

Use of Data Layering to Address Changes in Nitrogen Management Zone Delineation

D.W. Franzen, Extension Soil Specialist, North Dakota State University, Fargo, ND
T. Nanna, graduate student, North Dakota State University

Abstract—Use of N management zones appears to be a practical method of revealing dominant patterns of residual soil nitrate in North Dakota crop fields, where fall soil nitrate sampling is a common N management tool. Delineation of zone boundaries to date has been a largely subjective process. A weighted, classified method of delineating nitrogen management zones is presented. Soil electrical conductivity sensor measurements, aerial color photography, Landsat 7 satellite NDVI imagery, and yield maps were divided into five classes using natural break algorithms to separate data into classes. Five zones of topographic relief, and Order 1 soil surveys were also used as classes. Soil sampling was conducted in a 33-m grid in a 12.5 ha field. Areas within zones produced from classification were given residual soil nitrate values based on mean zone interior nitrate sampling. The resulting meta-data was compared with a base 33-m sampling grid nitrate analysis for the 12.5 ha field. Layers of data were also combined, classified into zones, and compared with the base grid. Combinations of layers were generally superior in correlation values, compared with individual layers.

Introduction

An alternative to dense grid soil sampling for delineating residual soil N levels or N availability is a zone sampling approach. The zone approach assumes that soil N patterns are logically linked to some inherent causal effect, either natural or man-made. A number of delineation methods have been examined, including apparent soil EC (Kitchen and others 1999), yield mapping (Taylor and Whitney 2001, Diker and others 2002), topography (Franzen and others 1998), aerial imagery (Williams and others 2002, Sripada and others 2002), satellite imagery (Shanahan and others 2000), use of soil survey (Franzen and others 2001), organic matter (Fleming and Buchleiter 2002), and grain protein (Long and others 1998).

Extensive research has been conducted on the best predictors for determining optimal nitrogen management zones in site-specific farming (Bausch and others 2002, Fleming and Buchleiter 2002, Franzen and Nanna 2002, Hendrickson and Han 2000, Lund and others 2002, Stenger and others 2002). A number of studies have begun to investigate the use of multiple data layers to improve delineation of nutrient management zones (Whelan and others 2002, Kitchen and others 2002, Chang and others 2002). Various statistical tools have been used, including cluster analysis (Jaynes and others 2003, Kitchen and others 2002, Ralston and others 2002) and neural networks (Drummond and others 2002, Gautam and others 2002) group data and delineate management zones.

The objective of our work is to investigate the application of a classified, weighted method to determine patterns of residual soil N. The resulting zones can then be sampled in preparation for an N fertilizer application. Several types of data layers, including yield maps, satellite and aerial imagery, Order 1 soil survey, apparent soil EC and topography, were compared individually, and grouped together to determine whether one method was superior to others, and whether a combination of layers would better delineate soil N patterns.

Materials and Methods

The study site was a 12.5 ha field located near Valley City, North Dakota, 46.87495° north and 97.91001° west. Data collection that took place during 2001 and 2002 consisted of soil and plant sampling, referenced with a DGPS (differentially corrected global positioning system) unit. Soil samples were taken in a 33-m systematic grid, for a total of 144 samples, and then analyzed for nitrate-N at the 0-60 cm depth and organic matter at the 0-15 cm depth. Apparent soil electrical conductivity readings were obtained using a Veris 3100™ sensor, driving in passes approximately 16 m apart. Elevation was measured with a laser beam survey emitter and detection pole, with readings at approximately the same locations as the soil samples. The Order 1 soil survey (1-8,000 scale) was produced by Dr. D. H. Hopkins, a registered soil surveyor

and Assistant Professor in the NDSU Department of Soil Science. Yield maps were developed using data from a John Deere Greenstar® yield monitor.

