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Evaluation of GIS Technology in Assessing and Modeling Land Management Practices

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ABSTRACT

There is an increasing concern of land owners to protect and maintain healthy and sustainable agroecosystems through the implementation of best management practices (BMP). The objectives of this study were: (i) To develop and evaluate the use of a Geographic Information System (GIS) technology for enhancing field-scale management practices; (ii) evaluate the use of 2-dimensional displays of the landscape and (iii) define spatial classes of variables from interpretation of geostatistical parameters. Soil samples were collected to a depth of 2 m at 15 cm increments. Existing data from topographic, land use, and soil survey maps of the Winfred Thomas Agricultural Research Station were converted to digital format. Additional soils data which included texture, pH, and organic matter were also generated. The digitized parameters were used to create a multi-layered field-scale GIS. Two dimensional (2-D) displays of the parameters were generated using the ARC/INFO software. The spatial distribution of the parameters evaluated in both fields were similar which could be attributed to the similarity in vegetation and surface elevation. The ratio of the nugget to total semivariance, expressed as a percentage, was used to assess the degree of spatial variability. The results indicated that most of the parameters were moderate spatially dependent. Biophysical constraint maps were generated from the database layers, and used in multiple combination to visualize results of the BMP. Understanding the spatial relationships of physical and chemical parameters that exists within a field should enable land managers to more effectively implement BMP to ensure a safe and sustainable environment.

Additional Index Words: geostatistics, soil variability, spatial variability, BMP, conservation.

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INTRODUCTION

An understanding of the distribution of soil properties at the field and watershed scale is important for making reliable soil interpretations and assessing the effects of agriculture on environmental quality. The level of variability in soil properties is an increasing concern of land owners who are attempting to protect and maintain healthy and sustainable agroecosystems. This is also of practical importance to researchers who are investigating the complex interrelationships between soil properties. The variability may be due to several causes including variation in geographic location, climate, topography, parent materials, land use history, and the biological, physical and chemical processes within the soil (Beckett and Webster, 1971).

Spatial variation studies are fundamental to the perception of the order within the spatial distribution of soil properties (Wilding and Drees, 1978) and can be used to facilitate reasonably accurate soil boundary delineations in soil surveys. A major relevance of studies of soil variables is to describe and map soil properties over the landscape from sample data (Beckett and Webster, 1971). Properties of soils vary from place to place both laterally and vertically. The vertical variation, profile, has been the concern of pedologist for many years. It has been described conventionally by recognizing layers, horizons, and then treating each of these separately. Lateral variation has been treated similarly. Soil surveyors recognize where the soil changes in a relatively abrupt manner and draw boundaries there to separate the soil into classes. They describe each class separately from sampling points within them. Average or typical values within classes are then used as predictors for those classes (Webster and Burgess, 1983).

Geographical Information Systems(GIS), in combination with geostatistics, can be effectively used in solving many management problems (Stein, 1994). Geostatistics has afforded scientists the capability to study the spatial dependency of various soil properties. It has been reported that soil properties are often spatially correlated either isotopically (Burgess and Webster, 1980a; 1980b) or anisotropically (Boss et al., 1984; McBratney and Webster, 1983). Geostatistical methods have been used to study the spatial dependence of soil salinity (Hajrasuliha, 1984), bulk densities (Entz and Chang, 1991), and electrical conductivities (Chery et al., 1994) within given field situations. This method has also been used to compute and display semi-variograms for soil texture and pH of soil derived from loess and glacial till (Cambell, 1978). Semi-variograms have been used to show the spatial correlation of soil properties such as phosphate-phosphorus and potassium over a range of greater than 100 m (Yost et al., 1992). Petiole nitrate content of cotton has been shown to be closely related to soil clay content and not soil nitrate (Tabor et al., 1985). Sharma and Karr (1994) showed that the high spatial variabilities of soil water and nitrogen fertilizer at the subsurface depths of an irrigated lateritic soil were affected by the high variability of clay and bulk density. It has also been shown that the average soil test potassium (K) values may be misleading if the spatial variation of K is not considered (Ndiaye and Yost, 1989).

