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Soil Sampling for Fertilizer Recommendations in Conservation Tillage with Paratill Subsoiling

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Abstract
Shallow sampling depths are recommended for collecting soil samples for lime and fertilizer recommendations when using conservation tillage. Some subsoiling implements used to disrupt the compacted horizon in some southeastern USA coastal plain soils can also disturb the surface soil. Our objective was to compare sampling depths for lime, P, and K recommendations in a conservation tillage system that includes paratill subsoiling. One-half of a 14-acre field was managed with conventional tillage. The other half was managed with conservation tillage which consisted of using a six-shanked paratill followed by planting. Soil samples from 0 to 3 inches and 0 to 6 inches were collected for four years on each side of the field around points in a 50-ft × 50-ft grid. The field was in a corn (*Zea mays* L.)-cotton (*Gossypium hirsutem* L.) rotation. Soil P and K concentrations differed for sampling depths in most years for both tillage systems. Generally, these differences were small but fertilizer P and K recommendation rates for the two sampling depths were the same more often for conventional tillage than for conservation tillage. After a lime application in 2002, pH of the soil 0 to 3-inch depth in the conservation tillage half of the field was 5.89 in 2003, 6.07 in 2004, and 6.29 in 2005 while the pH of the soil collected from the 0 to 6-inch depth was about 6.1 each year. When using the 0 to 6-inch sampling depth in fields managed with this conservation tillage system, it appears a separate sample for soil pH from a shallower depth may be beneficial in the years subsequent to a lime application.

Introduction
It has long been known that reducing tillage changes the distribution of nutrients and pH in the soil profile (7,10,15). On coarse textured soils, such as those commonly found on the southeastern USA coastal plain, some pH and P stratification occurs in conservation tillage systems (1,6,11). Potassium is somewhat mobile in these soils and less prone to stratification (9,11). Because of the vertical distribution of nutrients, recommendations have been made to collect samples from a relatively shallow depth when collecting soil samples for fertilizer recommendations. For soils in the southern United States, recommendations have been made for a sampling depth of 0 to 3 inches for fields managed with reduced tillage (12).

Crop production on many coastal plain soils benefits from some form of deep tillage to allow roots to grow through inherent compaction zones (2,3,8,14). Disrupting the compaction zone with narrow straight-shanked subsoilers is often done just prior to planting row crops. When used in conservation tillage systems, this subsoil/planting method results in minimal soil surface disturbance that is similar to no-tillage. Subsoiling implements that disrupt more of the compacted zone are becoming more common. These implements tend to loosen more of the soil surface than straight-shanked subsoilers. It is not known whether this surface disturbance is enough to affect the distribution of nutrients within the profile. Our objective was to compare soil sampling depths for lime and fertilizer recommendations in a conservation tillage management system that includes paratill subsoiling.

Site Description and Data Collection

Soil pH, P, and K data were collected from a split-field study that was conducted from 1997 through 2005 near Florence, SC to compare productivity of a combination of newer crop production technologies against typical practices used by growers in the mid-1990s in the region. A 14-acre field was divided roughly in half with the new production practices on one-half of the field and conventional practices on the other half. The new production practices consisted of conservation tillage, site-specific application of P fertilizer based on grid sampling, 15-inch row spacing (for corn only), and using a Bt/RR cultivar (for cotton only). The conventional practices were conventional tillage, one rate of P fertilizer for the entire half of the field, 30-inch row spacing (for corn only), and a nontransgenic cultivar. The field was divided in such a way that most soil map units in the field were represented on each side. Wheat (*Triticum aestivum* L.) double cropped with soybean [*Glycine max* (L.) Merr.] were grown in the fall 1997 through 1998. From 1999 through 2004, corn and cotton were rotated annually. Soil analysis data reported here are from samples collected during January in the years of 2002 through 2005. During these years, corn was planted in April and harvested in September and cotton was planted in May and harvested in October or November.

