	0.19	0.34
2003	0.29	0.18	0.23	0.47	0.22
2004	0.21	0.22	NA	0.13	0.33

The results at Crookston (Table 2) show that zones from each delineation tool had r correlation values higher than 0.30 for all but the EC zones for the 2001 sampling. Particularly high correlations were found in the 2002 soil nitrate comparisons from the topography, EC and yield frequency zones. Higher correlations were also seen in satellite imagery and topography for all three years. This site had the highest correlation with imagery of all sites in the project.

Table 2. Correlation of zone delineation method residual soil nitrate estimates with the actual residual soil nitrate grid sampling, Crookston, 2001-2003.

Year	Aerial zone	Satellite zone	Yield frequency zone	Soil EC zone	Topography zone
	------------------------------		r	--------------------------------	
2001	0.32	0.53	0.32	0.10	0.53
2002	0.38	0.26	0.73	0.78	0.76
2003	0.31	0.61	0.31	0.26	0.44

The Oakes site was the only irrigated location in the project, and was selected because of its past precision farming history as part of the regional MSEA, together with its system of lysimeters and tile drain measuring ports. The soil texture at the site is sandy loam, and the site was in continuous corn throughout the duration of the project. Correlations of 2-foot depth nitrate were low for yield frequency maps, probably because yield ranged only a small amount (less than 20 bu/acre) throughout the field (Table 3). Residual nitrate levels were also relatively low (less than 40 lb N/acre). Topography zones in 2002 and deep soil EC zones in both years were most highly correlated with soil grid sampling nitrate levels. This was the only site where deep soil EC was different than shallow EC zones.

Table 3. Oakes, zone nitrate-N estimates compared with sampling grid nitrate-N, 2002 and 2004.

Year	Yield 2002 map	Topography	Aerial photograph, 2002	Satellite image, 2002	SEC	DEC
	------------------	------------------	r	------------------	------------------	------------------
2002	0.12	0.43	0.24	0.37	0.34	0.46
2004	0.06	0.23	0.16	0.13	0.33	0.43

The correlation of zone nitrate-N estimates at Renville (Table 4) compared with the nitrate-N sampling grid measurements was generally lower than most other locations. Yield frequency zones, topography, satellite imagery and soil EC measurements were more highly correlated compared to the aerial photograph. 2002 was the only year that residual nitrate was available for comparisons.

Table 4. Renville, zone nitrate-N estimates compared with sampling grid nitrate-N, 2002.

Year	Yield frequency 2001-2003	Topography	Aerial photograph, 2002	Satellite image, 2002	EC
	------------------	------------------	r	------------------	------------------
2002	0.26	0.21	0.16	0.25	0.21

At Mandan in 2001, yield frequency maps were most highly correlated with grid sample results, with topography, satellite image and shallow EC also highly correlated (Table 5). In 2002, topography was most highly correlated. In 2003, aerial imagery was better correlated than other zone estimates, but topography, satellite image and EC were also highly correlated with grid sample results. Topography was most consistently the zone that had the highest correlation values.

Table 5. Mandan correlation of residual nitrate estimates from zones following winter wheat compared with grid sample results.

Year/Field	Yield frequency map	Topography	Aerial photograph, 2002	Satellite image, 2002	SEC
	------------------	------------------	r	------------------	------------------
2001/I4	0.82	0.47	0.18	0.78	0.51
2002/I6	0.21	0.37	0.13	0.25	0.16
2003/I5	0.11	0.44	0.51	0.39	0.41

At Minot in 2001, all zone delineation residual nitrate estimates were highly correlated with the grid sample nitrate results (Table 6). In 2002, EC and topography were most highly correlated. In 2003, satellite imagery and topography were most highly correlated. Topography was most consistently correlated at a high level with grid sample nitrate results. The Minot site was only cropped in 2001. The other years, the land was fallow and received no N fertilizer.

