Soil management system and landscape position interactions on nutrient distribution in a Coastal Plain field

K.S. Balkcom, J.A. Terra, J.N. Shaw, D.W. Reeves, and R.L. Raper

ABSTRACT: Soil nutrient concentrations vary with soil management system and landscape position, but limited information exists describing these interactions within a heterogeneous field. A three year experiment was conducted to evaluate pH, phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and zinc (Zn) concentrations at three depths, 0 to 5 cm, 5 to 15 cm, and 15 to 30 cm (0 to 2 in, 2 to 6 in, and 6 to 12 in), and three landscape positions, summit, sideslope, and drainageway, in a 9 ha (22 ac) field containing four different management systems. Management systems consisted of a conventional (chisel plowing/disking in-row subsoiling with no cover crops) and conservation tillage system (in-row subsoiling with cover crops) with or without dairy bedding manure. Soils ranged from Aquic to Typic Paleudults. Manure applications increased pH and nutrient concentrations in the soil surface at 0 to 5 cm (0 to 2 in) of conventional and conservation tillage systems, with highest values measured in conservation tillage. Landscape position affected soil pH and P concentrations; however, depth and landscape position interactions were observed for soil pH, P, and K concentrations. The lowest soil pH and P concentrations were measured from the sideslope position, while K concentrations did not exhibit consistent distributions across landscape positions. Future soil testing of Coastal Plain fields to account for erosion of the landscape may help direct future sampling methodology and interpretations for nutrient management.

Keywords: Conservation tillage, conventional tillage, dairy manure, stratification

Conservation and conventional tillage systems require different approaches to fertilizer management due to interactions with surface residue and degree of fertilizer incorporation. Conventional tillage uses plowing and disking that provides a residue free soil surface, prior to planting. Conservation tillage maintains previous crop residues on the soil surface by utilizing no-till planting systems, possibly including some form of non-inversion deep tillage, prior to planting. As a result of different tillage methods used in production agriculture, nutrient distribution within the soil profile differs among tillage systems. Conventional tillage systems enable nutrients, particularly immobile nutrients like phosphorus (P) and potassium (K), to be uniformly distributed throughout the soil profile (Touchton and Sims, 1986; Mackay et al., 1987). In contrast, conservation tillage systems prohibit mechanical incorporation of surface applied fertilizers into the soil profile (Dick, 1983).

Surface applied fertilizers, absence of mechanical incorporation, and the accumulation of surface residues associated with conservation tillage concentrates nutrients, especially immobile nutrients, at the soil surface (Blevins et al., 1983; Robbins and Voss, 1991; Crozier et al., 1999). In addition, acidification of the soil surface from the nitrification of surface applied ammonium fertilizer can affect soil pH (Blevins et al., 1978; Dick, 1983). In contrast, Eckert (1985) in a review found studies that documented an increase of basic cations, such as calcium (Ca) and magnesium (Mg), in the soil surface of conservation tillage systems. Other studies have reported increased concentrations of micronutrients, like zinc (Zn), in the surface soil of conservation tillage systems (Hargrove et al., 1982; Crozier et al., 1999). Evidence of nutrient stratification associated with conservation tillage systems has prompted some regions to recommend shallow 5 to 7 cm (2 to 2.8 in) soil samples for lime and fertilizer requirements in non-inversion tillage systems (Touchton and Sims, 1986; James and Wells, 1991).

The aforementioned research indicates differences in nutrient concentrations with depth between tillage intensities; however, research has focused on crop response in small plots that ignore landscape variability (Ginting et al., 2003). Recent work addresses landscape variability by examining crop response to selected nutrients and lime applied variably across the landscape to zones based on landscape position, soil series, grid sampling, or some combination of selected variables (Bermudez and Mallarino, 2002; Bianchini and Mallarino, 2002; Bronson et al., 2003). Variable nutrient concentrations across the landscape are identified, but nutrient stratification has not been evaluated.

