SOIL MANAGEMENT PRACTICES AND LANDSCAPE ATTRIBUTE IMPACTS ON FIELD-SCALE CORN PRODUCTIVITY

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ABSTRACT

The influence of terrain attributes on response of corn (*Zea mays* L.) to soil management practices has rarely evaluated, especially on degraded soils. Five management zones (MZ) were delineated in a 9-ha Alabama field (Typic and Aquic Paleudults) using a soil survey, topography and surfaces of soil electrical conductivity (EC), soil organic carbon (SOC) and soil texture. From 2001-2004, a conventional system (chisel plowing/disking with no cover crops) with or without manure (CT_{manure} or CT), and a conservation system (no-till and cover crops) with and without manure (NT_{manure} or NT), were established in strips traversing the landscape in a corn-cotton (*Gossypium hirsutum* L.) rotation, following long-term conventional tillage. Conservation systems had greater yield than conventional systems in all MZ in 2002 (dry season; 8.88 vs. 6.71 Mg ha^{-1}), and in four of five MZ in 2003 (wet season; 13.04 vs. 12.33 Mg ha^{-1}); no differences existed in the initial year, 2001, (9.85 Mg ha^{-1}). In 2004, CT (8.43 Mg ha^{-1}) had the lowest yield in all MZ; NT_{manure} (11.12 Mg ha^{-1}) had greater yield than NT and CT_{manure} (10.46 and 10.19 Mg ha^{-1} respectively) in some MZ. Yield differences between high and low productivity MZ within years were lower in conservation than in conventional systems. Soil degradation and field-scale water dynamics had significant impacts on yield variability. Soil texture, SOC and EC were typically related with yield in all treatments, and explained 15-71 % of yield variation. The aggregate of data indicates for degraded soils in warm humid climates, conservation systems increase corn productivity and spatial and temporal stability of yields even during initial adoption years.

Keywords. Conservation systems, cover crops, soil spatial variability, terrain attributes, management zones, dairy manure.

INTRODUCTION

Soil management practices that eliminate tillage and include crop rotations can increase productivity and reverse soil degradation caused by conventional tillage with row crop monocultures in the southeastern USA (Reeves, 1997). Corn is one of the best choices to rotate with cotton in Coastal Plain soils, particularly in conservation systems where high production of residues is critical. However, the frequent incidence of short-term droughts and degraded soils make farmers hesitant to include corn in the rotation, regardless of it long term potential benefits.

The inherent field- scale variability in Coastal Plain soils results in high crop yield variability over relatively short ranges. Soil properties and terrain attributes linked with water holding capacity, drainage and field-scale water regime are usually related to crop yield spatial variability (Kravchenko and Bullock, 2000; Fraisse et al., 2001). The utilization of temporally stable soil and terrain attributes related with systematic components of yield variation can lead to the development of rapid and cost effective methods for delineating MZ to optimize inputs (Fraisse et al., 2001). Soil spatial variability impacts on crop productivity have been increasingly studied in recent years (Kravchenko and Bullock, 2000; Kaspar et al., 2003). However, the interactions between soil management practices with soil and terrain attributes have been rarely assessed (Ginting et al., 2003; Bermudez and Mallarino, 2004). We hypothesize that landscapes have major effects on crop productivity, but these effects are management and climate dependent. The objective of our research was to determine the relative and interactive effects of four soil management practices (conservation and conventional systems with and without dairy manure applications) with soil landscape variability on corn yields in a Southeastern Coastal Plain field.

