STRATEGIES FOR ESTABLISHING MANAGEMENT ZONES FOR SITE SPECIFIC NUTRIENT MANAGEMENT

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Abstract

Recent precision agriculture research has focused on the use of management zones as a method to define areas for variable application of crop inputs. The goal of our work was to determine the relative importance of terrain information, aerial photographs, magnetic induction maps, and yield maps to define management zones. This work was conducted on a center-pivot irrigated field located near Gibbon, NE that has been planted to continuous corn for at least five years. Remotely sensed bare-soil images, elevation data, and soil electrical conductivity were used as an initial step to categorize field variability into management zones. Soil color reflectance data from bare-soil images were geo-referenced and processed in a GIS to develop three computer-generated management zones. A geo-referenced sampling scheme was designed to obtain soil chemical information for the zones. Geo-referenced yield monitor data were collected for the 1997-98 crop seasons. Interpolated layers for soil color, terrain features (elevation, slope, aspect), and grain yield were generated from point data using inverse distance weighting techniques and arranged into 15 m grids. Bare soil color alone accounted for 66% of the spatial variation in yield. Including elevation, aspect, slope, and soil electrical conductivity increased the yield prediction to 73%. These variables could help delineate management zones that might serve as a template for directed soil sampling and other cultural practices.

Introduction

Recent research in precision agriculture has focused on the use of management zones as a method to more efficiently apply crop nutrients across variable agricultural landscapes. Management zones, in the context of precision agriculture, refer to geographic areas that possess homogenous attributes in terrain and soil condition. When homogenous in a specific area, these attributes should lead to the same results in crop yield potential, input-use efficiency, and environmental impact.

Approaches to delineate management zones vary. Topography has been suggested as a logical basis to define homogenous zones in agricultural fields (Franzen et al., 1998). This approach has been applied in Illinois and Indiana, where 40% of grain-yield variability was explained by topographical characteristics and selected soil properties (Kravchencko and Bullock, 2000). Aerial photographs, crop canopy images, and yield maps have also been suggested as approaches to delineate management zones (Schepers et al., 2000). Remote sensing technology is especially appealing to identify management zones, because it is noninvasive and, low in cost (Mulla and Schepers, 1997). Additionally, scientific evidence for suggesting practical use of remote sensing technology to delineate management zones is increasing (Varvel et al., 1999).

Another promising noninvasive approach to define the boundaries of management zones involves the use of magnetic induction to measure soil electrical conductivity. This approach has been used to effectively map variations in surface soil properties such as salinity, water content, and percent clay (Sudduth et al., 1998). Magnetic induction has also been used to track soluble nutrient levels in soil (Eigenberg et al., 2000). Caution is necessary when using this approach because of the extreme sensitivity to soil type and management conditions, but its ease of use makes it an attractive tool for precision farming applications (Lund et al., 1998).

Yield mapping is yet another approach to delineate management zones. This approach is considered to be the primary form of precision agriculture technology in the U.S. (Pierce and Nowak, 1999). However, practical application of yield mapping to identify zones has been plagued by spatial and temporal variation in measured yield (Huggins and Alderfer, 1995; Sadler et al., 1995). Consequently, most efforts in yield map interpretation have focused on identifying generalized zones of low, medium, and high yield (Stafford et al., 1998).

The use of management zones as a method for variable application of crop inputs requires further evaluation before it can be successfully implemented. Specifically, approaches to define zones need to be refined, and relationships among them determined. Efforts to do so will improve our capacity to predict crop performance and environmental impact across variable agricultural landscapes.

The objective of this study was to evaluate approaches to delineate management zones. Specifically, we sought to determine the relative importance of terrain information, aerial photographs, magnetic induction maps, and yield maps to define management zones.

Materials and Methods

The study was conducted on a center-pivot irrigated field located near Gibbon, NE (40° 53' 27 N, 98° 51' 37 W, 2100 ft above m.s.l.), representing approximately 131 acre. The field has been planted continuously to corn since 1990, using ridge-till methods. The topography is rolling with approximately 98 ft of relief. Three soil series are present in the field: Hobbs (deep, medium-textured, well drained, nearly level to gently slope), Coly (deep, medium-textured, well drained, 11 to 31 percent slope), and Uly (deep, well-drained, medium-textured, 5 to 11 percent slope).