In addition to fertilizers, organic amendments applied to soils also alter soil nutrient concentrations (Chang et al., 1991; Eghball, 2002). Studies that examine manure applications across the landscape have focused on environmental impacts of N- and P-containing runoff within selected fields or watersheds (Sharpley, 1999; Sauer et al., 2000). Little information exists on the combined effects of soil management systems and landscape attributes on nutrient distribution by depth on a field scale between a conventional tillage system and a conservation tillage system that utilizes heavy surface residue. Our objective was to describe changes in soil pH and nutrient concentrations in a Coastal Plain field for three depths, 0 to 5, 5 to 15, and 15 to 30 cm (0 to 2 in, 2 to 6 in, and 6 to 12 in), across three landscape positions—summit, sideslope, and drainageway—for four management systems (conventional and conservation tillage with and without manure).

Methods and Materials

A field experiment was initiated in the fall of 2000 at the Alabama Agricultural Experiment Station's E.V. Smith Research Center in

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Table 1. Application date, rate, amount, and chemical composition of dairy bedding manure applied during three years on a 9-ha field-scale experiment in east-central, Alabama. Applied rate, nutrients, and ash content are on a dry weight basis.

Application date	Rate	C	N	P	K	Ca	Mg	Zn	Water	Ash
	Mg ha^{-1}	g kg^{-1}								
Feb. 2001	8.6	320	12.9	3.7	4.1	28.1	12.4	0.10	522	395
Nov. 2001	10.7	307	10.9	3.0	4.7	28.6	12.6	0.13	523	472
Aug. 2002	10.7	223	10.2	2.5	1.7	28.4	12.0	0.08	521	435

central Alabama (85°53'50" W, 32°25'22" N). The field site measured 9-ha (22 ac) and had a long history of row crop production; mainly cotton (*Gossypium hirsutum* L.), under conventional tillage (moldboard or chisel plowing and disking) for the last 30 years. Soils at the site were mostly fine and fine-loamy, kaolinitic, thermic Typic and Aquic Paleudults.

A factorial treatment structure was arranged in a randomized complete block design with six replications so as to traverse across the field in 6.1 m (20 ft) wide and ~240 m (787 ft) long strips. A 1.8 m (6 ft) wide border free of weeds and crops separated each strip. Treatments were management systems that consisted of two tillage systems (conventional and conservation) with and without an annual application of dairy manure in a corn (*Zea mays* L.) -cotton rotation. Application times, rates, and nutrient concentration of manure are presented in Table 1. Both phases of the rotation were present each year; therefore half the strips were in corn while the other half were in cotton. In the conventional systems, tillage consisted of chisel plowing, disking, and in-row subsoiling. No cover crop was planted in the fall, but winter weeds were not controlled. The conservation systems included only non-inversion in-row subsoiling and a mixture of winter cover crops that included white lupin (*Lupinus albus* L.), crimson clover (*Trifolium incarnatum* L.), and fodder radish (*Raphanus sativus* L.) prior to corn, and black oat (*Avena strigosa* Schreb.) and rye (*Secale cereale* L.) prior to cotton.

Each field length strip was divided into cells that measured 6.1 × 18.3 m (20 × 60 ft) for a total of 496 cells in the entire field. However, before the experiment was initiated, the field was divided into 24 grids measuring 4049 m^2 (1 ac) in size. Each grid was sampled to a depth of 20 cm (8 in) by compositing 20 soil cores [1.9 cm (0.75 in) diameter probe] from a 10 m (32.8 ft) diameter circle in the middle of each square, in the fall of 2000. Soil pH was measured in a 1:1 soil/water extract and P, K, Ca, and Mg were analyzed based on the Mehlich I extractant (Mehlich, 1953). Based on these soil tests, 30 kg P ha^{-1} (27 lb P ac^{-1}) was applied to the entire experimental area and an additional 15 kg P ha^{-1} (13 lb P ac^{-1}) was applied to more deficient cells. Cells deficient in K received 47 to 70 kg K ha^{-1} (42 to 63 lb K ac^{-1}). Different amounts of P and K were initially applied across the field to account for soil variability and create uniform soil P and K concentrations across the field. Lime [1.12 to 2.24 Mg ha^{-1} (1,000 to 2,000 lb ac^{-1})] was applied to selected cells within the field to raise the pH above 6.0. Approximately one week after manure application, in February 2001, each cell was sampled separately to a depth of 30 cm (12 in) by compositing 10 soil cores [1.9 cm (0.75 in) diameter probe] within a 2.5 m (8.2 ft) radius from the center of each cell. Initial P, K, Ca, Mg, and Zn concentrations were analyzed for each cell based on previously mentioned procedures and are shown in Table 2. Initial soil pH was 6.4. After three years, a subset of every other cell resulting in 240 cells were sampled by collecting 10 soil cores [1.9 cm (0.75 in) diameter probe] to a depth of 30 cm (12 in), partitioned into 0 to 5, 5 to 15, and 15 to 30 cm depths (0 to 2 in, 2 to 6 in, and 6 to 12 in), and composited (Figure 1). Soil pH and nutrient concentrations were determined as previously mentioned.

