Soil Management, Terrain Attributes and Soil Variability Impacts on Cotton Yields

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ABSTRACT: The ultimate goal of site-specific agriculture (SSA) is to optimise inputs for agronomic and environmental benefits. Soil and yield variability and their interaction with soil management practices are required to understand cause-effect relationships. However, these interactions have rarely been assessed at the landscape level. Our objective was to evaluate two years of cotton (*Gossypium hirsutum L.*) seed yield response to soil management practices and the interactions with terrain and soil attributes in a 10 ha field in the coastal plain of Alabama, USA. A soil survey, topography, and soil electrical conductivity (EC) maps were obtained to delineate management zones. Eight terrain attributes were derived from the digital elevation model. The field was divided into 496 cells of 20 x 6-m; composite soil samples (30 cm depth) were collected and analysed for soil organic carbon (SOC) and texture. Four treatments were established in a randomised complete block design with six replicates in 6 m wide strips traversing the landscape in a corn (*Zea mays L.*)-cotton rotation. Treatments were a conventional system with (CTM) or without dairy bedding manure (CT), and a conservation system with (NTM) and without manure (NT). In CT and CTM, tillage consisted of chisel ploughing/disking + in-row subsoiling; no cover crop was used in winter. The NT and NTM consisted of no-tillage with non-inversion in-row subsoiling and winter cover crops. Yield was analysed using mixed models with or without accounting for spatial correlation using the modelled semivariogram. Stepwise regression was used to establish relationships between terrain attributes and yield. Additionally, management zones were created using cluster analysis. Conventional systems yields were 10% lower than conservation systems in 2001 (2836 vs. 3122 kg ha^{-1}) and 19% lower in 2002, a drier year (1322 *vs* 1629 kg ha^{-1}). Neither manure nor the treatment*year interactions were statistically significant at $P \leq 0.05$. Accounting for spatial correlation reduced standard errors of treatment means, making the manure effect and the interaction manure*management system significant. Slope, EC, SOC and clay affected yield in all management systems and R^2 ranged between 0.25 and 0.62 (depending on year and treatment). The conservation system was more productive in all environments which resulted from the combination of two years x three management zones created. The conservation system has greater impacts in dry years and in management zones with lower yield potential.

Keywords. Site-specific agriculture, management zones, soil management systems, conservation systems, terrain attributes, soil electrical conductivity, soil organic carbon, cover crop, cotton.

INTRODUCTION

Site-specific agriculture is a method of production in which zones and soils are delineated and managed according to their unique properties (Plant, 2001). Field scale variability of soils and landscapes are major causes of spatial variability in crop yields.This has prompted the need to identify field zones, which can be delineated, grouped, and managed in a similar way in order to optimise inputs and or maximise profits for agronomic, economical and environmental benefits (Fraisse *et al.*, 2001). A fundamental understanding of what controls the systematic components of variability can lead to the development of rapid and cost effective methods for constructing management zones. Zone delineation techniques include: 1) remote sensing and aerial photography; 2) conventional soil testing; 3) conventional soil survey; 4) digital elevation models; 5) farmer knowledge and 6) yield mapping. The evaluation of SSA must be assessed through its impacts on soil quality and associated productivity. Although the underlying premise for the application of SSA and the development of management zones is the presence of spatial heterogeneity, temporal persistence of yield patterns are paramount for establishing management zones based on yield data (Sawyer, 1994). Because landscape attributes can be quantified, it is critical to evaluate how these attributes affect productivity and soil quality. Similar landscape elements can be grouped, facilitating management zone delineation. The ability to rapidly map soil EC offers great potential as a tool for constructing or refining management zones (Johnson *et al*., 1997), provided that the complex relationships between soil quality indicators, productivity, and EC readings are determined and quantified.

Soil management practices strongly influence soil quality and crop productivity (Logan *et al*., 1991; Reeves, 1997; Kumar and Goh, 2000). Research in the southeastern USA has shown that adoption of conservation systems that eliminate or reduce tillage operations and that include crop rotations incorporating high production of residues improves soil quality and productivity (Reeves, 1994; Tyler *et al*., 1999). Although the development of new technologies has allowed researchers to study the effects of soil and terrain attributes on crops yield (Kravchenko and Bullock, 2000; Fraisse *et al*., 2001, Kaspar *et al*., 2003), the impact of different soil management systems has rarely been assessed at the landscape level (Ginting *et al*., 2003). A combination of technological advances and new management strategies may provide a way to improve crop productivity, while improving environmental stewardship. Field scale experiments and the use of combines equipped with yield monitors and Differential Global Position Systems (DGPS) may allow the assessment of management effects over a field or for zones within it.