Conservation tillage management consisted of using a six-shanked paratill prior to planting the corn or cotton. The shanks on the paratill were spaced 26 inches apart and a roller was mounted on the back of the unit to firm and smooth the soil surface as it moved through the field. Corn was planted in 15-inch-wide rows with a 12-row planter and cotton was planted in 38-inch-wide rows with a four-row planter. Both planters had wavy coulters mounted directly in front of the planter units. On the side of the field managed with conventional tillage, a disk harrow was used to a depth of approximately six inches and then the soil surface was smoothed with an S-tine harrow equipped with rolling baskets. Corn was planted into 30-inch-wide rows following subsoiling with a straight-shanked subsoiler that was attached to a four-row planter. For cotton grown with conventional tillage, a straight-shanked subsoiler with row bedders was used to form the rows prior to planting. At planting, the top of the beds were leveled and the crop was seeded (38-inch-wide rows) with the same planter used in conservation tillage.

Soil sampling areas were assigned in January of 1998 based on a 50-ft × 50-ft grid. A global positioning system unit was used to determine the latitude and longitude of each grid point and to return to the same points each year. There were 164 points on the conservation tillage side and 136 points on the conventional tillage side. Separate 0 to 3-inch and 0 to 6-inch soil samples were collected at each grid point. For each depth, six to eight one-inch diameter soil cores within five feet diameter of each grid point were combined into one sample. Soil samples were air-dried and then sent to the Clemson University Extension Agricultural Service Laboratory for pH, P, and K analysis (4,5). Recommendations based on the 0 to 6-inch samples from the Service Laboratory were used to apply lime and fertilizer.

Fertilizer P and K were broadcast-applied at the rates shown in Table 1. Applications of K were made uniformly across each side of the field. Fertilizer P was uniformly applied on the conventional tillage side. On the conservation tillage side, however, we delineated application rate zones and made precision applications of P to those zones (rates applied are in Table 1). Lime was applied (1000 lb/acre of dolomitic limestone) uniformly in the spring of 2002 to both sides of the field. Lime, all K fertilizer, and P fertilizer on the conventional tillage side were applied with a commercial truck applicator. Precision applications of P on the conventional tillage side were made with a tractor-pulled drop spreader.

Table 1. Fertilizer P and K application rates from 1998 through 2004.

Year	**Phosphorus** (P_2O_5, lb/acre)		**Potassium** (K_2O, lb/acre)	
	Conservation	**Conventional**	**Conservation**	**Conventional**
1998[x]	0, 75, 100[y]	0	150	150
1999	0, 50	0	80	80
2000	0, 60	60	100	100
2001	0, 50	50	80	50
2002	0, 60	0	60	60
2003	0, 50	0	80	50
2004	0, 60	60	100	60

[x] Fertilizer applications for 1998 were made in the fall of 1997. For all other years, fertilizer applications were made in the spring.

[y] Multiple phosphorus fertilizer rates are shown because it was applied on a site-specific basis each year in conservation tillage.

The data were analyzed by making paired comparisons using the MEANS procedure of SAS (SAS Institute Inc., Cary, NC) to test whether the two sampling depths differed for soil pH and P and K concentrations in each tillage system. Then, the data were subjected to regression analysis (using the REG procedure of SAS) to evaluate the relationship of the two sampling depths for these soil chemical characteristics across the range of values.

Crop Yield

Crop yields from 2001 through 2004 are shown in Table 2 to provide the reader an indication of the relative productivity of the field during this study. Yield monitors were used to determine crop yields. Crop yields were similar to or higher than long-term South Carolina average yields [South Carolina's 10-year average (1997-2006) corn yield is 85.6 bu/acre and cotton yield is 636 lb lint/acre (16)]. The one exception was the cotton yield in 2002 when an extended rain-free period that occurred from June through late August resulted in low productivity.

Table 2. Corn and cotton yields from 2001 through 2004. Crop yields were determined with yield monitors.

Crop	Year	Tillage	**Mean**	**Median**	**Coefficient of variation** (%)
			Yield (bu/acre)		
Corn	2001	Conservation	97.6	97.6	18.9
		Conventional	88.8	89.6	19.1
	2003	Conservation	142.6	141.4	16.9
		Conventional	132.6	134.2	16.3
Crop	**Year**	**Tillage**	**Yield** (lb lint/acre)		**Coefficient of variation** (%)
Cotton	2002	Conservation	213	201	47.6
		Conventional	268	243	58.8
	2004	Conservation	915	952	36.7
		Conventional	850	875	47.2

Comparison of Sampling Depths

There was no difference between the 0 to 3-inch and 0 to 6-inch sampling depths for soil pH in conservation tillage in 2002 (Table 3). Soil pH for the conservation tillage system was similar to that for conventional tillage in that year. This is not surprising since no lime had been applied since the experiment was established in 1997. Prior to 1997 the entire field was managed with conventional tillage. Lime was applied in the spring of 2002. Differences between sampling depths occurred for soil pH in conservation tillage in 2003 and 2005, but not in 2004. Differences between sampling depths for pH occurred for conventional tillage in all three years after the lime application, but these differences tended to be small.