Remotely sensed images, consisting of aerial photographs and Landsat 7 satellite images were also obtained for the 2001 and 2002 crop seasons. Aerial pictures of the field were taken using Ektachrome color film, flown at about 1,650 m elevation and then scanned and saved as TIFF images with red, blue, and green bands. The Landsat 5 and 7 satellite images used in this study are composed of blue, green and red bands in the visible part of the spectrum, as well as three bands in the near and mid infrared and one band in the thermal infrared part of the spectrum. The Normalized Difference Vegetation Index (NDVI) from the satellite images were calculated using the Idrisi32© and the ArcGIS 8.2© software.

NDVI, derived from reflectance measurements in the red and infrared portions of the spectrum ($NDVI = (IR - red) / (IR + Red)$), is useful in describing the relative amount of green biomass on the field and is a good indicator of healthy and dense vegetation (Sah and others 2002). Minitab© was used to perform statistical analysis on the data. Surfer 8© was used to interpolate soil data, using inverse distance squared, with eight nearest neighbors to develop an interpolation grid, then to convert from grid to raster images and generate the zone maps.

Weighted Classified Method

This methodology consists of: 1) Classification of data; 2) assigning weights to different types of data, based on residual nitrate correlation between base soil nitrate grid and N zones; and 3) comparing the final nitrogen zones against actual soil residual nitrate data. Various criteria can be used for assigning weights according to the best candidates; however, when several layers of different types of data are involved care must be exercised.

Jessop (2003) recommends three techniques for assigning weights to candidates: 1) sensitivity analysis, which consists of assessment under a number of alternative scenarios; 2) robustness, which looks for the most superior alternative among a group; and 3) risk aversion, which seeks the alternative that is least inferior to others. Correlation and regression analysis can be applied at each scale to quantify the relationship between the different types of data (Long 1998) and identify the appropriate scale for modeling, as well as the effect that scaling has on the data.

The first step in detecting patterns for nitrogen zone delineation is classification of all datasets into performance zones, such as low, medium low, medium, medium high, and high. We have found in our study that if we compile zones out of a few large blocks of data,

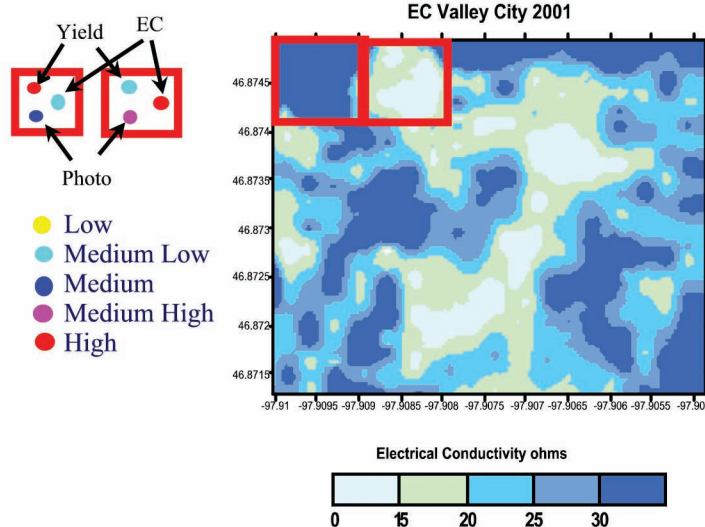


Figure 1. Data are classified into five performance zones and recorded at each sampling grid cell.

the patterns tend to reflect less variability of residual nitrate in the field than do more detailed zone patterns. For example our correlation values between topography and residual nitrate increased from about 5 to about 41 percent, when we further subdivided concave and convex slopes into various transitional categories. Therefore, we recommend compiling at least five zones for each type of data, in order to capture the maximum variability for the field, as shown in figure 1.

Next, an average nitrogen value is assigned to these different zones by selecting soil samples located at the center of each zone, which have been analyzed for residual nitrate. Figure 2 shows the layering of residual nitrate against spring wheat yield from data collected in 2002. The red polygons in figure 2 indicate the soil samples that will be chosen to calculate the average nitrogen for each zone. Select only the center samples, avoiding field corners and zone boundaries. Next assign the N average value to all the other points of the zone as shown in figure 3.