A soil survey, elevation, and electrical conductivity maps were developed for delineating soil and landscape variability in fall 2000. 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 twice with a Veris® Technology 3100 Soil Electrical Conductivity Mapping System equipped with differential GPS. Electrical conductivity measurements were taken at depths of 30 cm (12 in) and 90 cm (35.43 in). A Trimble® 4600 L.S. Surveyor Total Station was used to determine elevations across the field; digital elevation models and terrain attributes were developed using 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 (16.4 ft) grid resulting in a total of thirteen stacked layers (ELEVA, SLOPE, ASP, PROFC, PLANC, FA, CTI, electrical conductivity at 0 to 30 cm (0 to 12 in), electrical conductivity at 0 to 90 cm (0 to 35 in), soil organic carbon (C), clay, sand, water table depth). Using multivariate fuzzy k-means clustering of these data, three zones (land-

Table 2. Initial soil test values, initial soil test ratings, starter fertilizer, and sidedress nitrogen (N) applied in a 9-ha field located at the E.V. Smith Research and Extension Center at Shorter, Alabama.

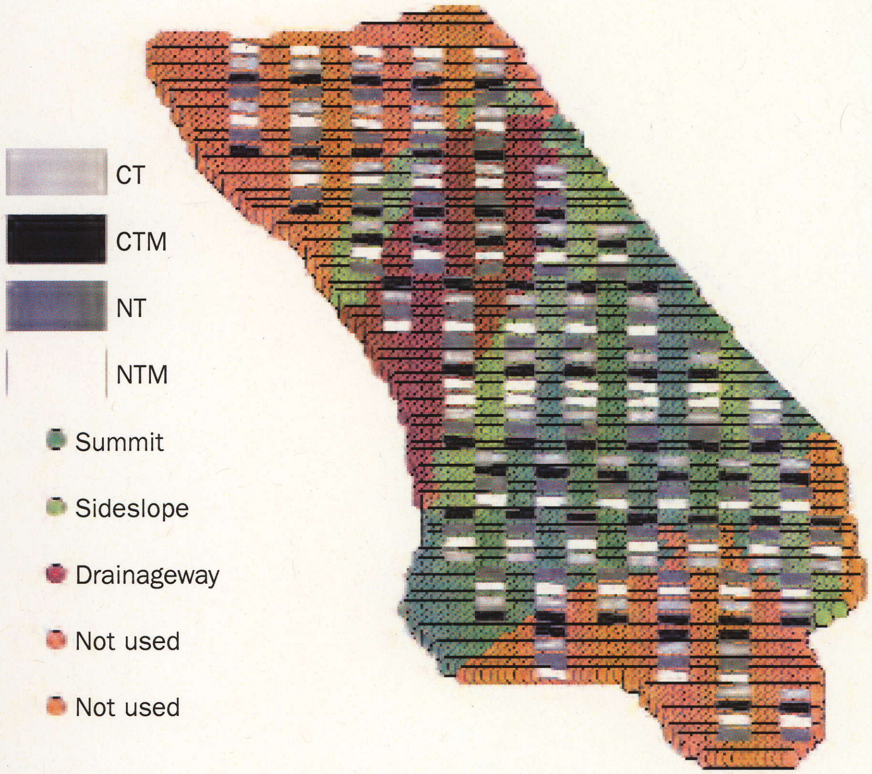
Nutrient	Initial soil test values	Soil test ratings*		Starter fertilizer†	
		Corn	Cotton	Corn	Cotton
	mg kg^{-1}			kg ha^{-1}	
N				56	47
P	29	High	High	12	9.5
K	94	High	High	0	0
Ca	475	High	High	0	0
Mg	128	High	High	0	0
Zn‡	1.27			0.9	0.8

* Based on the Auburn University Soil Testing Laboratory (Adams et al., 1994).

