MULTIVARIATE CROP PRODUCTIVITY ZONES IN THE ALABAMA COASTAL PLAIN

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Abstract.

Various data are used to develop management zones for site-specific crop production. Most evidence indicates that the technique used for zone development is crop and management dependent. The objective of this research is to evaluate which field-scale data are most appropriate for developing management zones for characterizing crop productivity and variability over multiple growing seasons and managements. Specifically, we are evaluating: 1) if field-scale crop yield variability is better described in zones derived from temporal or static data, and 2) the relationships between zone development approach and soil management system. This study was conducted on a field-scale (20 acre) experiment evaluating the interaction of soil management systems (conventional versus conservation) with soil landscapes on a site in the Alabama Coastal Plain. Six replications in a cotton (*Gossypium hirsutum L.*) - corn (*Zea mays L.*) rotation traverse the landscape. Soil landscapes range from Typic Paleudults on well drained uplands to imperfectly drained Oxyaquic Paleudults in drainageways. Field-scale data include satellite remote sensing imagery, terrain attributes generated from a LiDAR derived digital elevation model (DEM), field-scale electrical conductivity, and a first-order soil survey (1:5000). Management zones were developed using fuzzy k-means clustering, and geo-referenced crop yield data have been collected (2001-2006). Our results indicate that all evaluated data were generally suitable for characterizing crop productivity and variability using a clustering approach. As expected, satellite remote sensing data collected in season were more highly related to yield compared to terrain and soil variables. The relative effectiveness of these data for describing yield variability is most dependent on crop, and somewhat dependent on management.

INTRODUCTION

Multiple data are used in the development of site-specific crop management zones. Remote sensing imagery, terrain attributes generated from elevation models, field-scale electrical conductivity and soil surveys are among typical data. Each of these data has a demonstrated

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ability to describe crop productivity and variability. However, the effectiveness of these data is soil management dependent, and some of these data are highly temporally variable, requiring multiple acquisitions. These interactions complicate the optimum utilization and combination of these data for crop management zone development.

We are evaluating the relationship of field-scale data to crop productivity on an experiment investigating interactions of soil landscapes and management systems in the Alabama Coastal Plain. Multiple managements at this scale provide an opportunity to evaluate the performance of zone development data across both management system and landscape. Details on the first three years (2001-2003) of cotton productivity (as a function of landscape and management) and soil C sequestration for this experiment have been published elsewhere (Terra et al., 2005; Terra et al., 2006). The management and landscape effects on productivity have now been evaluated across six years. The specific objectives of this paper are to:

1) evaluate static and temporal data suitability for characterizing crop productivity and variability over multiple growing seasons, and
2) further develop relationships between zone development technique and soil management.

MATERIALS AND METHODS

Research Site and Experimental Design

The research site is located at the E.V. Smith Research Center, near Shorter, AL. The experiment is a joint undertaking between the USDA-ARS National Soil Dynamics Laboratory (NSDL) and the Alabama Agricultural Experiment Station (AAES). The experiment's 20 acre landscape is representative of the Alabama Coastal Plain region. Soils on the site range from Typic Paleudults in well-drained uplands to Oxyaquic Paleudults in drainageways. Cotton and corn yields have been collected and geo-referenced with a yield monitor since 2001. Various other data have been collected on this site between 2001 and 2006 (see Terra et al., 2004; Balkcom et al., 2005).

The treatments consist of a cotton-corn rotation in conservation and conventional management systems with and without manure amendments. The four treatments are replicated six times in strips (21.3-ft wide) that traverse the landscape. Experimental cells along each strip (21.3-ft wide by 59.1-ft long) have been developed for sampling efforts. The conservation system consists of winter cover crops before the summer cash crop (cotton and corn); conventional systems do not have cover crops. Conventional system tillage consists of chisel plow, disking and in-row subsoiling, while the conservation system utilizes strip-tillage (in-row subsoiling) that results in a narrow (4-6 inch) zone of surface disruption in heavy residue. Dairy manure amendments were applied as solids at 8 tons per acre. Both phases of the rotation exist in each year. Further details on treatments and experimental design for this test can be found in Terra et al. (2006).

