A WEIGHTED CLASSIFIED METHOD FOR NITROGEN ZONE DELINEATION

T. Nanna and D.W. Franzen
Department of Soil Science
North Dakota State University, Fargo, ND

Introduction

Even though zone management in precision agriculture is a relatively new science, extensive research has been conducted on the best predictors for determining optimal nitrogen management zones in site-specific farming (Bausch et al., 2002; Fleming and Buchleiter, 2002; Franzen and Nanna, 2002, Hendrickson and Han, 2000; Lund et al., 2002; Stenger et al., 2002). Different techniques, varying from cluster analysis (Jaynes et al., 2003; Kitchen et al., 2002; Ralston et al., 2002) to neural networks (Drummond et al., 2002; Gautam et al., 2002) have also been the focus of research whose goals are creating effective tools to handle and to analyze the data involved in zone delineation. Similarly, our study proposes and investigates the application of a statistical weighted technique to determine patterns of soil fertility, which can be used to map nitrogen zones. These zones are based on correlations performed between patterns of residual nitrate-N and patterns of remotely sensed and field collected data, such as topography, yield maps, satellite imagery, aerial photos, Order 1 soil survey, soil electrical conductivity, and various other soil properties. Management zone delineation, and in particular nitrogen management zone delineation, can involve the analysis of multiple layers of site-specific data, in order to detect differences and similarities in patterns. The main challenge has been to decide which types of data and combinations of data contribute the most to the formation of nitrogen zones.

We analyzed what constitutes reoccurring patterns in nitrogen distribution and also some of the factors that are known to cause certain data patterns to change from year to year. The one key factor in zone definition that seems to be most important is knowledge of the history of the crop field. This helps in detecting trends, as well as in selecting the best candidates for zone delineation based on those trends. Our study indicates that while it is possible to build fairly accurate patterns for nitrogen zone delineation, it is also difficult to determine the precise boundaries for those zones with accuracy. The reason being is that the zones tend to shift slightly from season to season due to soil dynamics, crop, and climate relationships. Therefore, careful investigation of zone delineation must also capture variability that arises from temporal data in order to increase the consistency of the generated 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 following a grid sampling technique: a 12 X 12 sampling pattern taken in a 110 ft. systematic grid, for a total of 144 samples, and then analyzed at the NDSU Soil Laboratory for nitrate-N and organic matter. Soil electrical conductivity readings were conducted using a Veris 3100™ sensor, driving in passes approximately 50 ft. apart. Elevation points were measured with a laser beam survey emitter and detection pole, with reading at approximately the same locations as the soil samples. The Order 1 soil survey (1-8,000) was produced by Dr. D. H. Hopkins, a registered Soil Surveyor and Assistant Professor in the NDSU Department of Soil Science.

Remotely sensed images, consisting of aerial photographs and Landsat 5 or 7 satellite images were also obtained for the 2001 and 2002 crop seasons. Aerial pictures of the field were taken using Ektochrome film, 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. In general, color was found to be a good indicator of crop health and stress. For example, a study by Sah et al. (2002) used NDVI from infrared aerial photography to map the nitrogen status of crops using a simple linear regression model, which has been shown to be a very consistent aid in fertilizer management. In our research we have used Minitab™ to perform the statistical analysis and Surfer 8™ to interpolate soil data from grid to raster images and to generate most of the zone maps.

Weighted Attributes Method

This methodology consists of: 1) assigning weights to different types of data, based on the best candidates for residual nitrate correlation; 2) combining the data to create nitrogen delineation 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. Generally, there are cases when the best candidate for zone delineation is obvious, such as slopes in determining movement of mobile nutrients or crop reflectance in determining dense crop vegetation. In other cases, however, the best candidates are not as obvious. 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, 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%, 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.*

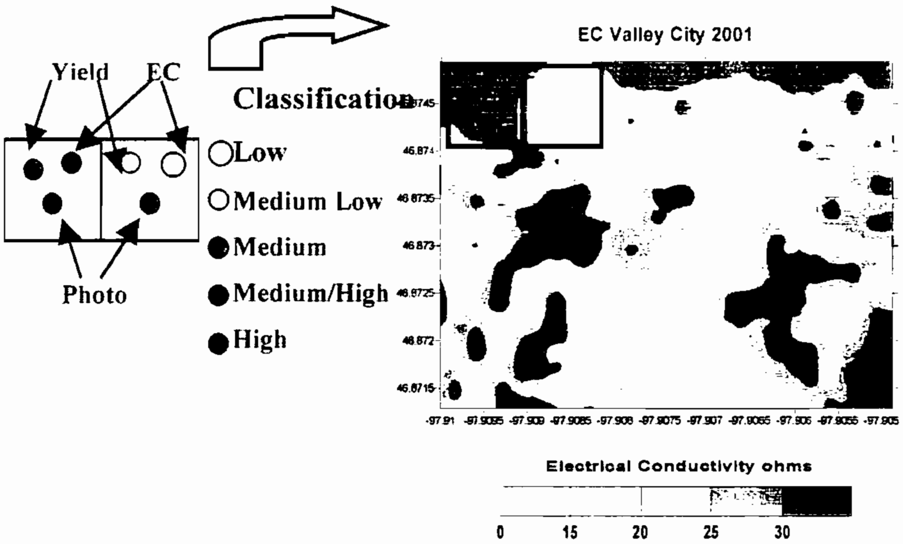

Figure 1. Classifying data into performance zones and recording them at each grid cell.