The objective of this study was to evaluate cotton yield response to different soil management practices and their interactions with landscape and soil attributes for two years (2001–2002).

MATERIALS AND METHODS

This study was conducted in a 10 ha field located at the Alabama Agricultural Experiment Station's E.V. Smith Research Center in central Alabama, USA. Soils at the experiment site are mostly Aquic and Typic Paleudults. Cotton (Suregrow 125 B/R') was planted the last week of May in 1-m rows at 170,000 seeds ha^{-1} both years. Management practices including fertilization, herbicides, insecticides, growth regulators and defoliation followed Alabama Cooperative Extension System recommendations.

Treatments were established in 6-m wide and ~250-m long strips in a randomised complete block design (RCB) with six replicates. A factorial arrangement of two soil management systems with and without annual application of 20 Mg ha^{-1} of dairy manure (50% dry matter) was evaluated in a corn-cotton rotation. Treatments included a conventional system, a conventional system + dairy bedding manure, a conservation system and a conservation system + manure. In the conventional systems, tillage consists of chisel ploughing/disking and in-row subsoiling. No cover crop was used in winter, but winter weeds were not controlled. The conservation systems included no-tillage with non-inversion in-row subsoiling and a winter cover crops mixture of white lupin (*Lupinus albus* L.), crimson clover (*Trifolium incarnatum* L.), and fodder radish (*Raphanus sativus* L.) prior to corn and a mixture of black oat (*Avena strigosa* Schreb.) and rye (*Secale cereale* L.) prior to cotton. Each strip was divided into cells of 6 x 20 m resulting in a total of 496 cells in the entire field. Composite soil samples were collected inside each cell and analysed for organic carbon and soil texture at the beginning of the experiment. Seed cotton yield was determined across the field with a spindle-harvester equipped with DGPS and yield monitors during the second week of October in both years.

A soil survey, elevation, and EC maps were developed for delineating soil and landscape variability. A detailed soil survey (order 1) was developed according to National Cooperative Soil Survey (NCSS) standards; drainage classes were assigned for each map unit. The field was surveyed two times with a Veris® Technology 3100 Soil EC Mapping System equipped with DGPS. Electrical conductivity measurements were taken at depths of 30 cm and 90 cm. A Trimble® 4600 L.S. Surveyor Total Station was used to determine elevations across the field; digital elevation models (DEMs) and terrain attributes were developed using geographical information systems ArcInfo® and Erdas® Imagine. Terrain attributes included: elevation (ELEV), slope, aspect (ASP), profile curvature (PROFC), plan curvature (PLANC), flow accumulation (FA), catchment area (CA) and compound topographic index (CTI). All terrain and soil attributes were interpolated (ordinary kriging) to a 5-m grid resulting in a total of thirteen stacked layers (ELEVA, SLOPE, ASP, PROFC, PLANC, FA, CTI, EC at 0-30-cm, EC at 0-90-cm, SOC, clay, sand, water table depth).

Yield responses were analysed by four procedures. In the first, the experiment was analysed as a conventional RCB design using the strips as the experimental units and cells within strips as subplots. In the second, we accounted for the spatial correlation of cells residual yield, using the modeled semivariogram in order to reduce the experimental error (Mulla *et al.*, 1990; Littell *et al.*, 1997; Mallarino *et al.*, 2000). The MIXED procedures in SAS® were used for the first two approaches. For the overall mixed model, treatment (manure addition and management system), year and their respective interactions were considered to be fixed effects, while replication and interactions with treatments and year were random. In analysis within years, treatment and the management*manure interaction were fixed effect whereas replication and replication*treatments were random. An F statistic with $P \leq 0.05$ was used to determine the significance of the fixed effects.

We used multiple regression analysis in the third approach to evaluate the effect of soil and terrain attributes on yield of each treatment using the average values of each cell. A stepwise linear regression procedure with $P \leq 0.10$ as the criterion for retaining a variable in the model was used. The fourth procedure assessed treatment effects for zones of the field with different landscape attributes. Management zones were determined using an unsupervised classification of terrain and soil attributes following a similar procedure described by Fraisse *et al*. (2001). Principal component analysis and Pearson correlation coefficients were used to determine the variables explaining field and yield variability, respectively. An unsupervised classification of the most related stacked layers was run in Erdas Imagine® using the ISODATA clustering algorithm.

RESULTS AND DISCUSSION

Seed cotton yield was affected by year and soil management system but was not affected by manure addition (Table 1). No interactions were found between years and treatments or between management system and manure. Yield was 50% lower in 2002 (1475 kg seed cotton ha^{-1} vs. 2979 kg ha^{-1}) due to 50% less rainfall in 2002 than in 2001 during the critical period between first and peak bloom. The NT and NTM yields (2355 kg ha^{-1} and 2366 kg ha^{-1}) were significantly higher than the CTM (2147 kg ha^{-1}); the lowest yields occurred with CT (2027 kg ha^{-1}). Conventional systems (CT and CTM) yields were 10% lower than the conservation systems (NT and NTM) in the average rainfall year (2001) and 19% lower in the dry year (2002).