MATERIALS AND METHODS

A 9-ha field-scale strip trial was conducted from 2001 through 2004 in a degraded soil (Typic and Aquic Paleudults) located in the Atlantic and Gulf Slope Coastal Plain of Alabama, USA. A conventional system with or without annual application of 10 Mg ha^{-1} (dry matter) dairy manure (CT_{manure} or CT), and a conservation system with and without manure (NT_{manure} or NT), were evaluated in a corn-cotton rotation (both phases present each year). The conventional system consisted of chisel plowing/disking (Fall) and field cultivation/in-row subsoiling (Spring); no cover crops were used. The conservation system included no-surface tillage with non-inversion in-row subsoiling and a winter cover crop mix 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; sunn-hemp (*Crotalaria juncea* L.) was planted between the corn and the rye-oat cover crop. Treatments were established in 6.1-m wide and ~240-m long strips in a randomized complete block design (RCB) with 6 replications. Strips were divided into cells of 6.1 × 18.3-m, resulting in 496 cells for the entire field. Corn (Pioneer® 34A55 LL resistant) was planted at 70,000 seeds ha^{-1} in 0.76-m rows during the last week of March. Crop management, including fertilization and pesticide application, followed Alabama Cooperative Extension System recommendations. Corn grain yield was geo-referenced across the field using a four row head John Deere Hydro 4435 combine (Deere & Company, Moline, IL) equipped with a GPS and an Ag Leader PF3000 yield monitor (Ag. Leader Tech. Inc., Ames, IA).

Soil samples (0.3-m depth) were taken at the beginning of the test from the 496 cells and analyzed for SOC (dry combustion) and particle size distribution (pipette method). A detailed soil survey (scale ~1:5000) was developed and the seasonal high water table depth (SHWT) for each map unit was estimated. Soil electrical conductivity (mS m^{-1}) surfaces of the field at 0-30 cm (EC_{30}) and 0-90-cm (EC_{90}) depths were obtained with a Veris® Tech 3100 soil sensor (Veris Tech. Salina, KS) equipped with a GPS. Field elevation was assessed using a cm-level accuracy RTK-GPS and terrain attributes were developed using the appropriate algorithms in Arc/Info® 8.0 (ESRI, Redland, CA): elevation, slope, profile and plan curvature, catchment area, and compound topographic index (CTI) (Moore et al., 1993). Map units and terrain attributes were rasterized to a 5 × 5-m grid and stacked with surfaces of SOC, EC, sand, silt and clay content created by ordinary kriging. Average soil and terrain attributes were determined for each of the 496 cells. The field was subdivided into five management zones using a fuzzy k-means unsupervised clustering algorithm (Fridgen et al., 2004) using soil and terrain data that was most related with yield.

The experiment was analyzed with the MIXED procedure in SAS® (SAS Inst., Cary, NC). For the overall mixed model, treatments and years were considered as fixed effects, while replication was considered as a random effect. We accounted for spatial correlation of cell yield residuals, using the modeled semivariogram parameters to reduce experimental error (Littell et al., 1996; Mallarino et al., 2000). For treatment effects within cluster, treatments were considered as fixed effects and sample cells within each cluster as repeated observations. An F statistic with $P \leq 0.05$ was used to determine the significance of the fixed effects for all analyses. Factor analysis was used to reduce the dimensionality of the original data and express original variables in terms of a few common factors (Khattree and Naik, 2000). The FACTOR procedure of SAS® was used with soil and terrain attributes to create latent factors of correlated variables (Mallarino et al., 1999). Factors with eigenvalues > 1 were used for calculating factor scores for each cell. Regression models between corn yield and factors scores were obtained for each treatment × year combination using stepwise regression (Freund and Littell, 2000).

RESULTS AND DISCUSSION

A significant year × treatment interaction was found for corn grain yield (Table 1). Neither manure effects nor its interactions effects on corn yield were significant in 2001 or 2002. No significant management system effects on yield were found in 2001, the initial year of the study, following decades of conventional tillage practices. However, in 2002, with less rainfall, yield in conservation systems was 32 % higher compared with conventional systems (8.88 vs. 6.71 Mg ha^{-1} respectively). In the 2003 wet season, yields in conservation systems were 6% greater than in conventional systems (13.04 vs. 12.33 Mg ha^{-1}). Although manure tended to increase yield in both systems in 2003, the greatest effects of manure on corn yield were observed in 2004 in the conventional system (21 % increase) rather than in the conservation system (6 % increase). In 2004, CT (8.43 Mg ha^{-1}) had the lowest yield; while NT_{manure} (11.12 Mg ha^{-1}) had greater yield than NT and CT_{manure} (10.46 and 10.19 Mg ha^{-1} respectively).