The next step in construction delineation zones consists of performing simple linear regression analysis for each type of data, where the averaged N values are compared against the actual soil nitrate values. At this point, weights can be assigned to each type of data according to those correlations, in order to form patterns that will predict future delineation zones for nitrogen. A final map is compiled by combining all the selected data multiplied by the appropriate weights into one map using the expression: $Zones = (data-1 * R-1) + (data-2 * R-2) + \dots + (data-n * R-n)$. Regression analysis is then once again performed, but this time it will be correlating the final patterns against residual nitrate. At this stage,

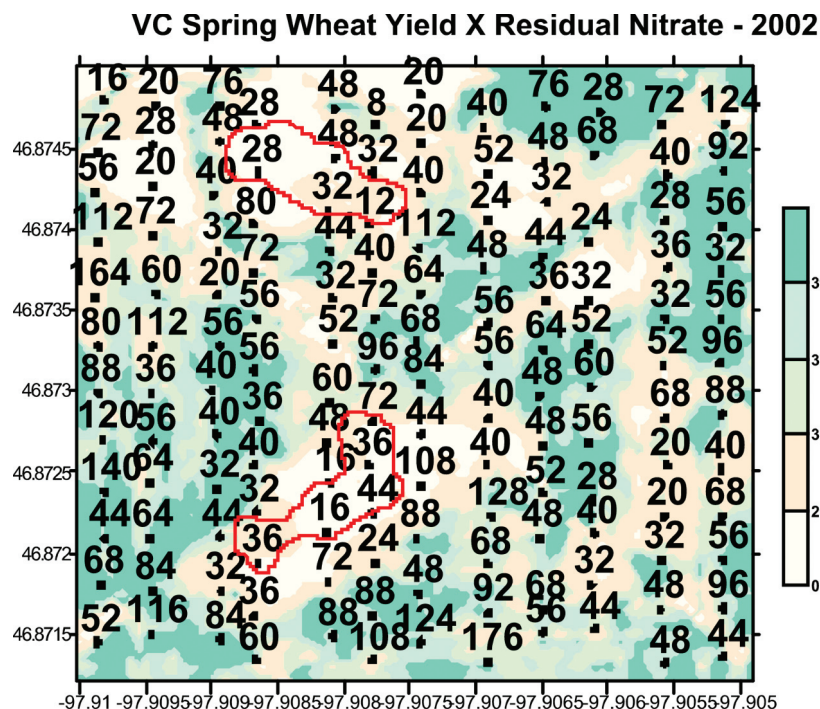


Figure 2. Residual nitrate is overlaid against the yield map, then the samples located within the interior of each zone are selected (two examples shown in red polygons). Values at the edge of the zone are not considered.

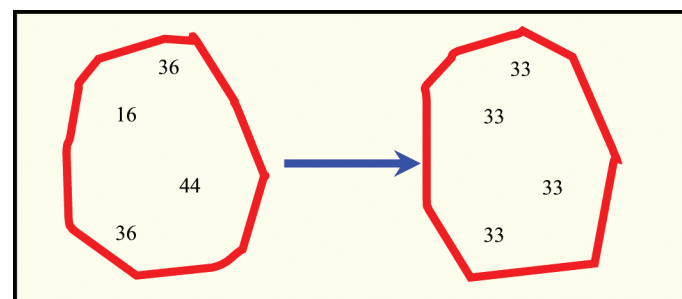


Figure 3. Mean nitrate-N values are assigned at sampling locations within each zone.

we recommend trying different combinations of smaller datasets or comparing data from different years, if available, to strengthen the model and detect consistent trends. Analysis of trends is an invaluable tool for building a reliable model. Rather than obtaining a perfect correlation with the nitrogen data, the main goal is to provide an overall pattern that characterizes the key zones of nitrate homogeneity in the field.