† Remaining fertilizer was applied at sidedress and only contained N.

‡ Specific recommendations do not exist for zinc (Zn) in Alabama, however, Zn is recommended for corn on sandy soils where the pH is above 6.0 or the first year after applying lime (Adams et al., 1994).

Figure 1
Intersection of four management systems, three landscape positions, and the 240 cell subset of sampling points located in a 9-ha field at the E.V. Smith Research and Extension Center in Shorter, Alabama.



scape positions) were created on our site. Characteristics of the summit, sideslope, and drainageway positions are described in Table 3. Further discussion of zone creation can be found in Terra et al. (2004).

Initially, soil pH and nutrient concentrations measured after three years were analyzed by strip as a conventional randomized complete block design with a split-plot treatment structure using the MIXED procedure in SAS®. Main plots were management system and sub-plots were depth. Single degree of freedom (df) contrasts were calculated to separate management system means. Replication, replication X treatment (manure addition and management system) and replication X depth were random. The second analysis was analyzed as a conventional randomized complete block design with a split-split-plot treatment structure that included landscape position as the sub-plot with management systems as the main plots and depth as the sub-sub-plot using the MIXED procedure in SAS®. Each landscape position was considered a fixed effect because positions are repeatable and can be classified similarly in another field. Replication and the interactions with each fixed effect were considered random in the model. Standard errors for the difference for simple and interaction means were used, in conjunction with published tabular t values for specified degrees of freedom, to calculate least significance difference between means (Gomez and Gomez, 1984). No three-way interactions were significant in the split-split-plot analysis. An F statistic with $P \leq 0.05$ was used to determine the significance of the fixed effects.

Results and Discussion

Fertility status on a field scale. Significance levels for management systems, depth, and interactions, across the whole field, for each dependent variable examined are shown in Table 4. Soil pH and K concentrations were different between management systems and depth when averaged over the entire field; however, P, Ca, Mg, and Zn exhibited an interaction between management systems and depth (Table 4).

Soil pH and K varied specifically with the manure component of management system and with depth (Table 4). Table 5 shows the increase in soil pH and K concentrations, regardless of depth. Soil K concentrations averaged 14 percent higher following manure application compared to no manure over all depths. Previous research has demonstrated that animal manure can increase the pH of acid soils. Higher pH from animal manure has been attributed to the buffer capacity of bicarbonates and organic acids present in the manure and to the liming effect of manure due to lime added in the cattle diets (Eghball, 1999; Whalen et al., 2000). The highest soil pH value was measured at the 5 to 15 cm (2 to 6 in) depth and the lowest was measured in the 15 to 30 cm (6 to 12 in) depth across manure applications (Table 5). Potassium levels were different for each depth increment, with the highest soil K concentration measured in the 0 to 5 cm (0 to 2 in) depth and decreasing with depth (Table 5). Although different from each other, soil K concentrations were concentrated in the 0 to 5 and 5 to 15 cm (0 to 2 and 2 to 6 in) depths. A 43 percent decrease in soil K concentrations in the 15 to 30 cm (6 to 12 in) depth compared to the average

Table 3. Number of cells, electrical conductivity measured at 30 cm (12 in), elevation, slope, and descriptions of three landscape positions identified in a 9-ha field located at the E.V. Smith Research and Extension Center in Shorter, Alabama.

Landscape position	Number of cells	EC_{30}	Elevation	Slope	Description
		(mS m^{-1})	(m)	(%)	
Summit	70	5.0	70.1	0.8	Elevated area, relatively flat topography, well drained soil.
Sideslope	51	7.2	69.4	3.3	Sloping, eroded, well drained soils, high clay content, and low organic matter content.
Drainageway	39	4.6	68.5	1.7	More poorly drained soils, depositional, relatively high organic matter content.