Temporal Data

Remote sensing satellite imagery was collected in July 2004 and August 2005 by the Quickbird (Digital Globe, Longmont, CO) multi-spectral imaging satellite. The four band (blue, green, red and near infrared), 8.0-ft resolution images were subsequently geo-referenced and ortho-rectified. The images were calibrated using coefficients provided by Digital Globe.

Normalized Difference Vegetation Indices (NDVI) were generated and averaged by cell for both cotton and corn crops in 2004 and 2005:

$$rNDVI=(NIR-red) / (NIR+red) \quad (eq. 1)$$

$$gNDVI=(NIR-green) / (NIR+green) \quad (eq. 2)$$

where rNDVI and gNDVI are the red and green NDVI, and NIR, red and green are reflectance values in the near infrared, red and green regions, respectively.

Field-scale electrical conductivity (EC) measurements were taken on the research site in March 2001 using the Veris ® 3100 (Veris Technology, Salina, KS). This method uses direct contact sensors to measure soil electrical resistivity, which is converted to apparent electrical conductivity (EC_a) ($mS\ m^{-1}$). Estimated depths of data resolution are 0-11.8 inches [(EC shallow)] and 0-35.4 inches [(EC deep)] (Veris Technologies, 2003). Data points were interpolated (kriging method) in ArcGIS (ESRI, Redlands, CA) to create continuous map surfaces at 16.4-ft resolution.

Static Data

An order 1 soil survey (1:5000 scale) of the research site was developed to characterize soil spatial variability. Selected soil samples from type pedons were analyzed to facilitate soil classification. The soil observations were overlaid with a maximum downhill slope raster (from an RTK-GPS derived DEM) to develop digitized map units across the landscape (Figure 1).

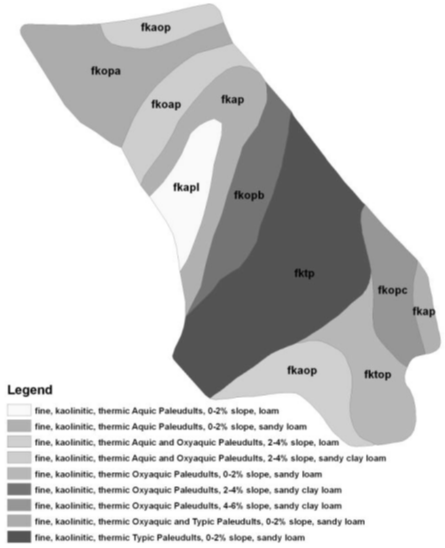

Figure 1 – Order 1 soil survey (1:5000) of the Coastal Plain research site.

LiDAR data were collected in spring 2006, and a 16.4-ft digital elevation model (elev) was developed. Terrain attributes including maximum downhill slope percentage (MDS), hydrologic flow direction and accumulation, specific catchment area (SCA) and compound topographic index (CTI) were generated using ArcGIS. The SCA and CTI (Moore et al., 1993) were calculated according to standard approaches. As a result of 'noise' artifacts (erroneous portions of a model not representative of the actual landscape) in the ArcGIS curvatures, landscape curvatures (plan, profile and mean) were modeled in ERDAS Imagine (Leica Geosystems GIS & Mapping, Atlanta, GA) using ArcGIS curvature formulas and an expanded neighborhood size (5x5 matrix with a 36.1-ft lag distance).

Management Zone Development

Selected terrain attributes – elevation, maximum downhill slope, CTI, flow direction and accumulation, and profile curvature – were utilized for terrain management zone development. These values were normalized and processed by the Management Zone Analyst (MZA) software (Fridgen et al., 2004), which employs fuzzy k-means clustering to create multivariate management zones or clusters. The output clusters were rasterized to a 16.4-ft image (Figure 2).

An identical process was used for the creation of field-scale electrical conductivity clusters using both depth intervals (i.e. EC shallow and EC deep) (Figure 3). Terrain attribute clusters, field-scale electrical conductivity clusters, and the order 1 soil survey were used to characterize landscape variability (i.e. three different approaches) and to relate to crop productivity.

Figure 2 – Terrain attribute management zones created using fuzzy k-means clustering of LiDAR derived terrain attributes.