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.

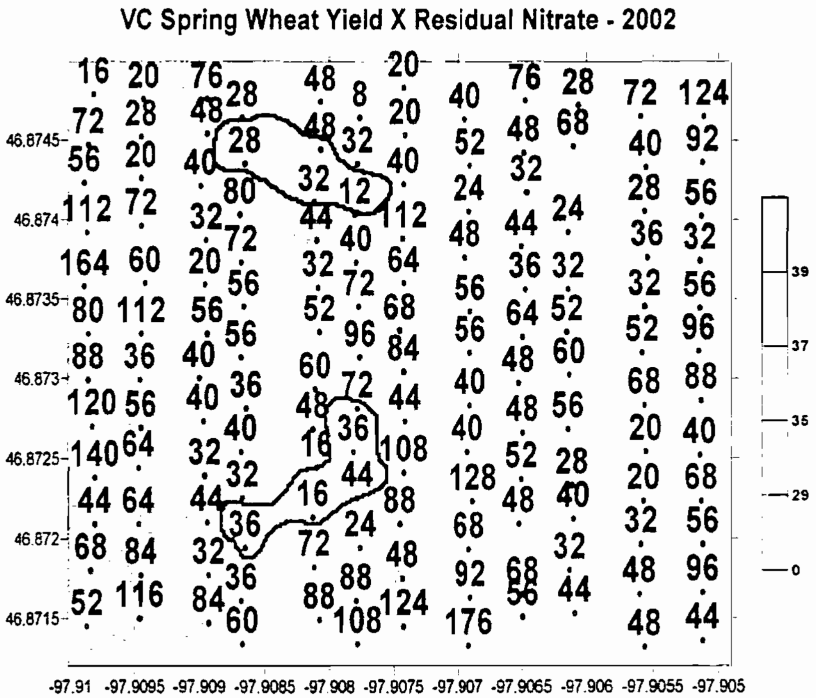

Figure 2. Residual nitrate is overlaid against the yield map, then the samples located at the center of each zone are selected (two examples shown in red polygons).

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*.

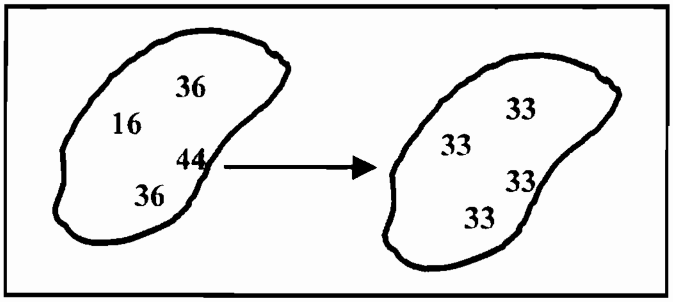

Figure 3. Assigning average Nitrate-N values to each zone

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) + ... + (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, 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.

Results and Discussion

In our analysis, we delineated nitrogen zones at the Valley City research site for both years 2001 and 2002. Our data consisted of topography, yield data, Order 1 soil survey, soil electrical conductivity, satellite images, and aerial photos. The best performers in 2001 were yield (R = 0.47), satellite (R = 0.41), topography (R = 0.39), and aerial photos (R = 0.38), while in 2002 the best performers were Order 1 soil survey (R = 0.46), topography (R = 0.41), yield (R = 0.36), and satellite (R = 0.35). By ranking the data according to such correlations, we obtained the nitrogen delineation maps for 2001 and 2002 shown in *Figure 4*.