Table 3. Comparison of sampling depths for soil pH, P concentration, and K concentration in conservation and conventional tillage systems.

Management	**Year**	**pH units**		**P** (ppm)		**K** (ppm)	
		Sampling Depth (inches)					
		0 to 3	**0 to 6**	**0 to 3**	**0 to 6**	**0 to 3**	**0 to 6**
Conservation	2002	5.70	5.68	41.5**	35.1	58.9**	44.2
	2003	5.89**	6.07	32.1**	33.2	28.8**	32.5
	2004	6.07	6.06	28.9*	30.9	32.6	34.2
	2005	6.29**	6.06	35.7**	30.8	46.7**	33.7
Conventional	2002	5.65**	5.61	33.8**	29.0	58.3**	49.8
	2003	6.41**	6.44	31.1	30.6	35.4**	38.4
	2004	6.31**	6.41	25.6**	26.9	36.1**	40.2
	2005	6.35**	6.22	29.4**	27.6	43.2**	31.1

*, ** indicate sampling depth means within a tillage system and year differ at $P \le 0.05$ and $P \le 0.01$, respectively.

Previous research (6,11,13) has shown surface stratification of soil pH with conservation tillage, presumably because lime is not incorporated with surface tillage. In our study, the surface stratification in pH was measurable within two years after lime application. The pH of the 0 to 6-inch sampling depth was 6.07 in the spring of 2003 while the surface 0 to 3-inch was only 5.89 (Table 3). Significantly lower pH of the 0 to 3-inch sampling depth compared to the 0 to 6-inch depth in that year may have been due to some incorporation of fine particles of lime during operation of the paratill. Over the next two years, the pH of the surface 3-inch continued to increase while the pH of the entire 6-inch surface soil did not change. Soil pH response to liming in conservation tillage was quite different from conventional where soil pH rose to 6.4 for both sampling depths by the January after the lime application (Table 3).

Differences in concentrations of P and K between sampling depths occurred in most years (Table 3). For P, these differences were small even when significant. Potassium concentration of the 0 to 3-inch sampling depth was substantially higher than the 0 to 6-inch sampling depth in 2002 and in 2005. Since this occurred for both conventional and conservation tillage, it is possible that higher K with shallower sampling was more related to the timing of the releasing of this nutrient from the residues of the previous crop rather than a stratification of K occurring in the soil.

The relationships between the two sampling depths for soil pH and concentrations of P and K were closer in conventional tillage than it was in conservation tillage. For all three, the r^2 values for these regressions were higher in conventional tillage than conservation in every year (Table 4). Also, with the exceptions of pH and K in 2005, slopes were nearer to 1.0 and y-intercepts closer to 0.0 in conventional tillage than in conservation. Data for P concentrations are plotted in Figure 1. The close relationship between sampling depths for pH and nutrient concentrations in conventional tillage is not unexpected. Crozier et al. (1999) (6) reported no difference between 0 to 4-inch and 0 to 8-inch sampling depths in conventional tillage across a range of soils in North Carolina. In our study, mixing the soil annually with the disk and S-tined harrows in conventional tillage (and after fertilizer and lime applications) seems to have kept the surface 6-inch of the soil rather uniform.

Table 4. Regression equations relating pH and concentrations of P and K in soil from the surface three inches to pH or concentrations in the surface six inches. All regression equations except for K with conservation tillage in 2002 (noted with ns) were significant ($P \leq 0.05$). In each equation, Y is the concentration in surface 3 inches and × is the concentration in surface 6 inches.