An aerial photograph of the bare soil surface was acquired during the spring of 1999, using an aircraft mounted 35-mm camera equipped with Kodak Ektachrome color film[1]. The aircraft was flown at the altitude of approximately 7000 ft during image acquisition. Prior to image acquisition, five targets (white-painted 4 x 8 ft wood sheets) were placed in the center and perimeter of the field area. Geological coordinates were obtained for the targets with a DGPS receiver for use in the image georegistration process. The 35-mm color slide was scanned, inputted into Imagine GIS software (ERDAS, Atlanta, GA), geo-referenced, and processed as brightness values for blue, green, and red. The brightness values were used to characterize three computer-generated management zones. Each sampling zone included 10 to 19 sampling points depending on the size and shape of the zone (total of 47 sampling points).

[1] Mention of commercial products and organizations in this article is solely to provide specific information. It does not constitute endorsement by USDA-ARS over other products and organizations not mentioned.

Prior to planting the 1999 crop, a geo-referenced soil-sampling scheme was used to characterize soil chemical properties at different points within each management zone. Within a 30-ft radius of each sampling point, twenty soil cores were collected to a 1.0-ft depth and composited. Samples were analyzed for soil electrical conductivity and pH (1:1 soil-water ratio), NO_3-N and NH_4-N (cadmium reduction followed by a modified Griess-Ilosvay method), extractable P (sodium bicarbonate extraction), and soil organic matter (estimated from soil organic carbon).

Soil electrical conductivity was mapped using an electromagnetic induction EM-38 ground conductivity sensor (Geonics Ltd, Ontario, Canada). The sensor uses electromagnetic energy to measure the apparent conductivity of earthen materials. The sensor was mounted on a nonmetallic cart, 14 inches above the soil surface, and pulled (10 mph) through the field with a truck following parallel swaths at 66-ft intervals. The sensor was operated in the vertical mode, which measured an effective soil layer of 0-3 ft. Conductivity data were geo-referenced using a DGPS receiver mounted on the top of the truck cab. Data were collected at one-second intervals and stored in a data logger. Elevation data obtained from the DGPS receiver were used to determine terrain attributes.

The field was yield mapped for two crop seasons (1997 and 1998) with a John Deere 9600 combine (12-row corn head) equipped with a GreenStar yield monitoring system. Data for yield, moisture, and geo-coordinates were recorded every second. Yield data were processed and mapped with Farm HMS software (Red Hen Systems, Fort Collins, CO).

Imagine software (ERDAS, Atlanta, GA) was used to develop interpolated layers from data points for soil color brightness, elevation, electrical conductivity, and grain yield. Inverse distance weighting was used as an interpolation method for creating maps with a 50-ft grid. Elevation measurements were converted into grid-based estimates of terrain, slope, and aspect. Slope describes the rate of elevation change, which is defined as the first-order derivative of elevation. Aspect identifies the steepest down-slope direction from each cell to its neighbors. The values of the output grid theme represent the compass direction of the aspect; 0 is true north, a 90-degree aspect is to the east, and so forth.

Simple correlation analysis was used to determine association between relative grain yield (normalized to the field average for each year) and various terrain attributes. Multiple stepwise regression analysis was used to assign relative importance of terrain attributes to grain yield.

Results and Discussion

The study site exhibited considerable variability in soil color and topographical relief. The darker-colored (less reflective) soil is located in the lower regions of the field, whereas, the lighter-colored soil is more prevalent on the upland locations. The bare-soil color image was used to produce the computer-generated management zones, resulting in three distinct regions.

The sampling scheme generated by computerized analysis of soil color revealed distinctly different soil chemical properties for these three zones (Table 1). For example, we detected an almost two-fold increase in soil organic matter (SOM) levels for the darker soil at lower elevations versus the lighter soil at higher elevations. Our results, regarding the association between elevation and SOM, are consistent with the observations of Kravchenko and Bullock (2000). Other indicators of crop productivity potential such as soil EC, pH, NO_3-N, NH_4-N, and P also indicated that the lowland dark soils were more fertile than the upland lighter soils. Soil brightness, an indirect indicator of SOM (Varvel et al., 2000), was positively associated with elevation in our work (Table 2).

