Soil Nutrient Distribution as Affected by Surface and Deep Tillage on the SE USA Coastal Plain

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ABSTRACT

For many SE USA soils, deep tillage is necessary to disrupt compacted zones for optimal crop production using conservation tillage. Our objective was to evaluate vertical and horizontal stratification of plant nutrients in the soil as affected by surface and deep tillage using controlled traffic. Soil samples were collected from both in the row and in the row middles after three years of growing wheat (*Triticum aestivum* L.) doublecropped with soybean (*Glycine max* L. Merr.) and then again after three years of continuous corn (*Zea mays* L.). The soil type was Goldsboro loamy sand (fine-loamy, siliceous, thermic, Aquic Kandiudult). Nutrient analysis for P, K, Ca, and Mg was conducted on soil from four depths. Higher concentrations of P, Ca, and Mg occurred near the soil surface with the conservation tillage treatment than with the disked treatment. Surface tillage did not affect K distribution. After six years soil that was subsoiled was lower in K concentration at the top of the B horizon and higher in K concentration at the surface than soil that was not subsoiled. Also after six years, soil P concentrations were lower in the row than in the mid-row while soil K concentrations were higher in the row than in the mid-row. These data will be useful in developing improved soil sampling schemes for conservation tillage production systems using controlled traffic in the SE USA.

INTRODUCTION

Conservation tillage, especially no-tillage, results in vertical stratification of plant nutrients in the soil profile. Several studies have shown that P, Ca, Mg, and K accumulate near the surface in no-tillage culture (Triplett et al., 1969; Lal, 1976; Dick, 1983). Crozier et al. (1999) studied nutrient stratification in the surface 20-cm of conventional and no-tillage fields and concluded sampling depth requires more attention to depth in no-tillage fields. Rhoton et al. (1993) compared conservation to conventional tillage for nutrient distribution in four long-term experiments in different areas of the Southeast USA. They found that differences between tillage systems for chemical properties near the surface were often not significant, but there was a trend for higher amounts of exchangeable basic cations in the conservation tillage surface samples. In another study, Edwards et al. (1992) compared conventional to conservation tillage for soil nutrient distribution after 10 years and found significant tillage X soil depth interactions for P, Ca, and Mg but not for K on a fine sandy loam soil.

Typical coastal plain soils contain coarse-textured A horizons. Below the A horizon is an elluviated E horizon that is highly compactable. Below the E is a sandy clay loam B horizon. Because compaction is common in the A and E horizons, in-row subsoilers are often used to loosen the soil directly under the row so that roots can penetrate to deeper horizons to acquire water and nutrients from the finer-textured B horizon.

Controlled traffic reduces compaction. Early research in the SE USA found a 20 percent increase in cotton yield when controlled traffic was used to limit soil surface area subjected to tire tracks (Trouse et al., 1975). Using controlled traffic by planting crops in the same row area year after year could cause horizontal plant nutrient stratification in the soil. If plant roots are concentrated in the same loosened area each year, that area may be depleted of nutrients faster than the soil profile as a whole. Our objective was to evaluate vertical and horizontal stratification of plant nutrients in the soil as affected by surface and deep tillage after three years of a wheat-soybean double crop system and then again after three years of continuous corn when the same row areas were used each year.

MATERIALS AND METHODS

The experiment was conducted at the Clemson University Pee Dee Research and Education Center at Florence on a Goldsboro loamy sand. A wheat-soybean double crop rotation was grown for the first three years (fall of 1993 through 1996). During the growing seasons of 1997, 1998, and 1999, corn was grown on the same plots, maintaining the same surface and deep tillage treatments as used for the wheat-soybean rotation. Soybean and corn were grown in 76-cm wide rows. Wheat was grown in 19-cm wide rows. Experimental design was randomized complete block with four replicates. Plots were 3-m wide and 15-m long.

The treatments in the study were surface tillage (conventional and conservation) and deep tillage management schemes. Conventional tillage consisted of double disking followed by smoothing with a harrow. Conservation tillage was directly seeding into existing residues. The three deep tillage management schemes for the first three years of the experiment were 1) none; 2) in-row subsoiling before planting the soybean in the spring; 3) broadcast deep tillage before planting wheat in the fall and in-row subsoiling in the spring. Deep tillage treatments for the corn in 1997 through 1999 were similar, except there was no fall deep tillage. All tillage operations were done either the day before or on the day of planting. Treatment effects on the wheat and soybean yields have been previously reported (Frederick and Bauer, 1996; Frederick et al., 1998).