Table 1. Soil management system effects on corn grain yields from a 9-ha field-scale test in Alabama, USA. Data analyzed as a randomized complete block design (RCB) accounting for spatial correlation (2001-2004).

Treatment	Year				Mean
	2001	2002	2003	2004	
	(Mg ha^{-1})				
Conventional System	9.52†a	6.77b	12.18c	8.44c	9.23
Conventional System + Manure	9.99a	6.64b	12.48b	10.19b	9.83
Conservation System	9.88a	8.72a	12.94ab	10.46b	10.50
Conservation System + Manure	10.01a	9.04a	13.14a	11.12a	10.83
standard error	0.25	0.18	0.17	0.20	0.11

† Least square means followed by the same letter within a column are not significantly different at P ≤ 0.05 level.

The rainfall regime and the residues produced in the conservation systems were the more likely reasons for the variety of responses among years. Rainfall (Apr - July) at the site was 525, 351, 714 and 410-mm in 2001, 2002, 2003 and 2004, respectively, compared with an average of 430-mm. The lack of yield responses in 2001 was attributed to the favorable rainfall regime and to the lack of residues in the conservation systems (0.7 Mg ha^{-1}). After the first season, cover crops prior to corn in conservation systems increased surface residues (2.5

Mg ha^{-1} yr^{-1}), soil N availability (90 kg ha^{-1} yr^{-1}) and SOC (Terra et al., 2005). These results were consistent with a study of Torbert et al. (1996). The lack of a yield response to manure additions in 2001-2002 was in agreement with the general finding that the greatest impacts of manure on productivity are normally obtained after some years (Arriaga and Lowery, 2003).

Factor analysis was used to extract four new variables out of the original 12 variables. The first four factors explained 76 % of the data variability (24, 23, 15 and 14% respectively). Slope, EC_{30}, EC_{90}, and SOC had the highest loading factors (0.86, 0.86, 0.79 and -0.59, respectively) for the first factor, hence, the new variable was considered to be related to 'soil degradation'. The second factor was dominated by catchment area (0.86) and CTI (0.79); this new variable was identified as 'wetness'. The third variable was termed 'texture' because it was dominated by sand (0.92) and clay (-0.81) quantities. Finally, the last variable was related with 'field drainage' since SHWT and elevation presented the highest loading factors (0.91 and 0.70 respectively). Coefficients of determination between factors and corn yield for each year × treatment combination are presented in Table 2. Factor 1 (soil degradation) and factor 4 (field drainage) were the factors most related with corn yield variability in all treatments and were negatively related with yield. Factor 2 was of minor importance in 2001 and 2003, but was an important term in 2002 and 2004 where it had a positive coefficient. Regression results indicate that soil quality and water dynamics were key variables explaining yield variability in all treatments. It is also noticeable from model parameters in Table 2 that conservation systems were less affected by soil degradation and drainage conditions than the conventional systems. Kravchenko and Bullock (2000) found that SOC, elevation and slope had the most consistent relationship with corn yield compared with other soil and terrain attributes. They concluded that SOC was a more significant yield-affecting factor in low compared with high SOC fields.

Table 2. Multiple regression model parameters relating corn grain yield with the latent variables identified by factor analysis (Principal component method with Varimax orthogonal rotation) in a 9-ha field-scale test in Alabama, USA (2001-2004).