Table 6. Correlation of zone delineation residual nitrate estimates with grid sampling from 2001, 2002 and 2005 at Minot.

Year	Yield	Topography	EC	Aerial photo	Satellite image
			r		
2001	0.61	0.47	0.32	0.43	0.49
2002	0.20	0.43	0.61	0.16	0.27
2005	0.39	0.58	0.29	0.16	0.74

The correlation of zone residual nitrate with the original residual nitrate-sampling grid was significant at Valley City for all comparisons except for the 2003 EC zones (Table 7). In 2003, the sunflower crop removal of N resulted in low residual N in the entire field, lowering the correlation of all zones with sampling grid compared with other years.

Combinations of zone methods were used to determine whether more than one zone represented nitrate levels better than single zones (Table 8). The results suggest that more than one layer of data, especially the better correlated data with residual nitrate sampling, results in more stable and more highly correlated patterns than any single data layer. The most successful combination of layers tested was topography, satellite imagery and yield.

Table 7. Correlation of sampling grid residual nitrate-N with various zone residual N estimates, Valley City, 2001-2004.

Year	EC	Topography	Yield frequency, 2001-2004	Aerial photograph	Satellite imagery
			r		
2001	0.28	0.39	0.27	0.43	0.39
2002	0.24	0.41	0.26	0.37	0.50
2003	0.16	0.30	0.21	0.23	0.25
2004	0.20	0.30	0.12	0.33	0.30

Table 8. Correlation values for different combinations of data subsets for 2001, 2002, and 2003, Valley City.

Comparison	Correlation (r)		
	2001	2002	2003
Topography + EC	0.44	0.40	0.32
Topography + EC +Yield	0.50	0.46	0.38
Topography + EC + Satellite	0.49	0.45	0.37
Topography + Satellite + Yield	0.52	0.48	0.40
All Data Layers*	0.54	0.37	0.42

* Includes Order 1 soil survey, topography, aerial photos, satellite, EC, and yield data.

Variable-rate N treatments were compared with uniform-N treatments at five locations in fourteen site-years (Table 9). There were four site-years where significant yield increases were recorded and one site-year where an increase in protein was seen. At Valley City, the soils are variable, with loamy sands to silty clays in texture, and droughty to wet in drainage class. However, it was evident after a couple years that N rate may not be the way to approach a site-specific N application. The field may most benefit from application of preplant N at a recommended rate for the crop over the loam and heavier soils in average drainage class soils, and then side-dress or top-dress the sandy/droughty and wet/heavy soils to avoid excessive leaching and denitrification. To continue the consistency of the project protocol, this was not done, but N application timing probably had a great deal to do with the lack of site-specific rate differences at this site. For example, if leaching was not a problem, one would expect residual levels in the fall following a poor crop on sandy hilltops to be high. The nitrate levels were always very low. In contrast, areas with highest yields tended to have high levels of residual nitrate, probably from lateral water movement from beneath the sandy ridges over some textural discontinuity at depth.

Following the project completion, deep soil cores were obtained at Williston from 2-4 feet. Levels of nitrate at this depth were generally about 200 lb N/acre. The lack of response at this site was probably due to excessive residual nitrate below the 2-foot depth, which was certainly in the rooting depth of the spring wheat crop. In addition, wheat was fertilized for an anticipated 40 bu/acre yield in each year, but only approached this goal in 2004. Therefore, regardless of treatment, the plots over-fertilized the wheat in 2001-2003.

Sugarbeets at both Crookston and Renville responded well to zone N management. The best zone at Crookston was one that utilized the soil EC and topography, while the best zone at Renville also used a multiple data set approach that included yield, previous crop N uptake and topography.