Interest in spatial pattern of soil properties on the landscape continues to grow and it is of practical importance to both researcher and producers in making land use decisions. Although land owners have always sought better ways to manage information, the GIS technology has not been within reach for many potential users. Hardware and software are gradually becoming affordable, with the new wave of personal computers and stand-alone workstation. Most potential users now see a GIS as inevitable because the system will help them do their jobs better and faster. The hypothesis established for this study states that there is no difference in properties of soils as a result of management practices as assessed using field-scaled GIS techniques.

The objectives of this study were: (i) To develop and evaluate the use of Geographic Information System (GIS) technology for enhancing field-scale management practices; (ii) to evaluate the use of three-dimensional modeling techniques to visualize changes due to different management practices and (iii) to define spatial classes of variables from geostatistical analysis.

MATERIAL AND METHODS

Data Base Analysis and Decision-Making

A 50-m grid system was established at the Alambama A&M University Winfred Thomas Agricultural Research Station located in Hazel Green, Alabama. Soil mapping units and interpretation were extracted from the soil survey report of Madison county, Alabama (Swenson et al., 1958). Soil cores were extracted down to a depth of 30 cm, characterized using standard soil horizon terminology (Soil Survey staff, 1985) and separated into 15 cm increments. Soil physical properties (particle size distribution, organic matter, and pH) were determined for each sample using standard procedures in Methods of Soil Analysis, Part I (Klute, 1986). Land use and best management practice (BMP), depth of the A-horizon, depth to the B-horizon, drainage, infiltration rate, permeability, and water holding capacity of each soil mapping unit were coded according to the terminology set forth in the National Soils Handbook (Soil Survey Staff, 1985) used by the USDA-Natural Resource Conservation Service. The GIS analysis and modeling were done using the UNIX version of ARC/INFO and Arcview software (ESRI, 1995) on a SunSPARCstation 10 platform. The Motorla Global Positioning System by Geolink with base station was used to determine the geographic coordinates of the study area. The resulting map was then used to spatially locate areas of interest for further investigation.

Geostatistical Data Analysis

The spatial structure of the soil properties was determined using standard geostatistical techniques. Semivariograms were computed omnidirectionally at each sampling depth and at 4 angles (0, 45, 90, 120) to test for anisotropy. There were 83 samples for fileld 1 and 68 samples for field 2. The semivariograms were computed for a maximum distance of 50 m. Variance was graphed as a function of sample separation distance. The model coefficients (sill, nugget effect and range) were calculated. All geostatistical computations were performed using geostatistical software (GS+, Gramma Design Software, St. Plainwell, MI).

Table 1. Summary statistics of selected soil physical properties at different depths for field 1 and field 2.

Parameters	Depth (cm)	Mean	Minimum	Maximum	Standard deviation	# of Samples
Field 1						
Sand, %	0-15	12.99	3.68	67.68	10.74	83
	15-30	16.2	3.68	57.68	9.74	83
Silt, %	0-15	43.83	0.00	62.88	10.26	83
	15-30	38.97	0.00	72	11.03	83
Clay, %	0-15	42.88	1.44	60.32	7.86	83
	15-30	45.14	8.32	62.88	9.04	83
Org. Matter, %	0-15	1.34	0.74	1.79	0.24	83
	15-30	0.82	0.23	1.52	0.32	83
pH in water	0-15	6.23	4.74	7.29	0.45	83
	15-30	6.2	4.87	7.3	0.54	83
Field 2						
Sand, %	0-15	14.61	0.80	32.80	8.29	68
	15-30	12.78	0.80	32.80	8.56	68
Silt, %	0-15	40.59	12.00	60.00	8.56	68
	15-30	37.97	8.00	60.00	9.88	68
Clay, %	0-15	44.80	7.20	71.20	9.94	68
	15-30	49.28	31.20	71.20	8.74	68
Org. Matter, %	0-15	2.95	2.01	4.02	0.53	68
	15-30	2.57	0.67	4.02	0.71	68
pH in water	0-15	5.93	4.96	6.79	0.40	68
	15-30	5.98	4.93	6.78	0.44	68

Table 2. Semivariograms of selected soil physical properties at different depths for field 1 and field 2.