Multiple combinations of data were compared first by normalizing the data, then by assigning a weight to each data layer based on the correlation of individual data layers with nitrate. At each grid point, the normalized, weighted value of the one layer is multiplied by the other normalized, weighted layer or layers of data to create a new zone map. The average nitrate values within each

of the five zones produced were determined as explained above and regression analysis was conducted against the point sampled nitrate data set.

Results

Nitrogen zones at the Valley City research site were delineated in both years 2001 and 2002. By ranking the data according to correlations (tables 1 and 2) the nitrogen delineation maps for 2001 and 2002 were obtained (fig. 4).

The patterns expressed from our data in 2001 and 2002 are similar. The northwest corner has consistently showed low residual nitrate for both years, while the northeast and southeast corners have presented higher levels of nitrate-N. Since this site has pronounced differences in elevation between

those corners, it is possible that slope position and landform can greatly help explain nitrogen distribution. Studies by Franzen and others. (1998) have shown that in North Dakota topography patterns may be related to residual nitrate patterns. Nitrate responds to water movement on and within the landscape. Even though nitrate is a mobile nutrient, it usually moves to the same slope positions in the landscape. In addition, the northwest corner appears to be a location where limited drainage frequently causes ponding and plant growth is poor. Figure 5 shows the distribution of nitrogen over the research site terrain for both 2001 and 2002.

All comparisons of zone delineation methods were significantly correlated with the base nitrate sampling grid at the 5 percent probability level or less. Methods with r values less than 0.3 were 2001 EC, 2002, EC, 2001, Order 1 soil survey and 2002 aerial photograph (table 1). The 2002 aerial photograph may have been lower than 2001 because the photograph taken was an infrared digital photograph, compared to the Ektachrome color photograph taken in 2001. Direct correlation with EC data was evident in both years. Low EC values are common in both low nitrate areas and areas with apparent lateral water flow over a sloping argillic horizon, which results in an area lower in total salts, but higher in nitrate. Higher r values were obtained with topography, yield, 2001 Order 1 soil survey, 2001 aerial photography and satellite imagery in both years.

Consistency of correlation between years would probably be important for any delineation method, since most commercial applications would not have as robust a data set to compare and evaluate their zone strategy choice.

Table 1. Correlation of zone delineation method with base nitrate results from a 110 ft. systematic grid sampling, Valley City, ND, 2001 and 2002.

Comparison – Method vs. nitrate sampling data	Correlation (r)
2001 topography	0.39
2002 topography	0.41
2001 yield	0.47
2002 yield	0.36
2001 EC	0.28
2002 EC	0.24
2001 Order 1 survey	0.24
2002 Order 1 survey	0.46
2001 Satellite image	0.41
2002 Satellite image	0.35
2001 Aerial photo	0.38
2002 Aerial photo	0.16

Table 2. Comparison of zone delineation method combination on correlation with sampling base nitrate data, Valley City, ND, 2001 and 2002.

Comparison	Correlation (r)
2001 Topography + EC	0.44
2002 Topography + EC	0.39
2001 Topo + EC + Satellite	0.49
2002 Topo + EC + Satellite	0.45
2001 Topo + EC + Yield	0.49
2002 Topo + EC + Yield	0.46
2001 Topo + Yield + Satellite	0.52
2002 Topo + Yield + Satellite	0.48
2001 All methods	0.54
2002 All methods	0.37

Topography, yield and satellite image had the most consistent *r* values in a higher range than other comparisons between years. Topography, as depicted in figure 5, seems to show some promise in correlation with residual nitrate distribution at this study site, with the best crop production areas concentrated in the mid- slopes and areas of water recharge. Areas in the field where water stands and ponds were found to be low in nitrogen probably due to leaching. In addition, a sandy ridge located next to the northwest corner of the field presented soil conditions with low nitrogen levels both in 2001 and 2002. The research field has various depressions, some low, and some perched, that cause drainage problems with stagnant water when rain accumulates. Furthermore, the sandy ridges in the field can cause rapid infiltration of water, which serves for the transport of mobile nutrients downward and laterally.