Year	Treatment‡	Intercept (Mg ha^{-1})	Factor † Factor 1 'Degradation'	Factor 2 'Wetness'	Factor 3 'Texture'	Factor 4 'Drainage'	R^2
2001	CT	9.69	-0.45	0.26	0.44	-0.56	0.47
	CT_{manure}	10.26	-0.82	NS	NS	-0.46	0.46
	NT	10.07	-1.30	NS	NS	-0.28	0.51
	NT_{manure}	10.28	-1.08	NS	0.40	-0.38	0.49
2002	CT	6.70	-0.91	0.49	NS	-0.85	0.56
	CT_{manure}	6.64	-0.74	0.51	NS	-0.79	0.48
	NT	8.64	-0.73	0.47	0.32	-0.45	0.58
	NT_{manure}	9.02	-0.59	0.62	0.30	-0.81	0.59
2003	CT	12.20	-0.20	-0.38	-0.36	0.38	0.39
	CT_{manure}	12.53	-0.22	NS	-0.19	NS	0.11
	NT	-	NS	NS	NS	NS	-
	NT_{manure}	13.20	NS	NS	-0.26	NS	0.12
2004	CT	8.28	-1.17	0.50	NS	-0.47	0.56

CT_{manure}	10.07	-1.00	0.33	NS	-0.45	0.53
NT	10.43	-0.53	0.28	0.30	NS	0.35
NT_{manure}	11.20	-0.44	0.53	NS	-0.30	0.33

† See text for interpretation of names assigned to these variables.

‡ CT = Conventional System, CT_{manure} = Conventional System + Manure, NT = Conservation System, NT_{manure} = Conservation System + Manure.

Five clusters were the optimal number of clusters for most treatments in our field. Cluster 1 was a relatively flat area with relatively higher SOC and silt content, and lower sand content compared with other clusters. Cluster 2 was an elevated area of relatively flat topography, and is dominated by well drained soils with high surface horizon sand content and a deep SHWT. Cluster 3 corresponded to a concave drainage way position occupying the lowest elevation in the field, with more poorly drained soils that collect sediments from upslope zones. Cluster 4 corresponded to sloping eroded upland soils with high EC and clay content, and low SOC and CTI. Finally, Cluster 5 presented relatively high surface horizon clay content and low EC_{90}.

Although corn yield response to soil management practices differed between years for different clusters, conservation systems were of equal or higher productivity than conventional systems in all cluster × year combinations (Fig. 1). Similar to above, when manure increased yield within a cluster, it was mostly in the conventional system. Averaged over years, clusters 1 and 3 were the zones of greatest corn productivity for all treatments. However, there were some differences on clusters of low productivity between treatments. In conventional systems the lowest yields were observed in clusters 2 and 4, but in conservation systems the lowest yields were observed in clusters 4 and 5. Over all years, maximum relative yield differences between conservation and conventional system were observed in clusters 2 and 4 (15 and 14%, respectively) and minimum relative yield differences were observed in clusters 1 and 5 (9 and 5%, respectively). The greatest impacts of conservation systems compared with conventional systems on yield were observed in clusters 2 and 4 in 2002 (40 and 37%, respectively) and in 2004 (21 and 30%, respectively), suggesting that conservation systems may provide a greater yield response relative to conventional systems in dry years on eroded landscape positions. Moreover, relative yield differences between the two highest and the two lowest productivity clusters within years were lower in conservation systems than in conventional systems in 2002 (22 vs. 33%), 2003 (3 vs. 12%), and 2004 (11 vs. 21%), suggesting higher spatial stability across the field. Few studies comparing conservation with conventional systems at the landscape level have obtained the consistent results favoring conservation practices. Ginting et al. (2003), in a study conducted in Minnesota during a dry year, found that corn grown with no-tillage had higher yields than corn grown with conventional tillage regardless of landscape position. However, Bermudez and Mallarino (2004) reported that corn grown with reduced tillage had higher yield than corn grown with no-tillage in four out of seven Iowa fields; they reported that yield responses to tillage were similar between the predominant soils of the fields.