Parameters	Depth (cm)	Nugget variance	Sill	Range	Isotropic* model	Nugget %	R^2	Spatial** Class
				Field 1				
Sand, %	0-15	27.2	137.2	97.5	S	19.83	0.40	S
	15-30	49.4	80.2	109.9	E	61.59	0.07	M
Silt, %	0-15	54.0	121.0	128.7	S	44.62	0.43	M
	15-30	123.0	142.6	664.8	E	86.25	0.15	W
Clay, %	0-15	36.10	67.27	17.2	E	53.66	0.07	M
	15-30	64.9	80.7	43.5	E	80.42	0.36	W
Org. Matter, %	0-15	0.04	0.07	810.9	S	57.14	0.68	M
	15-30	0.09	0.12	791.7	S	75.00	0.59	M
pH in water	0-15	0.12	0.22	190.4	S	54.54	0.72	M
	15-30	0.25	0.31	227.0	S	80.64	0.72	W
				Field 2				
Sand, %	0-15	45.50	76.50	121.3	E	59.47	0.97	M
	15-30	64.00	85.00	259.5	S	75.29	0.38	W
Silt, %	0-15	48.49	72.73	105.0	L\S	66.67	0.28	M
	15-30	56.7	85.1	105.0	S	66.62	0.68	M
Clay, %	0-15	53.0	107.6	252.3	S	49.25	0.87	M
	15-30	52.10	86.35	179.0	S	60.33	0.90	M
Org. Matter, %	0-15	0.27	0.41	652.0	E	65.8	0.41	M
	15-30	0.36	0.52	131.7	S	69.23	0.24	M
pH in water	0-15	0.12	0.16	85.2	S	31.25	0.41	M
	15-30	0.08	0.20	85.3	S	40.00	0.28	M

* L=Linear
L/S=Linear/sill
S=Spherical
E=Exponential
** S=Strong (% nugget < 25)
M=Moderate (% nugget between 25 and 75)
W=Weak (% nugget > 75)

RESULTS AND DISCUSSION

Multi-layered field-scale GIS

The GIS framework described herein is a first step toward developing a more comprehensive management system for assessing and modeling land management practices. The study addresses the use of 2-D displays while providing detailed spatial data needed for the implementation of best management practices (BMP).

The thickness of the A-horizon ranged from 5 to 20 cm. Water table depths exceeded the 2 m sampling depth; however, in low areas evidence of the presence of a high water table for intermittent periods during the year was observed. Infiltration rates ranged from 0.5 cm / hr to 7.5 cm / hr and permeability ranged from 0.06 cm / hr to 50.1 cm / hr. Slope percentages ranged from 0.1 to 20 percent. The advantage of viewing information contained in the database in 2-D is that it provides a more realistic and simplistic view to the user as conditions are being evaluated.

The GIS database allows one to make any number of comparisons or speculative analyses of the entire land area or any specified field. It provides the land manager an opportunity to quickly perform analyses comparing previous management practices with current practices. The potential usefulness of this technology in evaluating crop performance due to soil variablilty as result of soil physical properties and spatial variability has been demonstrated. The Two and three-dimensional displays have been proven to be useful as decision aid for land managers. Conversely, two dimensional displays affords the farm manager an opportunity to view and model landscape conditions that are consider to be potential problems. The systems will enable decision-makers to develop a better management plan and maximize their inputs.

Variation of Soil Physical Properties

Table 1. shows that the clay content ranged from 1.44 to 60.32 in field 1 at the 0-15 cm depth. The range in clay at the same depth in field 2 was narrower (7.20-71.20%). Mean clay content in the 15-30 cm depth was significantly higher in field 2 than in field 1, however, similar amounts were obtained in the topsoil of both fields.

Silt content was higher in the topsoil and subsoil in field 1 than in field 2.

Mean of sand, organic matter, and pH in the top soil were significantly different at both sites. The same relationships were obtained in the subsoil.

Semivariograms

Semivariograms were used to determine the spatial dependence of soil physical parameters at both sites. The attributes of the semivariogram investigated were the sill, which is directly related to total sample variance, the range which is the lag distance at which the variance levels off and nugget variance which represents random and sampling error. Another attribute was the nugget semivariance expressed as a percentage of the total variance. This ratio was used to define distinct classes of spatial dependence for soil physical parameters (Cambardella et al., 1994). Majority of the parameters in field 1 were fitted to spherical models (Table, 2) spherical models were also defined for most of the same parameter in field 2 except sand content at 15-30 cm depth.