Each year, approximately 30 randomly selected soil cores were collected from the surface 20-cm of the profile and bulked for lime and fertilizer recommendations from the entire experimental area. Based on that sampling, fertilizer that contained equal amounts of P_2O_5 and K_20 was broadcast applied each year. In the first three years of the experiment (the wheat-soybean doublecrop rotation), fertilizer was applied before wheat planting. In the second three years, the fertilizer was applied prior to corn planting. Amounts and dates of application were 90 kg ha^{-1} on 17 November 1993; 84 kg ha^{-1} on 15 November 1994; 84 kg ha^{-1} on 16 November 1995; 84 kg ha^{-1} on 12 March 1997; 56 kg ha^{-1} on 24 March 1998; and 56 kg ha^{-1} on 4 March 1999. Dolomitic limestone was used as the source of the Ca and Mg. Throughout the duration of the study, soil testing called for only two applications of lime, which were made on 9 November 1994 (1120 kg ha^{-1}) and on 4 March 1999 (2240 kg ha^{-1}).

Soil samples were collected in the fall of 1996 and 1999. Sampling consisted of collecting 5 to10 cores (2.5-cm diameter in 1996; 5-cm diameter in 1999) from each plot. Separate samples were collected throughout the entire length of the plots from the mid-row areas around the two center rows and directly from within the two center rows. Soil cores were separated by profile depth. The four depths were the surface 5-cm, the rest of the soil in the A horizon, all soil in the E horizon, and the top 7.5-cm of the B horizon. Although there is considerable variability for depths of horizons in SE USA fields, these four sampling depths roughly correspond to 0-5 cm, 5-25 cm, 25-35 cm, and 35-42 cm.

After collection, samples were air-dried, ground, and passed through a 2-mm screen. Soil samples were analyzed for nutrients at the Clemson University Soil and Plant Analysis Laboratory. Plant available P and exchangeable cations (K, Ca, and Mg) were extracted with Mehlich 1 reagents (0.05 N HCl and 0.025 N H_2SO_4) and quantified.

Data from 1996 and 1999 were analyzed separately with analysis of variance. When sources of variation were significant, means were separated with an LSD, using a probability level of 0.05.

RESULTS AND DISCUSSION

The vertical stratification of nutrients in this coastal plain soil was similar to previous work (Karlen et al., 1990). Phosphorus concentrations decreased considerably with depth while K, Ca, and Mg were more uniformly distributed throughout the profile. Main effects and two-way interactions were often significant in the analysis of variance for most nutrients. However, no higher level interactions were significant for any nutrient in any year. Therefore, only two-way interactions are presented and discussed.

After three years of the wheat-soybean rotation, higher levels of P, Ca, and Mg were found in the surface 5 cm in the conservation tillage treatment than in the conventional tillage treatment (Table 1). After an additional three years of corn, differences for these nutrients in the surface 5 cm were even greater (Table 1). Accumulation of these nutrients near the surface with conservation tillage was expected. All nutrients were broadcast applied. Disking the conventional tillage treatment mixed the nutrients throughout the surface 15-cm to 20-cm. With conservation tillage, nutrients were left on the surface and not mixed with the soil. No differences occurred between surface tillage treatments for K. These results are similar to those found by Edwards et al (1992) after 10 years of tillage comparisons on a sandy-loam soil.

With the exception of K, deep tillage (in-row subsoiling) had little effect on nutrient distribution in this study. Although P concentrations were higher in the surface 5-cm without subsoiling than with subsoiling after three years of wheat-soybean, there were no differences between for P at any depth after an additional three years of corn (Table 2). The horizontal distribution of K differed between deep tillage treatments after the three years of corn. In areas of high rainfall such as the coastal plain, K can leach through the soil profile (Bertsch and Thomas, 1985). In our study, concentrations of K at the top of the B horizon were higher in the non-subsoiled treatment than in the subsoiled, while K concentrations in the surface 5-cm of the profile were higher for the subsoiled plots. This is likely due to loosening of compacted zones by subsoiling which allowed roots to extract more K from the B horizon and redistribute that nutrient to the surface soils. Subsoiling had no effect on the distribution of Ca and Mg in the profile (Table 2).

Soil in the row middles had the same soil nutrient concentrations as soil in the row after the first three years of the experiment (Table 3). After six years, however, significant differences between row positions occurred throughout the A horizon for concentrations of P and K. Concentrations of P were higher in the mid-row than in the row, both in the surface 5-cm of the horizon and in the rest of the A horizon. It is likely that more roots directly under the row depleted the P in that area. Opposite of P, concentrations of K were higher in the row than in the mid-row in both the surface 5-cm and in the rest of the A horizon (Table 3). The higher in-row K concentrations were probably due to higher amounts of K leached from decomposed stalks and leaes which accumulated in the in-row region.