Accounting for spatial correlation in field experiments is critical for strip trials (Mulla *et al*., 1990; Mallarino *et al*., 2000, Bermudez and Mallarino, 2002). When treatment and replication effects were removed from the cell yields averages, the modeled semivariogram of the residuals revealed spherical models in both years and strong spatial correlation of cotton yield with a range of 55 m and 70 m in 2001 and 2002, respectively. The sill/nugget ratio was more than 15 in 2001 and more than 5 in 2002. Given that the analysis without spatial adjustment accounted for > 90% of the variance among observations (cells), the improvement expected using spatial information was deemed to be small. The maximum change in treatment yield was 7 and 22 kg ha^{-1} in 2001 and 2002, respectively (Table 1). The most interesting results of this approach were that the manure effect and manure*management system interactions, that were not significant in the first approach, became significant when yield adjustments were done using the modeled semivariogram. Manure addition increased cotton yield by 7% in the conventional system but did not have any effect on yield in the conservation system.

Table 1. Effect of management system and manure on seed cotton yields for two years of a field experiment analysed as randomised complete block design with or without accounting for spatial correlation.

	RCB† Design			**RCB and SEM‡**		
	Year			**Year**		
Treatment	**2001**	**2002**	**Overall Mean**	**2001**	**2002**	**Overall Mean**
	----------------kg ha^{-1}-------------------			------------------kg ha^{-1}-----------------		
Conventional Tillage	2767	1266	2027	2774	1251	2014
Conventional Tillage + Manure	2904	1377	2147	2909	1397	2157
No Tillage	3100	1629	2356	3096	1651	2373
No Tillage + Manure	3145	1628	2366	3149	1612	2375
standard error	87	41	60	72	31	44

† RCB = Least Squares Means for the Randomised Complete Block
‡ SEM = Least Squares Means of the analysis of a RCB including a spherical semivariance model

Correlation coefficients between yield, terrain attributes and soil properties for each year and management system are presented in Table 2. Although correlation coefficients varied among treatments and year; slope, surface EC, clay content and initial SOC, were generally better related to seed cotton yield under all management conditions in both years.

Table 2. Correlation coefficients (r) and coefficients of determination (R^2) from stepwise regression (P ≤ 0.1) observed between cotton yields and soil and terrain attributes for each year and treatment.

	Treatment 2001†				Treatment 2002†			
Terrain and Soil Parameters	CT	CTM	NT	NTM	CT	CTM	NT	NTM
Elevation	-0.32	-0.29‡	-0.19	-0.03	-0.11	0.16	0.28‡	0.25
Slope	-0.37	-0.35	-0.36‡	-0.25‡	-0.38	-0.67‡	-0.60‡	-0.39‡
Aspect	0.20‡	0.18	0.09	0.20	0.16	0.11	0.10	0.04
Flow Accumulation	0.14	0.25‡	0.05	0.19	0.51‡	0.14	0.28	0.14
Profile Curvature	0.18	-0.19	-0.08	-0.19	0.14	-0.08	0.11	0.20
Plan Curvature	0.39	0.39‡	0.32‡	0.18	0.06	-0.14	-0.02	0.10
Compound Topographic Index	0.13	0.26	0.15	0.19	0.23	0.14	-0.13‡	-0.19‡
Electrical Conductivity (0-30cm)	-0.56‡	-0.61‡	-0.46	-0.38	-0.46‡	-0.69‡	-0.48	-0.31
Electrical Conductivity (0-90cm)	-0.49	-0.51	-0.34	-0.14	-0.20‡	-0.38	-0.42	-0.14
Clay (%, 0-30 cm)	-0.36	-0.38	-0.47‡	-0.50‡	-0.47	-0.46	-0.13	-0.22
Sand (%, 0-30 cm)	0.10	0.15	0.33	0.38	0.27	0.20	0.01	0.17
SOC (%, 0-30 cm) (initial)	0.41	0.51‡	0.15	0.08	0.47‡	0.35	0.53‡	0.31‡
Depth of Water Table	-0.42‡	-0.36	-0.29	-0.05	-0.25	-0.30‡	0.06	0.11
R^2	0.48	0.61	0.35	0.32	0.53	0.62	0.60	0.26

† CT = Conventional System, CTM = Conventional System + Manure, NT = Conservation System, NTM = Conservation System + Manure. ‡ Variable retained in the stepwise regression model

Results were consistent with others reported in the literature (Kravchenko and Bullock, 2000; Kaspar *et al.*, 2003). Electrical conductivity, clay content and slope were negatively correlated with yield. Areas in the field presenting high values for these variables corresponded to areas of eroded and degraded soils, which are inherently less productive due to severe limitations in water storage capacity and other soil physical properties.