At Oakes, zones were based on a clustering technique that included deep soil EC, topography and imagery. In one out of four years, there was a yield increase due to zone N application. Part of the lack of response was probably the history of precision ag activity at this site, and also a history of reduced N levels compared with the general practices of growers in the area. This was illustrated by the discharge of nitrate through tile beneath the study field compared with the neighboring farmer-managed field. Lysimeter N was measured from both the zone delineation field and an adjacent field that was farmer-managed. N inputs over three years at the precision-managed site were 404 lb/acre, compared to 496 for the farmer-managed field. Leaching losses were 61 lb/acre over three years for the precision-managed site, and 266 lb/acre for the farmer-managed field.

Table 9. Summary of variable-rate N treatment results on crop yield and quality at Valley City, Williston, Crookston, Oakes and Renville. The * designation within the yield or quality column indicate a significant increase with variable-rate treatment at P<0.05.

Site/Year		Crop	Yield	Quality
Valley City	2001	Barley		
	2002	Spring wheat	*	*
	2003	Sunflower		
	2004	Spring wheat		
Williston	2001	Spring wheat		
	2002	Spring wheat		
	2003	Spring wheat		
	2004	Spring wheat		
Crookston	2003	Sugarbeet	*	
Oakes	2001	Corn		
	2002	Corn	*	
	2003	Corn		
	2004	Corn		
Renville	2003	Sugarbeet	*	

Summary

A study was conducted at several sites in North Dakota and Minnesota to evaluate zone delineation tools to construct N management zones. Topography was one data set tool that was effective in constructing zones at all locations. Other tools with merit include soil EC, satellite imagery, aerial photography and yield frequency maps. Use of multiple data sets to construct zones generally improved correlation with soil nitrate patterns. Increases in yield with zone N treatments were recorded at four of fourteen site-years. There was an increase in wheat protein with zone N management in one site-year.

Use of zone management appears to be effective in delineating larger areas of relatively homogenous residual nitrate. However, from the degree of correlation there is still a significant amount of small-scale variability within zones.

References

Diker, K., G.W. Buchleiter, H.J. Farahani, D.F. Heerman, and M.K. Brodahl. 2002. Frequency analysis of yield for delineating management zones. p. 737-747, *In* P.C. Robert (ed.) Precision Agriculture [CD-ROM]. Proc. 6th Int. Conf., Minneapolis, MN. 14-17 July 2002. ASA, CSSA, SSSA, Madison, WI.

Fleming, K.L., and G.W. Buchleiter. 2002. Evaluating two methods of developing management zones for precision agriculture. p. 346-362. *In* P.C. Robert (ed.) Precision Agriculture [CD-ROM]. Proc. 6th Int. Conf., Minneapolis, MN. 14-17 July 2002. ASA, CSSA, SSSA, Madison, WI.

Franzen, D.W., L.J. Cihacek, V.L. Hofman, and L.J. Swenson. 1998. Topography-based sampling compared with grid sampling in the Northern Great Plains. J. Prod. Agric. 11:364-370.

Rehm, G.W., A. Mallarino, K. Reid, D. Franzen, and J. Lamb. 2001. Soil sampling for variable rate fertilizer and lime application. NC Multistate Report 348- NCR 13 Committee. University of MN, St. Paul.

Sims, A.L., J.T. Moraghan, and L.J. Smith. 2002. Spring wheat response to fertilizer nitrogen following a sugar beet crop varying in canopy color. Prec. Agric. 3:283-295.

PROCEEDINGS OF THE

THIRTY-FIFTH NORTH CENTRAL EXTENSION-INDUSTRY SOIL FERTILITY CONFERENCE

Volume 21

November 16-17, 2005
Holiday Inn Airport
Des Moines, IA

Program Chair:

Brad Joern
Purdue University
West Lafayette, IN
(765) 494-9767

Published by:

Potash & Phosphate Institute
772 – 22nd Avenue South
Brookings, SD 57006
(605) 692-6280
Web page: www.ppi-ppic.org

Our cover: To world food security and agricultural production, the Haber-Bosch process has been the most economical means for fixation of nitrogen for fertilizer. Fritz Haber won the Nobel Prize for Chemistry in 1918 and Carl Bosch shared the prize in 1931.