Soil Quality in Integrated Crop-Livestock Systems with Conservation and Conventional Tillage

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Abstract: Integration of crops and livestock could be either detrimental or beneficial to soil quality, depending upon timing and intensity of animal traffic and residue cover of the soil surface. Key soil properties (reflective of soil quality) of a Typic Kanhapludult in Georgia USA were analyzed in a 12-ha field experiment testing the effect of tillage [conventional tillage (CT), no tillage (NT)] and cover crop utilization (no utilization, grazed by cattle) variables. Soil organic C and N fractions (total, particulate, microbial biomass, and readily mineralizable), water-stable aggregate distribution, bulk density, penetration resistance, and single-ring infiltration measurements were determined at various times from initiation of the experiment in 2002 until present. With initially high soil organic C due to previous pasture management, depth distribution of soil organic C and N fractions became widely divergent between CT and NT, but changed little in response to whether cover crops were grazed or not. Some evidence of soil compaction with grazing of cover crops eventually became apparent in bulk density, penetration resistance, and water infiltration measurements. However, the compactive effects were relatively small when viewed in terms of the system-level effects on grain, forage, and animal production. Although CT management could initially alleviate compaction with periodic tillage, NT management may also have an advantage in pasture-crop rotation systems by preserving the organic matter-enriched surface soil to buffer against compactive forces.
Key words: Bulk density; Carbon; Nitrogen; Penetration resistance; Ring infiltration; Soil organic matter; Water-stable aggregation

INTRODUCTION and LITERATURE REVIEW

Soil organic matter has become an increasingly utilized indicator to discern management-induced changes in soil quality and agricultural ecosystem functioning (Weil and Magdoff, 2004). Perennial pastures have been shown to be an effective conservation measure to increase soil organic matter (Franzluebbers et al., 2000). Tillage and crop management under conditions of initially high soil organic matter content following termination of pastures have not been adequately evaluated in the southeastern USA, since most cropping has occurred on soils stripped of organic matter from decades of degradative tillage practices (Langdale et al., 1992). No-tillage management of crops following termination of pastures could be a viable approach to preserve accumulated soil organic matter, rather than a traditional approach of moldboard plowing of pasture. However, few data are available to quantify the expected difference in decline in soil organic matter between conventional- and conservation-tillage systems following pasture (Hargrove et al., 1982).

A relatively large portion of agricultural land in the southeastern USA is devoted to perennial pastures (USDA-National Agricultural Statistics Service, 2007). Previous research has shown that grazing of warm-season grasses in the summer can have positive impacts on soil organic C and N accumulation and no observable detriment to surface soil compaction (Franzluebbers et al., 2001). Rotation of pastures with crops often provides soil quality, yield, and soil erosion benefits (Garcia-Prechac et al., 2004). Cover crops following grain crops can be an excellent source of high quality forage to be utilized in small, mixed-use farming operations (Franzluebbers and Stuedemann, 2007), such as those commonly found throughout the southeastern USA. A potential impact of large herbivores grazing cover crops, however, could be compaction due to hoof action, as observed in conventionally tilled Southern Piedmont soils under relatively low soil organic matter condition (Tollner et al., 1990). Surface residue cover may provide a significant buffer against animal trampling effects, such that no-tillage crop production following long-term pasture may mitigate negative trampling effects.

Objectives in this research were to characterize (1) soil biochemical (organic C and N fractions) changes in depth distribution and stocks and (2) soil physical changes in water-stable aggregation, penetration resistance, bulk density, and water infiltration during 7 years of tillage (conventional and no tillage) and cover crop management (grazed and not grazed) following termination of pastures.

MATERIAL and METHOD

A 13-ha field experiment was located near Watkinsville GA (33° 62' N, 83° 25' W) on Cecil sandy loam and sandy clay loam soils (fine, kaolinitic, thermic Typic Kanhapludults) with 2 to 6% slope. Soil was moderately acidic (pH ~ 6) and contained moderate total N (1.2 g kg^{-1}) in the upper 20 cm. Mean annual temperature is 16.5° C, precipitation is 1250 mm, and pan evaporation is 1560 mm.

In May 2002, 16 of 18 tall fescue pastures were terminated either with (a) moldboard plow (plowed in first year only to 25-30 cm depth and subsequently tilled with tandem disks to 15-20 cm depth) or (b) glyphosate (no tillage except for drill planting). The experimental design from 2002 to 2005 consisted of a factorial arrangement of (1) tillage (conventional and no tillage) and (2) cropping system (summer grain/winter cover crop and winter grain/summer cover crop) with four replicated paddocks each, for a total of 16 main plots. Two of the original 18 pastures remained as control pastures. Main plots were split into grazed (0.5 ha) and ungrazed (0.2 ha) cover crop treatments.

Tillage systems were: (1) conventional disk tillage (CT) following harvest of each grain and cover crop and (2) no tillage (NT) with glyphosate to control weeds prior to planting.

