MEASURING SOIL QUALITY ON THE 'OLD ROTATION'

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ABSTRACT

Low residue-producing crops such as cotton (*Gossypium hirsutum* L.), especially when grown in monoculture, are detrimental to soil quality. Cover crops, crop rotations with legumes and high-residue crops can improve soil quality. The 'Old Rotation' (1896) is the oldest continuous cotton experiment in the world and includes rotations and winter legume cover crops in cotton production systems. There are six treatments in the 'Old Rotation': a three-year rotation of cotton and grain crops plus a winter legume cover crop; two fertilizer treatments (with and without N fertilizer) imposed on a two-year rotation of cotton and a grain crop plus a winter legume cover crop; and three continuous cotton cropping systems (with N fertilizer, without N or N supplied from a winter legume cover crop). Because of the uniqueness of 'Old Rotation' and the current interest in soil quality, the specific objectives of this study were: 1) to determine the effects of rotations on soil quality after 100 years; 2) to evaluate the *USDA Soil Quality Kit* and compare results with standard procedures for selected indicators; and 3) to develop a baseline of soil quality indicators to monitor change. After 100 years, soil quality was better for the three-year rotation and the two-year rotation plus N due to higher soil C (1.3 and 1.1%, respectively, compared to a mean of 0.8% for others). The three-year rotation had higher percentage water stable aggregates (64% compared to a range of 34 to 53% for other treatments). Cation exchange capacity was highest for the three-year rotation and the two-year rotation (5.5 and 5.4 $cmol_c$/kg, respectively, compared to a mean of 4.4 $cmol_c$ /kg for other treatments). Soil strength was lowest (six bars) for the three-year rotation while continuous cotton without a cover crop or N had the highest soil strength in the top 4 in. of the plow layer. Kit measurements had higher variability relative to standard procedures. Soil moisture was greater at the time Kit measurements were taken and fewer samples were used, which may explain increased variability. The Kit can be used to evaluate trends and comparisons but should not be used in place of standard procedures for research. Information from this study will set a baseline for soil quality indicators for the 'Old Rotation', and future studies will measure the differences in soil quality as a result of the conversion to conservation tillage in 1997.

INTRODUCTION

The 'Old Rotation' experiment at Auburn University has been in continuous production since 1896 (Mitchell et al., 1996), and the purpose of this study was to show that the use of crop rotations and legume cover crops could sustain cotton and corn yields. In the spring of 1997, after 100 year of conventional tillage, the 'Old Rotation' was converted to conservation tillage. We were interested in the effects of long-term legume cover crops, crop rotations and N fertilizer on soil quality. We also needed a baseline value for soil quality in order to monitor change as the 'Old Rotation' was converted to conservation tillage.

Soil quality is "the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation" (Karlen et al., 1997). Soil quality cannot be measured directly but must be inferred by its attributes or indicators (Seybold et al., 1998). Karlen et al. (1997) suggested using indicators such as organic matter, infiltration, aggregation, pH, bulk density, electrical conductivity and available nutrients to monitor soil quality.

Because of the uniqueness of the long-term rotations in the 'Old Rotation' and because of the current interest in soil quality, we wanted to measure the effects of these long-term treatments on soil quality. The specific objectives of this study were: 1) to determine the effects of rotations on soil quality indicators after 100 years; 2) to evaluate the *USDA Soil Quality Kit* (Liebig et al., 1996) and compare results with standard procedures for selected indicators; and 3) to develop a baseline of soil quality indicators in order to compare future effects of conservation tillage, cover crops and crop rotations on soil quality.

MATERIALS AND METHODS

The 'Old Rotation' consists of 13 plots (Mitchell et al., 1996). Each plot is 21.5 ft by 136.1 ft and is separated by 3-ft alleys. Treatments in the 'Old Rotation' have evolved into six rotations (Table 1). The soil at the site of the rotation is currently identified as Pacolet fine sandy loam (clayey, kaolinitic, thermic Typic Hapludults), a typical Piedmont soil. The soil has a Coastal Plain cap similar to

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a Marvyn loamy sand (fine-loamy, siliceous, thermic Typic Kanhapludults). The site is on a gently rolling slope (~3 %). Confusion for the soil identification is due to Auburn being located at the junction of the two physiographic regions with the upper part of the site (plot #1) more characteristic of a Coastal Plain soil and the lower portion (plot #13) more characteristic of a Piedmont soil (Mitchell et al., 1996).