Table 4. Analysis of variance for pH, phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and zinc (Zn) for a whole field analysis comprising of four management systems and three depths averaged over a 9-ha field located at the E.V. Smith Research and Extension Center at Shorter, Alabama.

Source of variation	df*	pH	P	K	Ca	Mg	Zn
		P>F					
Management system	3	0.0024	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
CT vs NT†	1	0.0692	<0.0001	0.1363	0.0079	0.3194	0.0002
M vs no M‡	1	0.0009	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
T x M§	1	0.6335	0.0003	0.1989	0.0011	<0.0001	<0.0001
Depth	2	0.0061	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Management system x depth	6	0.4773	<0.0001	0.0988	<0.0001	<0.0001	<0.0001

* Numerator degrees of freedom; denominator degrees of freedom determined by the Kenward Rogers method in Proc Mixed (Littell et al., 1996).

† CT = conventional tillage; NT = conservation tillage.

‡ Manure vs. no manure.

§ Tillage system x manure.

concentration in the upper 15 cm (6 in) may be attributed to the immobile nature of K and the lack of mixing with either tillage system within the lowest depth.

Phosphorus concentrations indicated manure effects in the 0 to 5 cm (0 to 2 in) depth with the highest P concentration measured for the conservation tillage system receiving manure (Table 6). No differences were observed between management systems not receiving manure. Although in all treatments, there were significant reductions in P concentrations for the 5 to 15 cm (2 to 6 in) depth compared with the 0 to 5 cm (0 to 2 in) depth, the conventional tillage system with dairy manure exhibited the highest P concentration (Table 6). Again, no soil P differences in the 5 to 15 cm (2 to 6 in) depth were detected between management systems not receiving manure. At the 15 to 30 cm (6 to 12 in) depth, P concentrations were higher for the conservation tillage system with manure compared to the other systems (Table 6). This finding is interesting because expected results would indicate the highest P concentration would be measured in the conventional system receiving manure because of nutrient input from manure and soil mixing from tillage compared to essentially no mixing in the conservation tillage system receiving manure. The 126 mg P kg^{-1} (113 lb P ac^{-1}) measured in the 0 to 5 cm (0 to 2 in) depth for the conservation tillage system receiving manure was the highest concentration observed, but the concentration decreased 68 percent in the 5 to 15 cm (2 to 6 in) depth compared to only a 35 percent decrease for the conventional tillage system receiving manure (Table 6). Consequently, the corresponding decreases for the 15 to 30 cm (6 to 12 in) depth increment were the opposite (48 vs. 74 percent). These results are contrary to Hargrove et al. (1982), who found no difference between conventional and no-tillage at the 15 to 30 cm (6 to 12 in) depth. However, their study utilized strict no-tillage and did not have a manure component. Generally, high levels of extractable P and low P adsorption capacity are required to promote P mobility (Motta et al., 2002).

The high P concentration at the surface of the conservation tillage system with manure combined with a low cation exchange capacity and improved water infiltration of the conservation tillage could have resulted in P movement deeper into the soil profile. Sims et al. (1998), in a comprehensive review, reported P leaching on deep sandy soils, high organic matter soils, and in soils with excessive use of organic wastes; however, the manure rates applied in this study are not considered excessive. Phosphorus application averaged 30 kg P ha^{-1} yr^{-1} (27 lb P ac^{-1} yr^{-1}). Phosphorus removal from high yielding corn and cotton crops in Alabama has been estimated at 34 kg P ha^{-1} (30 lb P ac^{-1}) and 12 kg P ha^{-1} (11 lb P ac^{-1}), respectively (Mitchell, 1999).

Manure effects were apparent for soil Ca regardless of tillage system, especially in the 0 to 5 cm (0 to 2 in) depth. Both tillage systems receiving manure had higher soil Ca concentrations than tillage systems not receiving manure, and the conservation tillage system receiving manure had a higher soil Ca concentration than the conventional system receiving manure (Table 6). This may also be attributed to the lime in the cattle diets

Table 5. Soil pH and potassium (K) concentrations measured for three depths and two manure applications averaged over a 9-ha field located at the E.V. Smith Research and Extension Center at Shorter, Alabama.