With the exception of organic matter and silt nugget variable of the parameters were higher in field 2 than in field 1 at corresponding depths (Table, 2). Similar relationships were obtained for the sill and range. Organic matter had an unusually large sill at both sites. All of the parameters in field 2 exhibited moderate spatial dependency (nugget percentage 25-75%), except sand content at 15-30 cm depth. Sand in the 0-15 cm depth were strongly spatially dependency (nugget percent < 25%) in field 1. Silt, clay and ph in the subsoil exhibited weak spatial dependency (nugget percent >75%) in field 1.

CONCLUSION

The study illustrates that there are only slight differences in the amounts and distribution (both vertically and horizontally) of soil physical properties at two sites studied. It was ascertained through the construction of semivariograms that there were similarities in spatial variability patterns for most of the soil physical parameters evaluated. It must be emphasized that the two fields studied were not chosen to represent any specific different physical-chemical conditions. The use of this technology will become more acceptable as a management tool for assessing and modeling land management practices.

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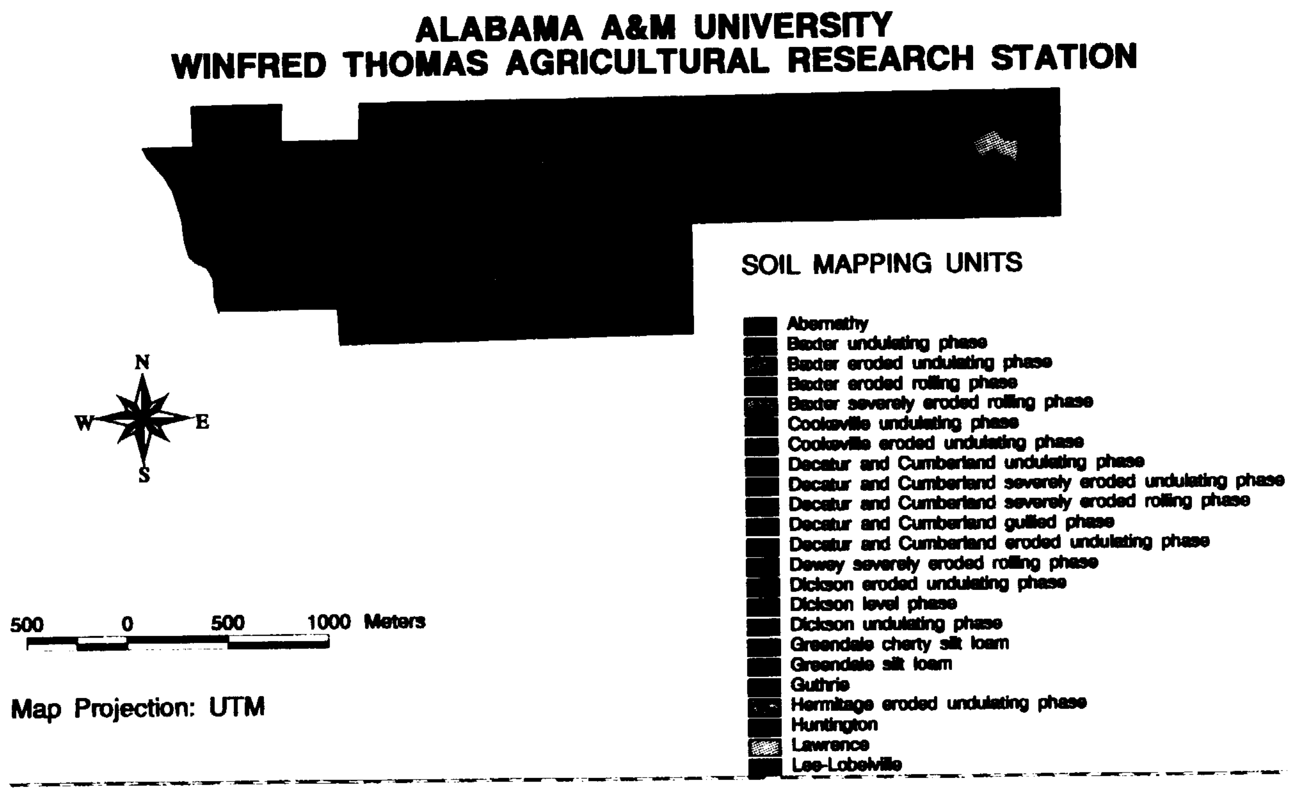

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