The *r* value of EC comparisons across years was consistent, but with a lower *r* value than other methods. This may be the reason for poor correlation between soil electrical conductivity (EC) and residual nitrate (28 percent and 24 percent for 2001 and 2002, respectively). Electrical conductivity is known to be influenced by different factors, such as terrain curvature, soil texture,

water content, and levels of salts in the soil (Franzen 1999). Soil texture at this site is widely variable, with textures ranging from fine-loamy to loamy sands (Franzen and others 2002). It is clear in this study that EC should not be used as a direct measure for residual nitrate-N. However, because of its interactions with so many other soil parameters, it is a good nitrate pattern indicator.

Order 1 soil survey presented the best correlation with residual nitrate in 2002 (table 1). However, we were not able to reproduce the same results for the 2001 dataset. Yield, crop reflectance, and topography, on the other hand, had very reproducible results between the two years. Analysis of infrared or multi-spectral image can reveal plant vigor due to nitrogen and, therefore, it may be deduced that it is one of the best candidates for consistent nitrogen prediction. Similarly, yield data was better correlated with residual nitrate when determining patterns for nitrogen delineation. However, neither crop reflectance nor yield data should be used as sole means of prediction (table 2). Yield maps may not be reliable enough to consistently identify nutrient zones in a single year (Franzen 1999, Strock 2000) because crop yields are so dependent on various factors, such as insects, disease, weed infestation, soluble salts, and cultural practices. Also nitrogen delineation zones that are based on a single satellite image might miss significant within-field variability. To avoid this problem, some studies (Bergerou and others 2002, Locke and others 2000) suggest averaging crop reflectance from multiple satellite images, taken at key stages of crop development.

Correlation of multiple data-layer comparisons of topography and EC, topography, EC and satellite image, topography, EC and yield, and topography, yield and satellite imagery with soil nitrate data is shown in table 2. A combination of topography, yield, and satellite imagery had the highest correlation values compared to other combinations, although all combinations were consistent between years and generally had higher values than their individual parts. Although one might expect EC to pull the correlations down compared to the better individual correlation of topography, yield, and satellite image, it did not. Generally *r* values were somewhat higher with combinations of zone delineation methods than topography alone. Perhaps one of the reasons that a combination of topography with EC did not hurt the correlation was that EC received about half the weight as topography and yield. Previous investigations with un-weighted comparisons resulted in reduced correlations of multiple comparisons.

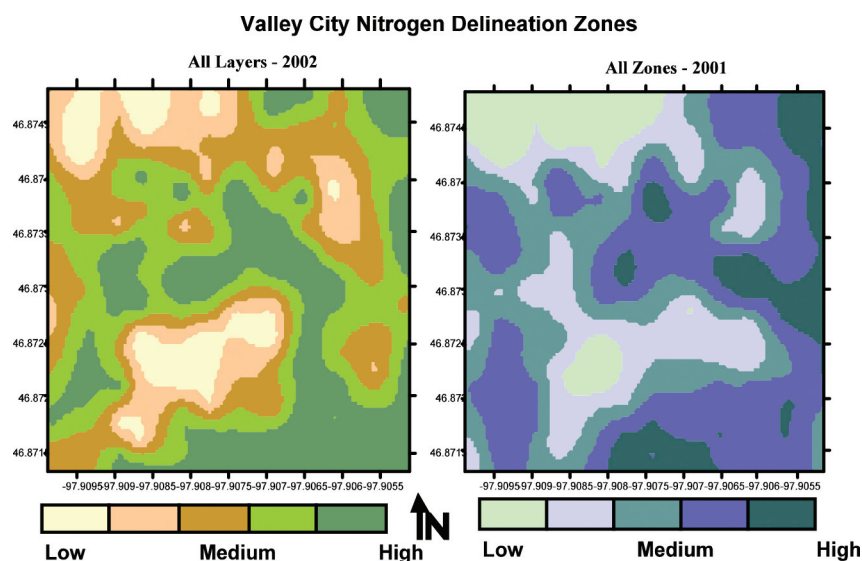


Figure 4. Zones of nitrogen delineation for 2001 and 2002, developed with multiple data layers.