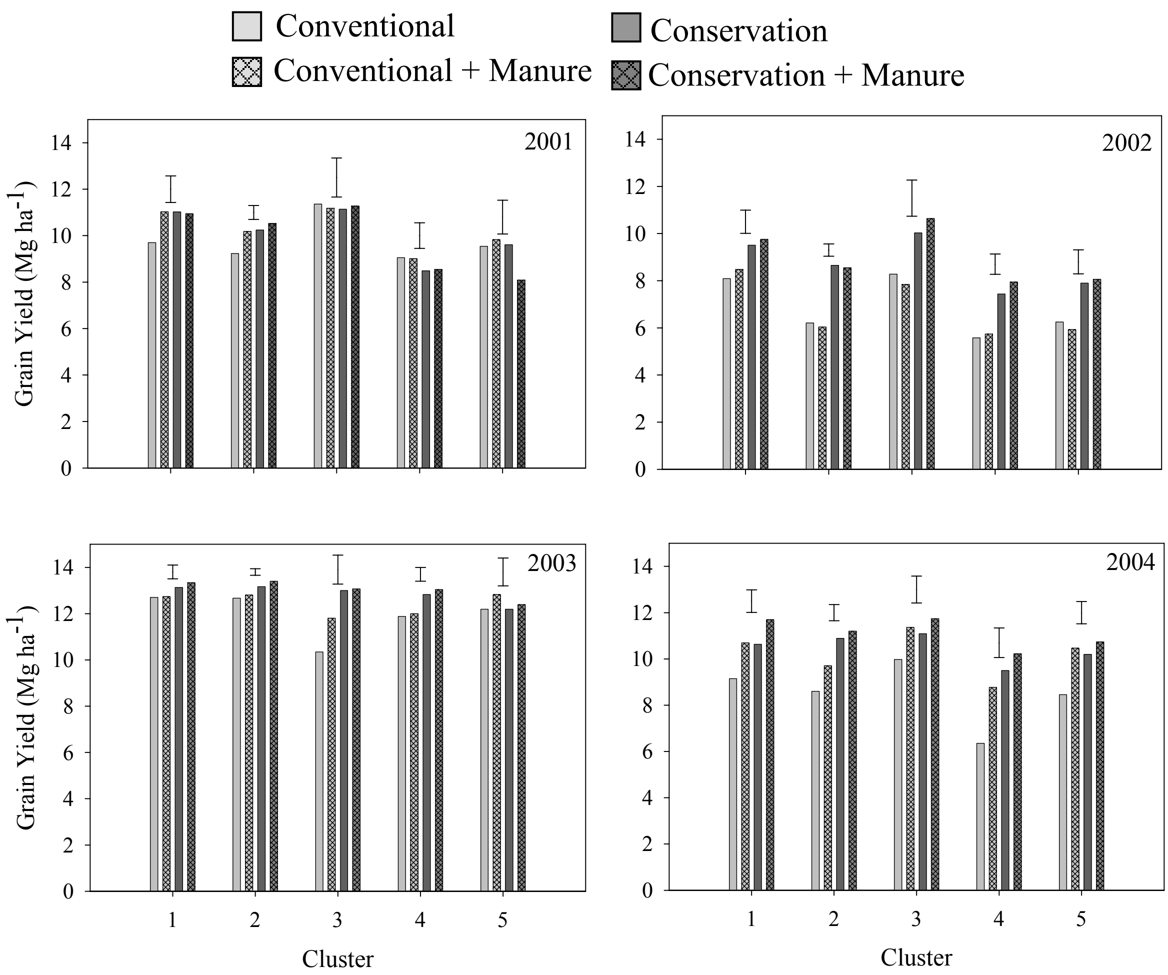

Fig. 1. Effect of soil management system and manure addition on grain corn yields on five clusters of a 9-ha field-scale test in Alabama, USA (2001-2004). Vertical bars indicate LSD $_{(0.05)}$.

CONCLUSIONS

In our 4 yr trial, conservation systems averaged 12 % greater corn grain yields than conventional systems overall the field. This increase was not only observed during the transition period from conventional to conservation systems in three contrasting rainfall seasons, but also in field positions differing in soil properties and terrain attributes. There was also a trend for manure to increase corn yield in same clusters in the conventional than the conservation system after the second year. The aggregate of data indicates for degraded soils in warm humid climates like those prevalent in the coastal plain of Alabama, conservation systems integrating cover crops, no tillage and in-row subsoiling increase corn productivity and spatial and temporal stability of yields even during initial adoption years.

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