	Manure application			
Depth	No manure	Dairy manure	Mean	$LSD_{0.05}$*
(cm)	pH†			
0-5	6.37	6.81	6.54	
5-15	6.67	6.78	6.72	0.04
15-30	6.20	6.40	6.29	
Mean‡	6.37	6.62		
	K (mg kg^{-1})			
0-5	103.8	117.4	110.6	
5-15	94.3	105.6	99.9	5.1
15-30	55.4	65.2	60.3	
Mean‡	84.5	96.0		

* Compare any two depth means across manure applications.

† Hydrogen ion concentrations used in analysis.

‡ Only two means; no least significance difference calculated.

Table 6. Phosphorus (P), calcium (Ca), magnesium (Mg), and zinc (Zn) concentrations measured for three depths, two tillage systems, and two manure rates averaged over a 9-ha field located at the E.V. Smith Research and Extension Center at Shorter, Alabama.

	Management system				
	Conventional tillage		Conservation tillage		
Depth	No manure	Dairy manure	No manure	Dairy manure	$LSD_{0.05}$*
(cm)					
	P (mg kg^{-1})				
0-5	41.4	82.4	47.2	126.0	
5-15	33.0	53.4	30.6	40.5	7.4
15-30	10.3	13.8	10.6	21.1	
	Ca (mg kg^{-1})				
0-5	493.8	735.1	499.0	1008.2	
5-15	499.2	626.3	469.1	507.3	46.8
15-30	366.2	389.3	364.3	434.3	
	Mg (mg kg^{-1})				
0-5	118.2	169.0	111.4	230.0	
5-15	126.2	155.2	110.6	128.5	9.1
15-30	127.6	128.4	119.8	136.6	
	Zn (mg kg^{-1})				
0-5	0.69	2.23	0.83	4.61	
5-15	0.80	1.40	0.59	1.00	0.37
15-30	0.35	0.50	0.38	0.86	

* Compare any two management system means at the same or different depths.

LSD = least significant difference.

(Eghball, 1999). Soil Ca concentrations measured in the conventional system receiving manure were greater than all other management systems for the 5 to 15 cm (2 to 6 in) depth (Table 6). No differences in soil Ca concentrations between management systems were detected in the 15 to 30 cm (6 to 12 in) depth. No differences were detected between either tillage system not receiving manure for any depth increment, but Ca concentrations were lowest in the 15 to 30 cm (6 to 12 in) depth for both tillage systems not receiving manure compared to the upper 15 cm (6 in) (Table 6).

The conservation tillage system receiving manure had the highest soil Mg concentrations in the 0 to 5 cm (0 to 2 in) depth, while both tillage systems without manure had the lowest Mg concentrations (Table 6). In the 5 to 15 cm (2 to 6 in) depth, Mg concentrations were highest for the conventional tillage system receiving manure and lowest for the conservation tillage system not receiving manure, with no difference between the remaining management systems (Table 6). In the 15 to 30 cm (6 to 12 in) depth, conservation tillage with no manure had lower Mg concentrations compared to each of the other systems. Magnesium concentrations, unlike Ca, did not change from the surface to the lower depths for either of the two systems not receiving manure. For the systems receiving manure, a difference was observed for each depth increment in the conventional tillage system, but for the conservation tillage system, the only difference was observed between the 0 to 5 cm (0 to 2 in) depth and the remaining depth increments (Table 6).

Manure increased soil Zn concentrations compared to systems not receiving manure for the 0 to 5 (0 to 2 in) and 5 to 15 cm (2 to 6 in) depths (Table 6). Similar to P, only the conservation tillage system receiving manure increased soil Zn concentrations above concentrations measured for tillage systems not receiving manure in the 15 to 30 cm (6 to 12 in) depth. In the 0 to 5 cm (0 to 2 in) depth, conservation tillage with manure had Zn concentrations more than double the concentrations measured for conventional tillage with manure. The effect was reversed in the 5 to 15 cm (2 to 6 in) depth, but the margin was only 40 percent greater (Table 6). For tillage systems receiving no manure, Zn concentrations were no different in the upper 15 cm (6 in), however, due to incorporation with tillage, Zn concentration was higher in the 5 to 15 cm (2 to 6 in) depth compared to the lower depth for conventional tillage. For the conservation tillage system, the difference was observed between the 0 to 5 (0 to 2 in) and 15 to 30 cm (6 to 12 in) depth. Since Zn is a micronutrient, plants require very small quantities; however, corn is more sensitive to Zn levels (Mallarino and Webb, 1995). Alabama does not recommend Zn applications for crops, but in general, deficiencies are more likely on high pH (calcareous) soils (Lins and Cox, 1988).