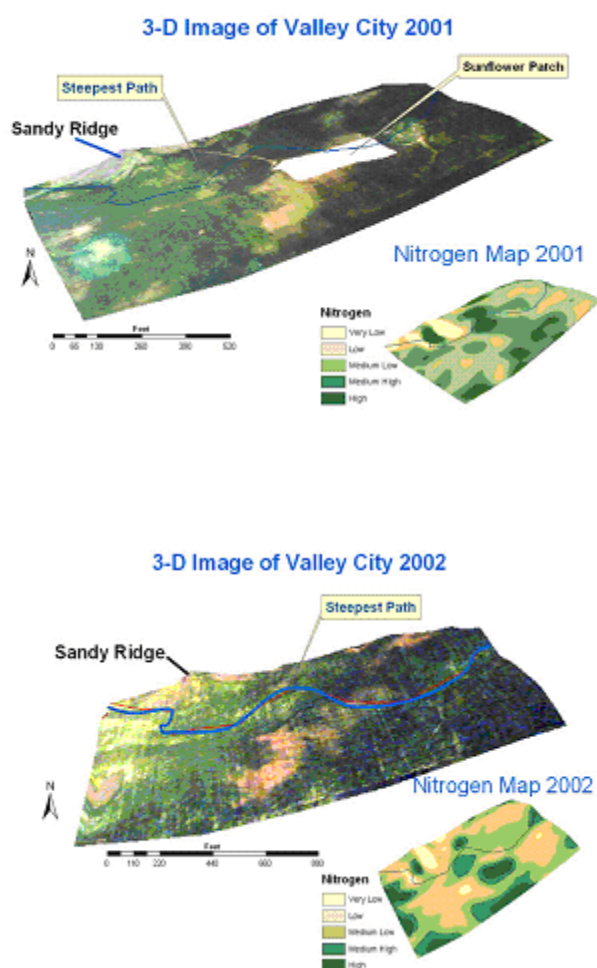


Figure 5. Nitrogen distribution according to topography in 2001 and 2002.

The exception to higher correlation using multiple comparisons appears to be using all methods, which perhaps illustrates a danger in adopting a “shotgun” type of approach to delineation methods.

Summary

Six nitrogen zone delineation methods, topography, yield, Order 1 soil survey, aerial photography, satellite imagery and apparent soil EC, were compared with a sampling base of soil nitrate. All methods were significantly correlated with the base nitrate patterns. Zones for each delineation method were produced using a classified

data approach. The highest, most consistent correlations were achieved with topography, satellite imagery, and yield mapping. Combinations of methods using weights based on relative correlation of each method individually resulted in generally higher correlations than any method used alone. Patterns for nitrogen zone delineation can be determined from various remotely sensed and field collected data. However, in order to build a sound model, each type of data has to be individually classified and analyzed in order to determine its contribution to the overall patterns relevant to nitrogen management. Our findings show that it is important to compile nitrogen zones from a variety of data to safeguard against data patterns that might change from one planting season to another. In addition, it is also important to examine trends over multiple years. For example in 2002 the best predictor of nitrogen was Order 1 soil survey, however, we were not able to reproduce the same result for 2001 and when comparing multiple years, topography, yield, and NDVI from satellite images have been much more reproducible than the detailed soil survey. It is, therefore, important not only to have good predictors, but also consistent predictors that set a trend over several crop seasons. From this work, multiple layers of data together provide a combined consistency. When one method is not as highly correlated as expected, the combination with other layers still resulted in a highly correlated zone delineation.

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