Since nutrients and root growth both concentrate near the surface in conservation tillage production, recommendations for soil sampling to determine fertilizer requirements include taking the samples only from the surface 7.5 to 10 cm of soil (Kovar, 1994). We found significant differences in surface nutrient concentrations after only three years of comparing conventional and conservation tillage, indicating that sampling procedures need to be modified soon after converting to conservation tillage. Although deep tillage did not have a large impact on the distribution of nutrients, our data suggests that subsoil samples for K may be beneficial, especially if deep tillage has not been practiced. Finally, with controlled traffic and in-row subsoiling, sample collection from the row may be physically easier to collect because of the loosened soil. Our data suggest that when sampling fields, sample collection should from both in the row and in the row middles to avoid errors in estimating P and K fertilizer needs.

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Table 1. Soil nutrient concentration at different depths in the soil profile as affected by surface tillage after three years of soybean (1996) followed by three years of corn (1999).

		Surface Tillage			
		1996		1999	
Nutrient	Depth	Conventional	Conservation	Conventional	Conservation
		mg kg^{-1}			
P	Surface 5-cm	34	20	48	35
	Rest of A	20	16	15	11
	E	4	5	2	2
	Top 7.5-cm of B	0	0	0	0
	LSD	5		4	
K	Surface 5-cm	78	68	79	83
	Rest of A	43	48	38	38
	E	40	36	41	37
	Top 7.5-cm of B	76	62	72	64
	LSD	ns†		ns	
Ca	Surface 5-cm	369	296	306	220
	Rest of A	186	238	130	153
	E	169	173	150	163
	Top 7.5-cm of B	328	308	320	318
	LSD	34		33	
Mg	Surface 5-cm	76	63	61	42
	Rest of A	27	40	20	22
	E	29	32	30	33
	Top 7.5-cm of B	75	79	72	79
	LSD	10		9	

†ns indicates the surface tillage X depth interaction was not significant.

Table 2. Soil nutrient concentration at different depths in the soil profile as affected by deep tillage after three years of soybean (1996) followed by three years of corn (1999).

Nutrient	Depth	Deep Tillage 1996 No Subsoil	Deep Tillage 1996 Subsoil	Deep Tillage 1999 No Subsoil	Deep Tillage 1999 Subsoil
		mg kg^{-1}			
P	Surface 5-cm	30	17	44	39
	Rest of A	19	18	15	12
	E	4	6	2	2
	Top 7.5-cm of B	0	0	0	0
	LSD	6		ns†	
K	Surface 5-cm	62	66	71	86
	Rest of A	41	53	37	39
	E	37	40	42	39
	Top 7.5-cm of B	72	63	82	57
	LSD	ns		13	
Ca	Surface 5-cm	334	279	262	251
	Rest of A	216	209	154	138
	E	182	170	162	158
	Top 7.5-cm of B	339	289	358	308
	LSD	ns		ns	
Mg	Surface 5-cm	74	58	52	50
	Rest of A	33	38	21	22
	E	30	32	31	33
	Top 7.5-cm of B	83	71	85	73
	LSD	ns		ns	

†ns indicates the deep tillage X depth interaction was not significant.

Table 3. Soil nutrient concentration at different depths in the soil profile both in the row and in the mid-row after three years of soybean (1996) followed by three years of corn (1999).

		Row Position			
		1996		1999	
Nutrient	Depth	Mid-row	In-row	Mid-row	In-row
		mg kg^{-1}			
P	Surface 5-cm	29	25	49	34
	Rest of A	18	18	15	11
	E	4	5	2	2
	Top 7.5-cm of B	0	0	0	0
	LSD	ns[†]		4	
K	Surface 5-cm	75	61	43	118
	Rest of A	47	43	31	45
	E	39	37	39	40
	Top 7.5-cm of B	69	67	64	70
	LSD	ns		11	
Ca	Surface 5-cm	298	309	282	247
	Rest of A	194	166	130	153
	E	175	223	161	151
	Top 7.5-cm of B	328	337	323	316
	LSD	ns		ns	
Mg	Surface 5-cm	65	79	54	49
	Rest of A	29	39	19	24
	E	31	29	31	31
	Top 7.5-cm of B	78	76	75	76
	LSD	ns		ns	

[†] ns indicates the row position X depth interaction was not significant.