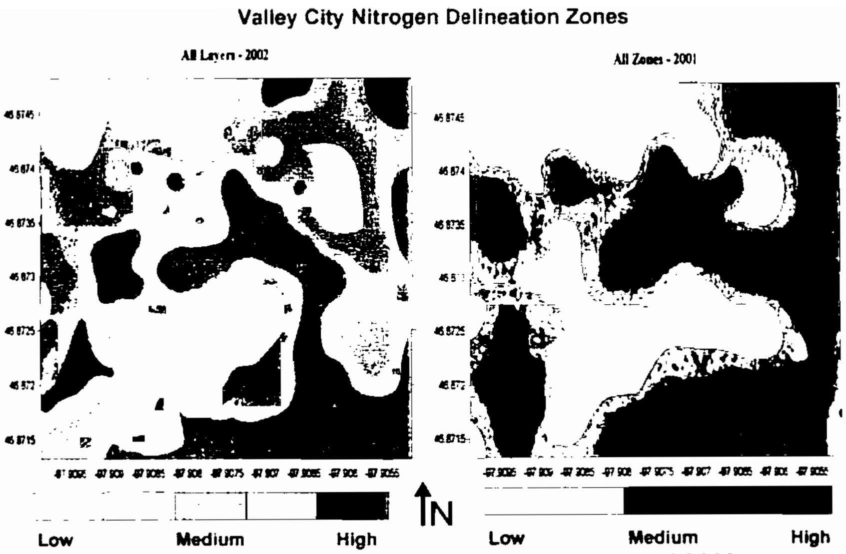

Figure 4. Zones of nitrogen delineation for 2001 and 2002

The patterns expressed from our data seem fairly consistent between 2001 and 2002. 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 et al. (1998) have shown that in North Dakota topography presents a good correlation with nitrate. 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.

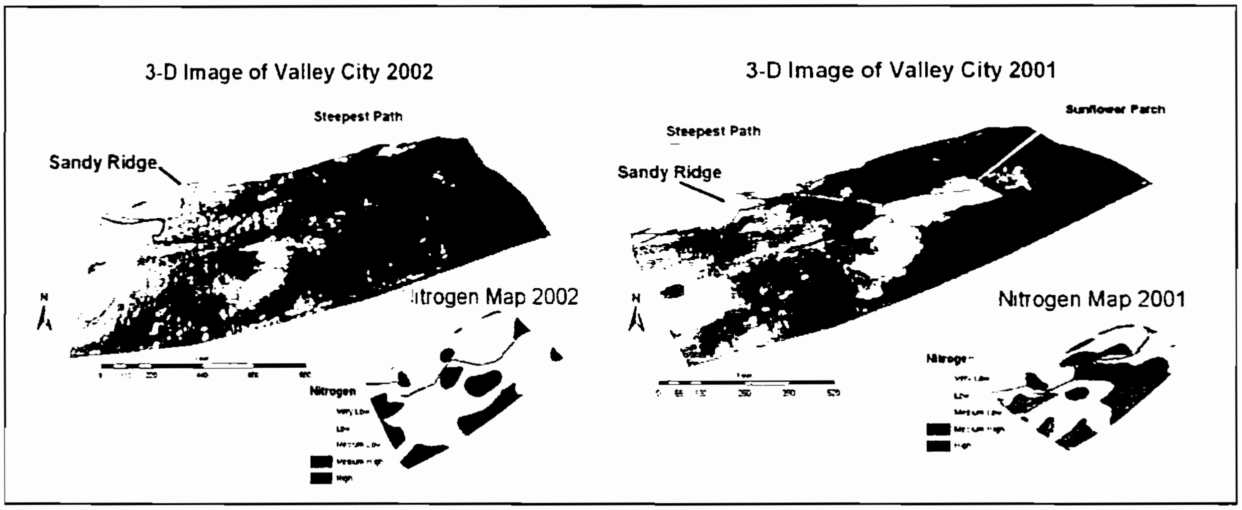

Figure 5. Nitrogen distribution according to topography in 2001 and 2002

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. Also, 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. This is surmised to be the reason for poor correlation between soil electrical conductivity (EC) and residual nitrate (28 and 24% for 2001 and 2002, respectively). EC 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). The Valley City site presents great variability of soil textures, ranging from fine-loamy to sandy and various soil types, such as Hapludolls, Argiudolls, and Calciaquolls (Franzen et al., 2002). At our research site, it has been determined 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 should not be discarded as an invaluable tool for delineating zones of soil fertility for nitrogen management.

Finally, among all of the datasets, Order 1 soil survey presented the best correlation with residual nitrate in 2002; 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. Yield maps do no appear to be reliable enough to consistently identify nutrient zones (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 et al., 2002; Locke et al., 2000) suggest averaging crop reflectance from multiple satellite images, taken at key stages of crop development.

Summary

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 predictors that set a trend over several crop seasons. Sometimes it pays to let go of one high correlation value and trade it for consistency. Rather than simply finding the nitrogen predictors for one single set of data, we also look for trends from one planting season to another. The ultimate goal of this study has been to identify the most significant parameters associated with

the choice of efficient residual nitrate-N predictors and, at the same time, use this process to enhance the quality of information presented.

Acknowledgements

This project is funded by USDA-CSREES IFAFS program grant number 00-52103-9652.

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PROCEEDINGS OF THE

THIRTY-THIRD NORTH CENTRAL EXTENSION-INDUSTRY SOIL FERTILITY CONFERENCE

Volume 19

November 19-20, 2003
Holiday Inn University Park
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Program Chair:

John E. Sawyer
Iowa State University
Ames, IA 50011
(515) 294-1923

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Potash & Phosphate Institute
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