Variable	Year	Conservation		Conventional	
		Equation	**r²**	**Equation**	**r²**
pH	2002	y = 2.57 + 0.55x	0.34	y = 0.69 + 0.88x	0.71
	2003	y = 1.71 + 0.69x	0.63	y = 0.20 + 0.96x	0.93
	2004	y = 1.13 + 0.82x	0.68	y = -0.21 + 1.02x	0.92
	2005	y = 0.95 + 0.88x	0.71	y = -0.13 + 1.04x	0.94
P	2002	y = 27.7 + 0.39x	0.14	y = 3.4 + 1.05x	0.81
	2003	y = 12.5 + 0.59x	0.52	y = 4.3 + 0.87x	0.78
	2004	y = 4.6 + 0.79x	0.21	y = 1.2 + 0.90x	0.91
	2005	y = 14.8 + 0.68x	0.36	y = 4.3 + 0.91x	0.88
K	2002	y = 46.9 + 0.55x (ns)	0.02	y = 16.4 + 0.84x	0.54
	2003	y = 4.1 + 0.76x	0.62	y = -3.7 + 1.02x	0.84
	2004	y = 8.0 + 0.73x	0.42	y = -1.9 + 0.94x	0.81
	2005	y = 11.9 + 1.03x	0.70	y = 3.4 + 1.28x	0.86