Figure 3 – Field-scale electrical conductivity management zones created using fuzzy k-means clustering of shallow (EC 0-30 cm) and deep (EC 0-90 cm) EC measurements.

RESULTS

Both cotton and corn yields are highly temporally variable from year to year (Table 1). 2002, 2005 and 2006 were dry during the critical periods for corn yield, while 2002 and 2006 were dry during the first flower to peak flower cotton stages, and thus yields are relatively low for those years. Adequate rainfall for cotton was received in 2004, but damage from Hurricane Ivan at harvest negatively impacted yields. Although annual effects vary, averaged over all years of this experiment, conservation system yields are approximately 10% higher than conventional system yields for both crops.

Table 1. Seed cotton and corn grain yields by year and treatment. CT=conventional management system, and NT=conservation management system.

Treatment	2001		2002		2003		2004		2005		2006		Average	
	Cotton	Corn	Cotton	Corn	Cotton	Corn	Cotton	Corn	Cotton	Corn	Cotton	Corn†	Cotton	Corn

lbs acre^{-1}

CT	2467	8515	1128	6194	2655	10881	1325	7609	3198	5307	745	-	1906	7777
CT + Manure	2597	9015	1222	6127	2718	11150	1289	9166	3585	4484	932	-	2043	8065
NT	2778	8955	1456	7831	3045	11556	1594	9383	3423	5466	883	-	2182	8715
NT + Manure	2825	8943	1451	8135	3076	11738	1521	9997	3479	4688	735	-	2167	8776

† Due to extremely limited rainfall, no corn yield in 2006.

Highly significant differences in yields between clusters were evident for all clustering techniques (Table 2), with corn yield differences being slightly less significant. Furthermore, significant interaction between cluster technique (of the three clustering techniques) and management were found. All clustering techniques for corn had highly significant interactions with management, while these interactions in cotton were slightly less significant. No significant interactions were found between clusters and manure application. These findings support previous studies suggesting relationships between zone development technique and soil management system.

Table 2. Management zone effects on and crop yield variability.

Cluster Technique	Cluster		Cluster*manure		Cluster*management	
	Cotton	Corn	Cotton	Corn	Cotton	Corn
Map Unit	***	***	ns	ns	**	***
Terrain Attributes	***	**	ns	ns	**	***
Electrical Conductivity	***	***	ns	ns	***	***

** and *** significant at the 0.01 and 0.001 level respectively; ns= not significant

Pearson linear correlation coefficients (r) were measured to relate terrain and soil data (without remote sensing data) to crop yield for all years of the test (2001-2006), and again solely for 2004 and 2005 when remote sensing data were acquired (Table 3). Although several variables were related to yield, the temporally dependent variables rNDVI and gNDVI were most highly related to corn and cotton yields in the season of remote sensing acquisition. The fact that the NDVI correlation values are much higher than the other variables is not surprising, as these data were acquired within that particular growing season and thus provide a timely view of growth characteristics and level of plant stress related to crop yield. In addition, NDVI values were more highly related to corn than cotton yields.

The EC shallow and EC deep values were significantly related to crop yield in both approaches, even though several years have passed since this EC data collection (2001). Among static variables, the maximum downhill slope was significantly related to crop yield, but correlation values were much lower than observed with the NDVI values. The negative correlation between slopes, EC and yields is similar to what other researchers have found (Terra et al., 2006), and is likely due to a higher EC occurring on more clayey, eroded sidelopes (with higher slope) of generally lower productivity.

Table 3. Pearson linear correlation coefficients relating terrain attributes, field-scale electrical conductivity (EC shallow and EC deep) and NDVI to corn and cotton yields.