Standard Procedures

Nine standard tests were used to measure selected soil quality indicators. Soil strength was measured using a recording cone penetrometer with 10 insertions per plot, beginning at 0.6 in. and recording a reading every 0.6 in. to 24 in. deep. Bulk density was determined from five undisturbed cores per plot at zero to 3 in. using the method of Blake and Hartge (1986). Gravimetric soil water content was measured by taking five undisturbed cores from each plot at the 0- to 3-in. depth (Gardner, 1986). Hydraulic conductivity (K_{sat}) was determined (Klute and Dirkson, 1986) from five undisturbed cores per plot at three different depths (0 to 3, 3 to 6 and 6 to 8 in.) for a total of 15 samples per plot. Soil samples for nutrient determination were taken at three depths (0 to 1.5, 1.5 to 6 and 6 to 10 in.) with composite samples from 10 random sites per plot. Soil nutrients were extracted using Mehlich-I and analyzed (Odom and Kone, 1997) using an inductively-coupled-plasma (ICP) analyzer. Elements determined were Ca, K, Mg, P, Cu, Fe, Mn, Zn, B, Mo, Al, Co and Na. Cation exchange capacity (CEC) (Rhoades, 1986) and pH were also determined (Tan, 1996). Samples for soil C and N were taken from five locations per plot to form three composite samples by depth (0 to 1.5, 1.5 to 6 and 6 to 10 in.) The samples were prepared by fine grinding on a conveyor-belt apparatus to reduce sample variability (Kelley, 1994). Duplicate samples were analyzed for carbon and nitrogen by a combustion technique. Percent water stable aggregates were determined (Kemper and Rosenau, 1986) from samples taken from five locations per plot forming three composite samples for depths of 0 to 1.5, 1.5 to 6 and 6 to 10 in. During wet sieving, two sub-samples were analyzed from each sample for a total of six samples per plot.

The Soil Quality Kit Procedures

The *USDA Soil Quality Kit* (Kit) was used to measure seven soil quality indicators. Samples for all indicators were taken at three random positions per plot to the 3-in. depth. Infiltration rate was measured using an aluminum ring 6 in. in diameter and 5 in. in length. The ring was driven into the ground to a depth of 3 in. Water (1 in.) was poured in the ring; the time it takes to infiltrate is the determined infiltration rate (in./min). A lid with a rubber septa was placed on top of the ring for 30 min to accumulate CO_2 respired by soil organisms and plant roots. Air in the covered ring was sampled with a syringe and passed through a Drager 0.1 % CO_2 tube and CO_2 determined colorimetrically. Bulk density and soil water content were measured by inserting a 3-in.-diameter cylinder into the ground. Calculations are similar to standard tests. Soil water content samples for the standard method were collected during a period of dry weather prior to planting (April 1997) while the *USDA Soil Quality Kit*'s sampling was done in July after several rains. Soil pH and electrical conductivity (EC) were measured using pocket meters in a 1:1 soil to water ratio. Soil nitrate content was determined by dipping nitrate test strips in a filtered extract. The test strip color was compared to a standard color chart, indicating concentrations of nitrate.

Statistical Analysis

Data were analyzed using the General Linear Model (GLM) procedure of the Statistical Analysis System (SAS Institute, 1988). Least-squares means statements were used for means separation. Pearson product-moment correlation among measured variables and methods were calculated using the CORR procedure of SAS (SAS Institute, 1988).

RESULTS AND DISCUSSION

The standard method for determining soil water content showed significant differences among treatments. The three-year rotation plus legume cover crop (treatment 1) had the highest average water content while the continuous cotton treatments (treatments 2 and 3) had the lowest soil water content (Table 2). Sampling for soil water with the Kit at a later date showed no significant differences among treatments due to a higher variance in the data. Also, we took five sub-samples during sampling for the standard procedures and only three sub-samples with the Kit. Fewer samples taken with the Kit likely contributed to more variability. There was good correlation between the two methods (r = 0.77), but the Kit's method had a much higher coefficient of variation (c.v.), 32% compared to 8% for the standard method.

There were significant differences in K_{sat} (standard procedure) among treatments but not by depth. The c.v. was high (62%). Infiltration measurements taken with the Kit showed a trend for differences between the three-year rotation and other treatments ($P \leq 0.14$); however, the c.v. was 95%.

Soil C was highest for the three-year rotation (treatment 1) and lowest for continuous cotton without a legume cover crop or N (treatment 2) (Table 3). Respiration measurements (Kit) showed no differences among treatments. However, there was good correlation between laboratory determination of total C and respiration as measured by the Kit (r = 0.75). The Kit's method showed more variation with a c.v. of 33% for respiration compared to 10% for soil C determination using standard procedures. Generally, soil respiration was commensurate with soil C concentrations. The continuous cotton plus N (treatment 3) and two-year rotation (treatment 4) were exceptions.