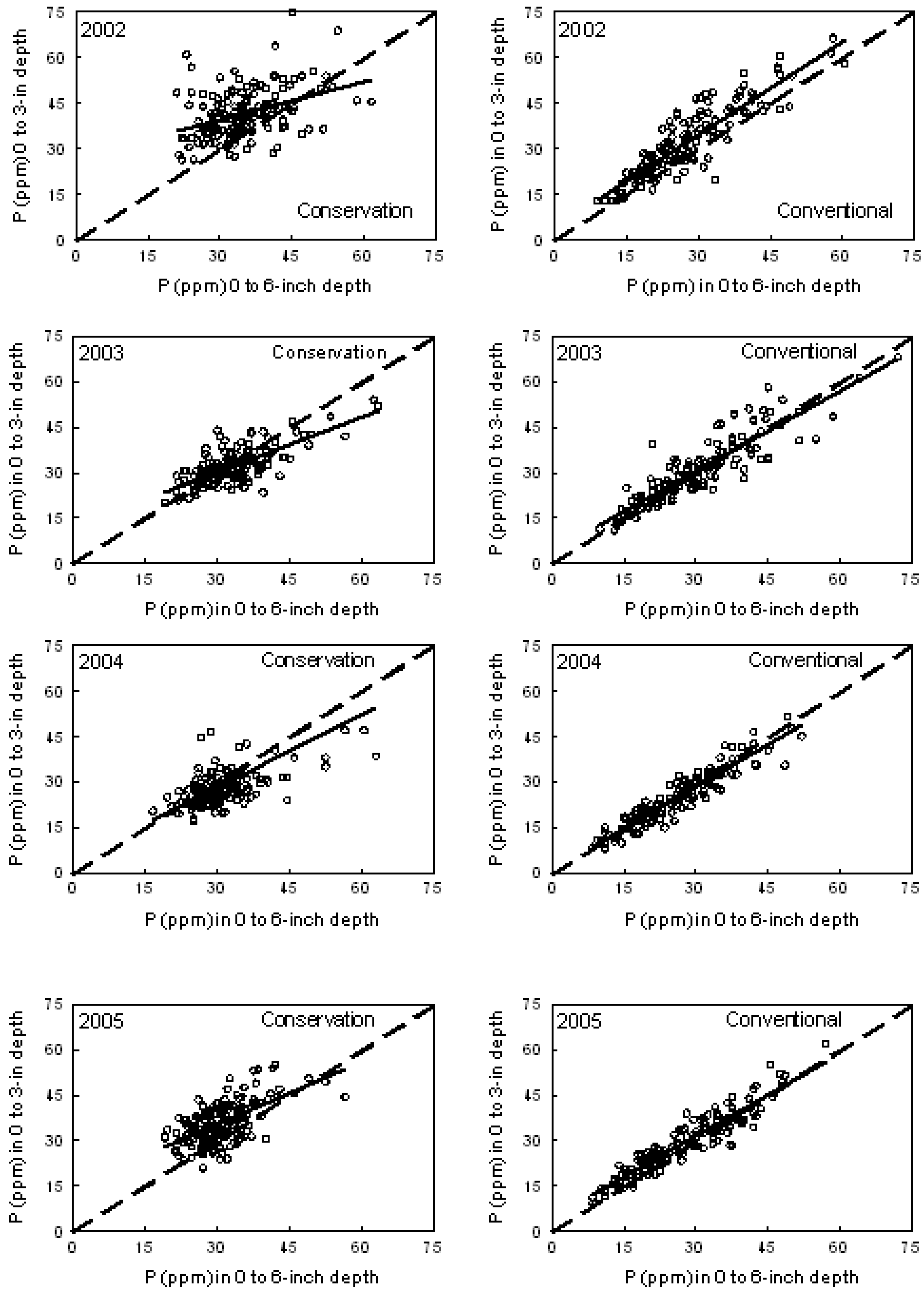

Fig. 1. Relationship between the 0 to 3-inch sampling depth to the 0 to 6-inch sampling depth for soil P in conservation and conventional tillage. Regression equations are given in Table 3. Dashed line represents the 1:1 relationship.

Inspection of individual years in Figure 1, plus inspection of means of all sampling points in Table 3, suggests that significant P stratification had not occurred on the side of the field with conservation tillage. Part of the explanation for this observation is likely the soil surface disturbance caused by the paratill after P was applied. We considered that at least a partial explanation of this result may have been the use of site-specific applications of P fertilizer. Since many individual sampling areas did not receive P fertilizer each year, detection of stratification averaged across all of the areas would be more difficult. Therefore, we compared the 0 to 3-inch and 0 to 6-inch sampling depths for P concentration using the 24 sampling areas on the conservation tillage side of the field that received P fertilizer every year (five areas) or all years except one (19 areas). Mean differences between these two sampling depths for these 24 sampling areas were not substantially different from those for all sampling areas (Table 3). Concentration of P in the 0 to 3-inch for these 24 areas was 12.5 ppm higher than the 0 to 6-inch sampling depth in 2002 ($P \leq 0.01$), not different from the 0 to 6-inch sampling depth in either 2003 or 2004, and 7.5 ppm higher than the 0 to 6-inch sampling depth in 2005 ($P \leq 0.01$). Even though substantial amounts of K fertilizer were applied annually (Table 1), there was also little evidence for K stratification in this study. This was not unexpected because of the mobility of this nutrient in these coarse-textured soils (9,11).

Fairly weak correlation occurred between the two sampling depths in conservation tillage (r^2 values were often below 0.50, Table 4). The plots in Figure 1 suggest that part of the reason for the lower r^2 values (at least for P) may simply be more localized variability for soil chemical properties in fields managed with conservation tillage with paratill subsoiling than in conventional. Further research on assessing small-scale spatial variability in production fields may be warranted.

Fertilizer recommendations for P and K in South Carolina are currently calculated based on the estimated weight of the surface six inches of an acre of soil (2,000,000 lb) (4). Field test validation data with shallower sampling depths are not available, so this conversion factor was used for both sample depths to provide recommended P and K fertilizer application rates for each grid point area. Even though there was weak correlation between the two sample depths with conservation tillage, the two depths provided the same recommendation for P over 60% of the time in every year with that tillage system (Table 5). The recommended rates for K were the same over 50% of the time each year. As expected, the two depths resulted in the same P and K fertilizer recommendation in conventional tillage more often than in conservation tillage (Table 5).

Table 5. Percent of observations where P and K fertilizer recommendations for the 0 to 3-inch sampling depth was less than, the same as, and greater than the 0 to 6-in sampling depth.

		P recommendation of 0 to 3 inch depth			K recommendation of 0 to 3 inch depth		
		< 0-6 inch depth	No difference	> 0-6 inch depth	< 0-6 inch depth	No difference	> 0-6 inch depth
Tillage	**Year**	**Percent of observations**					
Conservation	2002	26	72	3	34	57	9
	2003	10	74	16	3	74	23
	2004	8	69	24	7	70	22
	2005	34	61	5	43	56	0
Conventional	2002	18	79	3	21	74	5
	2003	7	83	9	7	79	14
	2004	3	87	10	7	75	17
	2005	12	83	5	36	64	0

The conservation tillage system with paratill subsoiling that we evaluated in our study did not result in significant stratification of nutrients so shallower sampling depths may be less critical with this system for fertilizer recommendations. Further research is needed on fields managed with this tillage system for a longer period of time and with more P applications. However, the results of this study do support previous work (6,12) with other conservation tillage systems in that sampling depth is important for pH, and, when using a 6-inch sampling depth, it seems a separate sample for soil pH from the shallower depth may be beneficial in the years subsequent to a lime application.

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