Variable	Pearson Linear Correlation Coefficient			
	2001-2006 (w/o NDVI)		2004 & 2005 (w/ NDVI)	
	Cotton	Corn	Cotton	Corn

Elev	ns	-0.077**	ns	-0.131**
MDS	-0.160***	-0.204***	-0.186***	-0.334***
CTI	ns	ns	ns	Ns
Flow Direction	-0.113***	ns	ns	-0.183***
Flow Accumulation	ns	0.113***	ns	0.180***
Profile Curvature	-0.077**	-0.123***	ns	-0.219***
rNDVI	-	-	0.416***	0.817***
gNDVI	-	-	0.336***	0.812***
EC shallow	-0.214***	-0.224***	-0.238***	-0.448***
EC deep	-0.129***	-0.183***	-0.159***	-0.323***

** and *** significant at the 0.01 and 0.001 level respectively; ns= not significant.

Similar to the correlation analyses, the temporally dependent NDVI values were highly significant in regression analyses (Table 4). In the absence of NDVI data for 2001-2006, the EC was more highly related to yield than the terrain factors. Regression analyses also indicated yield variability was better described for corn than cotton using the remote sensing, LiDAR derived terrain, and EC independent factors. Although the yield variability was generally better described in conservation management of corn, no definite trend was observed with respect to management in this regression approach.

Table 4. Linear regression relating independent variables to crop yield.

Treatment	2001-2006 (w/o NDVI)				2004 & 2005 (w/ NDVI)			
	Cotton		Corn		Cotton		Corn	
	R^2 †	Significant Variables ‡	R^2	Significant Variables	R^2	Significant Variables	R^2	Significant Variables
CT	0.134	EC30	0.073	EC90	0.544	rNDVI, gNDVI	0.712	rNDVI, EC30, Elev
CT + Manure	0.052	EC30	0.062	EC30	0.349	gNDVI	0.863	rNDVI, EC30
NT	0.090	MDS	0.114	EC30	0.485	rNDVI	0.829	rNDVI, EC30, Flow Direction
NT + Manure	0.130	EC30, CTI	0.106	EC30	0.233	rNDVI	0.870	gNDVI, EC30, Flow Direction

† Coefficient of Determination

‡ Partial Coefficient of Determination = 0.10

CONCLUSIONS

All data tested are generally suitable for characterizing crop productivity and variability over multiple growing seasons using a clustering approach. However, the relative descriptiveness of these data varies, and is greatly affected by crop and somewhat affected by management. For example, using a regression approach, corn productivity was better characterized by these soil, remote sensing and terrain variables than cotton productivity. The culmination of this suggests that an optimum combination of these data could be developed for a certain management system and crop to improve management zone delineation. The “in-season” remote sensing measures (NDVI) were far superior for that year as compared to the more static soil and terrain characterization (as expected). However, the timeliness and cost of acquiring these remote sensing data are such that seasonal acquisitions are sometimes impractical.

REFERENCES

Balkcom, K.S., J. A. Terra, J.N. Shaw, D.W. Reeves and R.L. Raper. 2005. Soil management system and landscape position interactions on nutrient distribution in a Coastal Plain field. J. Soil Water Cons. 60(6):431-437.

Fridgen, J.J., N.R. Kitchen, K.A. Sudduth, S.T. Drummond, W.J. Wiebold, and C.W. Fraisse. 2004. Management Zone Analyst (MZA): Software for subfield management zone delineation. Agron. J. 96:100–108.

Moore, I.D., P.E. Gessler, G.S. Nielsen, and G.A. Peterson. 1993. Soil attribute prediction using terrain analysis. Soil Sci. Soc. Am. J. 57: 443-452.

Terra, J. A., J.N. Shaw, D.W. Reeves, R.L. Raper, E. van Santen and P.L. Mask. 2004. Soil carbon relationships with terrain attributes, electrical conductivity, and a soil survey in a coastal plain landscape. Soil Sci.169:819-831.

Terra, J.A., D.W. Reeves, J.N. Shaw and R.L. Raper. 2005. Impact of landscape attributes on C sequestration during the transition form conventional to conservation management practices on a Coastal Plain field. J. Soil Water Cons.60(6): 438-445.

Terra, J.A., J. N. Shaw, D. W. Reeves, R. L. Raper, E. van Santen, E. B. Schwab, and P. L. Mask. 2006. Soil management and landscape variability affects field-scale cotton productivity. Soil Sci. Soc. Am. J. 70:98-107.

Veris Technologies. 2003. Frequently asked questions about soil electrical conductivity [Online]. [2 p.] Available at: http://www.veristech.com [cited 8 Oct. 2003; verified 15 Mar. 2005]. Veris Technologies, Salina, KS.