Fertility status by landscape position. Landscape position only influenced soil pH and P, but interactions between landscape position and depth were observed for soil pH, P, and K (Table 7). Soil pH varied across each landscape position for the 5 to 15 and 15 to 30 cm (2 to 6 and 6 to 12 in) depths, but the changes were not consistent between depths. Soil pH was consistently lower from the eroded sideslope position, but the soil pH measured between the summit and drainageway position were not different, regardless of depth (Table 8). Soil pH varied with depth between the sideslope and drainageway position with the lowest pH values measured in the sideslope position. A slightly acidic pH (5.83), significantly different from the upper 15 cm (6 in), was measured in the lowest depth from the sideslope position (Table 8). The high clay content of the eroded sideslope (Table 3), corresponding to a higher cation exchange capacity, would require more lime to neutralize soil acidity. Interestingly, in the downslope drainageway position, higher soil pH values were measured in the 5 to 30 cm (2 to 12 in) depth. The mass flow of rainwater through soil macropores could incorporate lime and increase soil pH below a depth of 5 cm (2 in) (Edwards and Beegle, 1988). Another explanation could be that in a saturated landscape position, like the drainageway, increased saturation causes biochemical reduction resulting in an increase in soil pH.

Soil P concentrations decreased with depth within each landscape position (Table 8). Phosphorus concentrations measured across landscape positions were different for each depth level (Table 8). The lowest P concentrations were measured from the sideslope position; however, no difference in P concentrations was observed between the summit and sideslope positions at the 15 to 30 cm (6 to 12 in) depth. The drainageway position had the highest P concentration at the 15 to 30 cm (6 to 12 in) depth. No differences were found between the summit and drainageway positions in the upper 15 cm

Table 7. Analysis of variance for pH, phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and zinc (Zn) for a landscape analysis comprising of four management systems, three landscape positions, and three depths averaged over a 9-ha field located at the E.V. Smith Research and Extension Center at Shorter, Alabama.

Source of variation	Df*	pH	P	K	Ca	Mg	Zn
		P > F					
Management system	3	0.0160	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Landscape position	2	<0.0001	0.0082	0.1110	0.2358	0.1023	0.1820
Management system x landscape position	6	0.4241	0.0606	0.4413	0.1809	0.4020	0.2161
Depth	2	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Management system x depth	6	0.8827	<0.0001	0.3648	<0.0001	<0.0001	<0.0001
Landscape position x depth	4	<0.0001	0.0009	<0.0001	0.5768	0.2055	0.9383
Landscape position x management system x depth	12	0.8820	0.8838	0.9679	0.8711	0.4149	0.9359

* **Numerator degrees of freedom; denominator degrees of freedom determined by the Kenward Rogers method in Proc Mixed (Littell et al., 1996).**

(6 in). The higher P concentrations found at the lower depths were confined to the conservation tillage system receiving manure and were attributed to potential P leaching. When examining landscape positions, the high P concentrations found in the drainageway position could result from P leaching, but deposition of P through surface runoff from upslope positions containing high P concentrations could also cause an accumulation of P in the drainageway position, increasing the potential for P leaching. This process is no different from the documented transport of P from agricultural soils to surface waters (Sims et al., 1998).