The soil EC map revealed patterns similar to the soil color and management zone maps. Low EC values are found with the lowland dark-colored soils, while higher EC values are found at the light-colored upland areas where erosion has been most severe. Since this soil possesses calcareous subsoil, eroded areas would be expected to have higher carbonate levels resulting in higher pH and EC values, as is shown in Table 1. The EM38-derived EC values were positively correlated with both elevation and slope (Table 2).

Table 1. Soil chemical properties in the 0-30 cm depth for the three management zones.

Zone (color)	*n*	$EC_{1:1}$ ($dS\ m^{-1}$)	pH	SOM %	NO_3-N	NH_4-N	P
					-------------	lb/acre	------------
Light	18	0.42	7.37	0.94	6.9	5.4	11.8
Medium	19	0.28	6.48	1.31	9.1	7.4	24.5
Dark	10	0.24	6.17	1.68	15.1	2.6	61.5

Table 2. Correlation matrix, representing associations between relative grain yield by year and various terrain attributes.

Attributes	Yield	Elevation	Soil Brightness	Slope	Aspect	EM-38
Yield	1					
Elevation	-0.7415	1				
Soil Brightness	-0.8104	0.6892	1			
Slope	-0.3163	0.3592	0.3053	1		
Aspect	0.1876	-0.0935	-0.1434	-0.4180	1	
EM-38	-0.5463	0.6051	0.5655	0.3725	-0.1178	1

Average grain yield in 1997 was 183 bu $acre^{-1}$ (range 114 to 256) and 194 bu $acre^{-1}$ (range 120 to 253) in 1998. Spatial patterns in grain yields were quite similar to the management zones, with high yields found at lower elevations and lower yields found at higher elevations. Yields were normalized to the field mean by year to facilitate comparison across years.

All terrain attributes except aspect were negatively correlated with grain yield (Table 2). Multiple regression analysis revealed that these attributes accounted for 73% of the variability in grain yield, with a ranking order of elevation, soil brightness, aspect, slope, and EC (Table 3).

These findings are supported by Kravachenko and Bullock (2000), where 40% of corn and soybean yield variability in eight fields in Illinois and Indiana could be explained with topographical characteristics and selected soil properties (SOM, CEC, P, and K).

Since soil brightness was correlated with many of the terrain attributes, aerial photography would seem to be a promising method for developing management zones and obtaining important field information related to soil properties and crop productivity. The value of using soil brightness to delineate management zones goes beyond differentiating organic matter content in that brightness integrates the effects of other soil processes such as erosion, water holding capacity, mineralization, denitrification, and pH.

Table 3. Stepwise (forward) multiple regression analysis of association between terrain attributes and relative grain yield for each year.

Step	Variable Entered	Number Included	Partial R^2	Model R^2	F	Prob>F
1	Soil Brightness	1	0.6568	0.6568	4894.8	0.0001
2	Elevation	2	0.0638	0.7206	583.7	0.0001
3	Aspect	3	0.0055	0.7260	51.17	0.0001
4	Slope	4	0.0002	0.7262	1.58	0.2079
5	EM38	5	0.0002	0.7265	2.33	0.1273

Summary

The goal of our work was to determine the capacity of terrain information, aerial photographs, magnetic induction, and yield mapping to effectively delineate management zones. For an irrigated cornfield near Gibbon, NE, soil color, elevation, aspect, slope, and soil electrical conductivity accounted for nearly 73% of the spatial variation in yield, indicating that these variables could be useful when developing management zones. These zones could in turn serve as a template for directed soil sampling schemes to characterize soil properties known to affect crop yield. Such information could provide a more economical means for variable application of crop inputs. Results of this study are somewhat site-specific because irrigation greatly minimized the potential for water stress. While bare-soil color helps characterize soil organic matter content and provides clues about other soil properties and processes, it largely represents a surface soil situation. Subsurface properties might be better characterized using other tools such as soil electrical conductivity. The relative importance of the various soil properties in predicting yield depends on the most limiting factor. In many situations, that factor is water. This study indicates that organic matter content and all of its attributes is a very important component of corn production.

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