Electrical conductivity measured by the Kit showed significant differences among treatments. Treatment 3, continuous cotton with 120 lb of N (plot #13) had a higher EC (0.67 dS/m) than other treatments (range from 0.10 to 0.20 dS/m). This may be the result of accumulation of Na from fertilizer treatments of sodium nitrate prior to Word War II. Plot # 13 is at the slope end of the site and has a higher clay content (25%) (Mitchell et al., 1996) than most of the other plots (< 20%), which may contribute to greater retention of salts. There were no differences among other treatments in EC.

Cation exchange ranged from 3.1 $cmol_c$/kg for continuous cotton without legume or N (treatment 2) to 5.5 $cmol_c$/kg for the three-year rotation (Table 4). Increases in CEC were due to more intense rotations, the use of legume cover crops and N fertilization. These results are similar to those for soil carbon (Table 4). Treatment 3 was relatively higher (5.6 $cmol_c$/kg) due to higher clay content compared to other plots.

The percentage water stable aggregates ranged from 35% in cotton without legume but N fertilizer (treatment 3) to 64% in the three-year rotation with legume cover crop (treatment 1). Aggregate stability was increased by rotation, cover crop use and N fertilizer but was also affected by clay content (data not shown).

The ICP analysis showed significant differences by treatment and depth for extractable P and by depth only for extractable K. Phosphorus levels were lowest for the two-year rotation without N (treatment 6) and three-year rotation (41 and 45 mg/kg, respectively) while continuous cotton without a cover crop and N was highest (99 mg/kg). Rotation treatments have had little effect on other nutrients due to the use of conventional tillage for the past 100 years, which has evenly distributed nutrients through the plow layer. Differences in P and K were limited to the upper 6 in. of the plow layer and were due to fertilizer applications, reduced plant removal of nutrients in less productive rotations and mixing of soil in the plow layer due to tillage. The elemental analysis data will serve as a baseline to monitor changes in nutrient stratification caused by conservation tillage in the future.

There were significant differences in soil strength among treatments to the 4-in. depth (Fig. 1). The two continuous cotton treatments without cover crops (treatment 2 and 3) had the highest mean ranges. There was a strong trend for differences to the 10-in. depth ($P \leq 0.25$). With the exception of continuous cotton (treatment 2), there was considerable compaction below the 10-in. depth. Continuous cotton (treatment 2) shows reduced soil strength at the 10-in. depth, possibly due to high variability in the data (~55 % c.v.) or inherent differences in the soil profile between it and other plots. The variability could be the result of the ‘Old Rotation’ plots being located in a transition zone, including both Piedmont and Coastal Plain soil types.

CONCLUSIONS

After 100 year of using a legume cover crop and crop rotations with high residue crops like corn and small grains, soil quality is better for the three-year rotation plus a winter legume cover crop (treatment 1) due to higher soil carbon, more water stable aggregates, higher CEC, reduced soil strength at the surface and higher soil water retention. In contrast, continuous cotton without a legume cover crop had lower soil carbon, lower water stable aggregates, lower soil water retention and greater soil strength down to 5 in. Nitrogen fertilizer and/or a legume cover crop within continuous cotton rotations contributed to more residues and greater soil carbon accumulation over past 100 years. The same can be said for the two-year rotations that included a high-residue crop (corn) plus a legume cover crop with or without nitrogen. With the exception of P, rotation treatments had little effect on extractable plant nutrients due to the use of conventional tillage for the past 100 years. However, these data will be used as a baseline to monitor future changes in nutrient stratification caused by conservation tillage.

The USDA Soil Quality Kit is designed for semi-quantitative assessments and for education on soil quality. The Kit can be useful for a conservationist or farmer to compare management practices to assess trends in soil quality but should not be used for research. Soil carbon data will be beneficial to interpret Kit respiration readings. The Kit had higher variation (c.v.) than comparable standard procedures. This may have been due to use of fewer samples for kit measurements than for standard procedures. More intensive sampling and incorporating data from standard tests can improve the reliability and usefulness of the Kit.

The benefits of crop rotations and cover crops should be enhanced by the addition of conservation tillage as a management practice in the ‘Old Rotation’. The impact of conservation tillage on soil quality in the ‘Old Rotation’ can be monitored in the future using these established baseline values.

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Table 1. The 'Old Rotation' treatments.