Regression models explained between 25 to 60% of yield variability depending on year and treatment. For most situations, slope, elevation, EC, SOC and clay were the variables that appeared most frequently in the regression models. However, their relative contribution was highly variable among treatments and years. Electrical conductivity was included in the regression models of the conventional system in both years, while slope was included in the models explaining yield variability in conservation systems. Results suggested that EC variability is related to soil-terrain characteristics that largely control soil properties and crop yields. Despite initial SOC being relatively low (between 0.5 and 1%) as a result of previous history of continuous cropping with conventional tillage, SOC was always positively correlated with yield and was included in four of the eight adjusted models.

Although 75% of the data set variance could be explained for the first five principal components, the technique was not effective for determining which terrain and soil attributes layers were the most related with this variability because of their similar relative contribution to the principal components. Therefore, cluster analysis was performed using the data layers of information that showed the highest correlation with yield (slope, elevation, electrical conductivity, SOC, clay content). The procedure was used to create different arbitrary number of zones ranged between two to five. For this study, three appeared to be the most convenient and reasonable number of management zones to evaluate because less distinct and interpretable areas were included when the number of clusters increased, making it difficult to have sufficient number of yield records for each treatment in each zone.

Table 3 shows the average of some of the terrain attributes for each of the management zones created. Terrain and soil attributes more likely to limit crop yield increased from zone 1 to zone 3. Zone 3 was the area with lower SOC, higher slope, clay content and EC and deeper water table, all factors affecting water relationships and plant productivity.

Table 3. Mean of terrain and soil attributes for the management zones resultant of the cluster analysis.

Cluster	Elevation (m)	Slope (degrees)	EC 0-30cm (mS/s)	EC 0-90cm (mS/m)	Water Table Depth (cm)	Clay (%)	SOC (%)
Zone 1	68.40	0.90	4.55	5.71	58.54	15.44	0.63
Zone 2	69.99	0.43	4.98	6.01	114.81	18.91	0.58
Zone 3	69.36	1.47	6.86	7.47	105.34	19.37	0.51

Table 4 show yield responses to treatments for the three management zones created (clusters). Significant statistical interactions between management systems and management zones were found both years. Yield in zones (cluster) 1 and 2 were statistically the same in the conservation system, but the conventional system showed a yield reduction in zone 2 compared with zone 1 and in zone 3 compared with zone 2 ($P \leq 0.05$). Cotton yields were higher in the conservation systems than in the conventional systems in most of the zones created for both years. The effect of the manure was more inconsistent and no clear effects on yield were found.

Table 4. Effect of management zones (clusters) and two soil management systems with and without annual application of dairy manure on seed cotton yield during two years of a strip field experiment.

	Yield 2001 †					Yield 2002 †				
Cluster	CT	CTM	NT	NTM	s.e.	CT	CTM	NT	NTM	s.e.
	----------------------------kg ha^{-1} --------------------------					---------------------------kg ha^{-1} --------------------------				
1	3074	3094	3120	3249	150	1582	1573	1684	1656	102
2	2731	2865	3112	3207	135	1281	1388	1759	1738	95
3	2481	2723	2889	2853	135	1147	1231	1536	1512	95

† CT = Conventional System, CTM = Conventional System + Manure, NT = Conservation System, NTM = Conservation System + Manure, s.e. = standard error

CONCLUSIONS

The conservation soil management system had significantly higher yield and less variation than the conventional system in both years. Slope, elevation, EC, SOC and clay content demonstrated the highest correlations with yield. Cluster analysis was an objective and effective method to create management zones; yield differences among cluster analysis-derived management zones were found in both years. However, variable combinations of diverse terrain and soil attribute information were similarly effective in delineating areas of variable cotton yield response, suggesting that economics and simplicity may determine the selection process for management zones in practicality. Yield was more affected in the drier year (2002) by terrain attributes. No clear effect from dairy bedding manure application was found, but there was a greater trend for manure to affect responses in the conventional than the conservation system. The conservation system had greater impacts on seed cotton yield in drier years and in zones with lower yield potential. Our data suggest for degraded soils in warm humid climates like those in the southeastern USA, that a conservation system including no-tillage and high-residue producing cover crops can increase cotton yield and yield stability. In regards to managing field variability on these soils and under these environmental conditions, we speculate that fewer and more simple management zones may be needed for conservation management practices than for conventional tillage practices.

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