Soil K concentrations also varied across landscape positions for each depth (Table 8). In the 0 to 5 cm (0 to 2 in) depth, the summit position had the highest soil K concentration, but it was not different from the sideslope position. The summit position also had the highest soil K concentration for the 5 to 15 cm (2 to 6 in) depth compared to the other landscape positions (Table 8). No differences between soil K concentrations were found between the summit and drainageway positions, but both were greater than the sideslope position at the 15 to 30 cm (6 to 12 in) depth. Comparing soil K concentrations within landscape positions, no differences were found in the upper 15 cm (6 in) for the summit or drainageway positions; however, on the sideslope, the soil K concentration was greater in the top 5 cm (6 in) compared to the 5 to15 cm (6 to 12 in) depth. Soil K concentrations in the 15 to 30 cm (6 to 12 in) depth were lower within each landscape position, compared to the upper 15 cm (6 in) (Table 8).

Table 8. Soil pH, phosphorus (P), and potassium (K) concentrations measured from four management systems and three depths across three landscape positions within a 9-ha field located at the E.V. Smith Research and Extension Center in Shorter, AL.

Depth	Landscape position: Summit	Sideslope	Drainageway	$LSD_{0.05}$*
(cm)				
		pH		
0-5	6.58	6.41	6.58	
5-15	6.73	6.58	6.82	0.18
15-30	6.60	5.83	6.77	
		P (mg kg^{-1})		
0-5	85.7	61.1	80.3	
5-15	47.5	25.8	53.2	9.8
15-30	15.0	10.9	25.4	
		K (mg kg^{-1})		
0-5	110.7	105.1	95.3	
5-15	104.2	89.3	90.5	12.4
15-30	61.6	48.9	66.0	

* **Compare any two landscape means at the same or different depths.**

LSD = least significant difference.

Each landscape position had unique physical and chemical soil characteristics. The elevation, slope, and EC_{30} reading were distinguishable between landscape positions (Table 3). The EC_{30} reading correlates to soil texture; high positive values correspond to high clay contents (Shaw and Mask, 2003). Soil texture influences soil test levels because the retention and leaching of applied nutrients are determined by clay content and organic matter (Davis et al., 1996). Based on the EC_{30} readings, there were differences in clay contents between landscape positions, and organic matter contents; however, only soil pH, P, and K concentrations were influenced by landscape positions.

Summary and Conclusion

Across the entire experimental field, management systems that received manure produced the highest nutrient concentrations in the surface soil. This can be attributed to manure being surface applied and not incorporated until four to five months after application for the conventional tillage system, and no manure incorporation in the conservation tillage system. Soil pH values measured in systems receiving manure were also highest possibly due to a liming effect of the manure from lime applied to cattle diets. Nutrient concentrations following manure application reflect differences between tillage intensities for the 5 to 15 cm (2 to 6 in) depth. Soil pH, P, Ca, Mg, and Zn concentrations measured in the conventional tillage system with manure were higher compared to concentrations in the conservation tillage system receiving manure at the 5 to 15 cm (2 to 6 in) depth. Phosphorus and Zn concentrations measured in the 15 to 30 cm (6 to 12 in) depth zone were higher from the conservation tillage system receiving manure compared to all other systems. No differences were detected for soil pH or nutrient concentrations between conventional tillage and conservation tillage systems not receiving manure.

Landscape position affected soil pH, P, and K concentrations with depth. Soil pH and P concentrations were lowest from the sideslope position, regardless of depth, while K concentrations were more variable across landscape positions. Regardless of landscape position, nutrient concentrations were generally lower in the 15 to 30 cm (6 to 12 in) depth compared to the upper 15 cm (6 in). This can be attributed to the immobile nature of P and K; however, P concentrations from the drainageway position were higher than even the summit position at the 15 to 30 cm (6 to 12 in) depth suggesting down slope movement of P, accumulation, and leaching. Textural differences existed across the landscape, which also suggest prior erosion and deposition across the landscape.

Observed concentrations are only after three year, but nutrient stratification does not appear to exist across the whole field because no differences existed between conventional and conservation tillage systems not receiving manure. This report confirms that continuous manure application can result in stratification of all nutrients examined in conjunction with conservation tillage and in conventional tillage as more time passes. The importance of soil testing at shallow depths to monitor nutrient concentrations following manure applications and prevent stratification is confirmed. Although this work is preliminary, soil testing in Coastal Plain fields to account for soil physical properties influenced by erosion of the landscape may help direct future sampling methodology and interpretations for nutrient management.

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