Treatment	Plots	Rotations	N management
1	10, 11 and 12	Three-year rotation of cotton fb[1] legume cover crop (*Trifolium incarnatum* L.) fb corn (*Zea mays* L.) fb wheat (*Triticum aestivum* L.) or rye (*Secale cereale* L.) for grain fb soybean [*Glycine max* (L.) Merr.]	60 lb/acre applied to wheat or rye
2	1 and 6	Continuous cotton without a cover crop	No N
3	13	Continuous cotton + N without a cover crop	120 lb/acre applied to cotton
4	2, 3 and 8	Continuous cotton + legume cover crop	No N
5	4 and 7	Two-year rotation of cotton-corn +legume cover crop	No N
6	5 and 9	Two-year rotation of cotton-corn + legume cover crop	120 lb/acre applied to cotton

[1]fb = followed by.

Table 2. Comparisons of some soil quality indicators determined from standard tests vs. the *USDA Soil Quality Kit.* Means followed by the same letter are not significantly different at P ≤ 0.10.

	Bulk Density		Soil Water		K_{sat}	
Treatments	Standard	Kit	Standard	Kit	Kit	Standard
	-----------g/cm³-----------		-------------%-------------		----------in./min----------	
Three-year rot. + legume cover crop	1.65	1.38	11.47a	19.75a	1.22	0.09bc
Cont. cotton with no legume	1.66	1.44	7.69c	9.98b	0.37	0.15a
Cont. cotton + 120 lb N/acre	1.73	1.45	9.40bc	12.27ab	0.04	0.03c
Cont. cotton + legume cover crop	1.66	1.49	9.47b	15.12ab	0.43	0.09bc
Two-year rot. + legume cover crop	1.68	1.42	10.11ab	14.87ab	0.57	0.08c
Two-year rot. + legume cover crop + 120 lb N/acre	1.62	1.40	11.67a	14.11ab	0.33	0.15a

Table 3. Comparisons of some soil quality indicators determined from standard tests vs. the *USDA Soil Quality Kit.* Means followed by the same letter are not significantly different at P ≤ 0.10.

Treatments	pH (standard)	pH (Kit)	Respiration (Kit)	Total C (standard)	Total N (standard)	Nitrates (Kit)
			lb/C/day	%	%	ppm
Three-year rot. + legume cover crop	5.92c	5.83b	60.16a	1.27a	0.05ab	4.78b
Continuous cotton with no legume	7.16a	7.10a	22.07b	0.50d	0.02c	1.67b
Continuous cotton + 120 lb N/acre	6.07bc	4.67c	36.28ab	0.87c	0.04abc	50.00a
Continuous cotton + legume cover crop	6.22b	5.93b	43.91ab	0.84c	0.04ab	6.11b
Two-year rotation + legume cover crop	6.32b	5.84b	60.42a	0.85c	0.05ab	2.83b
Two-year rotation + legume cover crop + 120 lb N/acre	5.52d	5.05c	44.73ab	1.09b	0.06a	10.34b

Table 4. Comparisons of CEC and water stable aggregates % (WSA) determined from standard tests. Means followed by the same letter are not significantly different at P ≤ 0.10.

Treatments	CEC	WSA
	$cmol_c$/kg	%
Three-year rotation + legume cover crop	5.5a	64.1a
Continuous cotton /no legume	3.1c	49.8b
Continuous cotton + 120 lb N/acre	5.6a	34.7c
Continuous cotton + legume cover crop	4.3b	52.2b
Two-year rotation + legume cover crop	4.6b	53.2b
Two-year rotation + legume cover crop + 120 lb N/acre	5.4a	48.9b

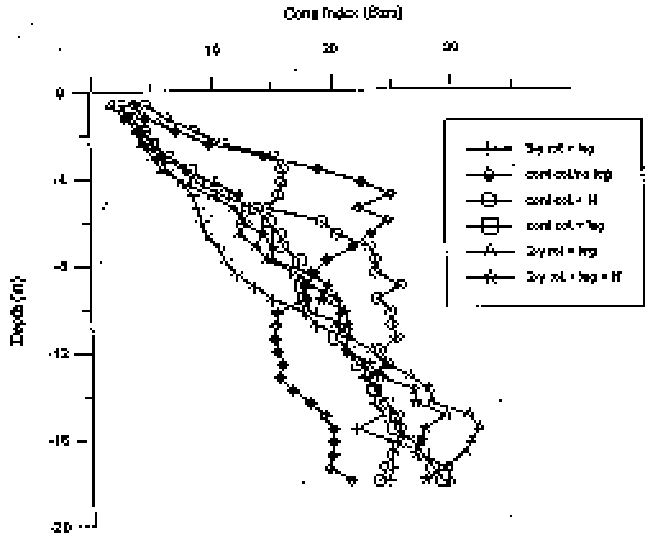

Fig. 1. Soil strength as influenced by treatment.