Cropping systems from 2002 to 2005 were: (1) summer grain cropping {grain sorghum [*Sorghum bicolor* (L.) Moench] or corn (*Zea mays* L.); April to June planting and September/October harvest} with winter cover cropping [cereal rye (*Secale cereale* L.); November planting and May termination] and (2) winter grain cropping [wheat (*Triticum aestivum* L.); November planting and May/June harvest] with summer cover cropping {pearl millet [*Pennisetum glaucum* (L.) R. Br.]; June/July planting and September/October termination}. Cropping from 2005 to 2008 was wheat/soybean [*Glycine max* (L.) Merr.] double-cropping rotated with either (a) clover (*Trifolium incarnatum* L.)/rye cover crop followed by corn or pearl millet receiving a low rate of N fertilizer or (b) ryegrass (*Lolium multiflorum* L.)/rye cover crop (fertilized with inorganic N) followed by corn or pearl millet receiving a moderate rate of N fertilizer.

Cover crop management was: (1) no grazing and (2) grazing with cattle to consume ~90% of available forage produced. Cover crops were stocked with yearling Angus steers in the summer of 2002 and in the spring of 2003. Thereafter, cow/calf pairs were used to simulate a more typical regional management approach. Ungrazed cover crops were grown until ~2 weeks prior to planting of the next crop and either (1) mowed prior to CT operations or (2) mechanically rolled to the ground in the NT system.

Plant and animal production were reported in Franzluebbers and Stuedemann (2007) and some soil properties were reported in Franzluebbers and Stuedemann (2008a, b).

Soil was collected for laboratory analysis of organic C and N fractions in May 2002, December 2002, March 2004, Nov/Dec 2004, February 2007, and February 2009. Sampling depths were 0-3, 3-6, 6-12, 12-20, and 20-30 cm. Eight cores (4-cm diameter) were collected in grazed subplots and five cores were collected in ungrazed subplots. Surface residue was removed and collected from 0.04 m^2 areas prior to soil coring. Bulk density was determined from oven-dried weight (55 °C, 3 days) and volume of cores.

Total organic C and N were determined with dry combustion. Particulate organic C and N were determined from the sand fraction (>0.053 mm) following soil dispersal (Franzluebbers et al., 1999). Potential C and N mineralization were determined from 22.5-65-g subsamples incubated in 1-L canning jars at 50% water-filled pore space and 25 °C for 24 days. Alkali traps were replaced at 3 and 10 days and titrated with 1 M HCl (with $BaCl_2$ as precipitant) to a phenolphthalein endpoint to determine the amount of

CO_2 evolved. Inorganic N (NO_3 + NH_4) was determined at initiation and the end of 24 days by KCl extraction and colorimetric determination on an autoanalyzer (Bundy and Meisinger, 1994). Water-stable aggregation was determined at the end of 10 minutes of wet-oscillation of sieves containing 1.0 and 0.25 mm openings. Soil and water passing the 0.25 mm sieve was poured over a sieve with 0.053 mm openings. The three fractions collected were oven dried at 55 °C for 3 days.

Water infiltration was determined from the linear rate of intake during 1 hr within a single, 30-cm diameter steel ring inserted 2-4 cm into the ground. Water intake was recorded at 10 minute intervals. Measurements were from two locations in each grazed and ungrazed subplot at various times throughout the study.

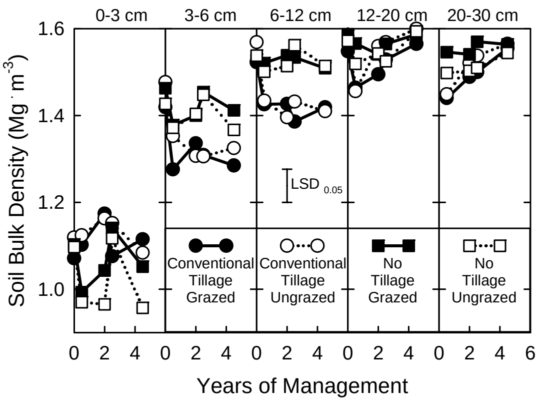

Figure 1. Soil bulk density at five soil depths as affected by time of management under different tillage (conventional and no tillage) and cover crop (grazed or ungrazed) systems.

Penetration resistance was determined with an impact penetrometer (Herrick and Jones, 2002). A 2-kg hammer was dropped 0.74-m distance repeatedly onto a 2.03-cm-diameter cone with a 30° tip. Number of strikes to reach a depth of 10, 20, and 30 cm was recorded. Measurements were from four locations in grazed subplots and two locations in ungrazed subplots at times approximately the same as for water infiltration measurements.

The experimental design was considered a multiple split-block design with four replications. Main plots were a factorial arrangement of tillage (n = 2) and cropping system (n = 2). Cover crop management (n = 2) was a split plot in horizontal space. Depth of sampling (n = 5) was a split plot in vertical space. Sampling event (n = 5-7) was a split plot in time. Differences were considered significant at $P \leq 0.05$.

RESULTS and DISCUSSION

Soil bulk density following long-term pasture (and prior to initiation of the cropping phase) averaged 1.10, 1.45, 1.54, and 1.58 Mg m^{-3} at depths of 0-3, 3-6, 6-12, and 12-20 cm, respectively (Figure 1). Following moldboard plowing of pasture, soil bulk density at the end of ½ year remained similar at 0-3 cm depth (1.11 Mg m^{-3}), but was reduced to 1.31, 1.43, and 1.46 Mg m^{-3} at 3-6, 6-12, and 12-20 cm depths, respectively. With shallower disk tillage in subsequent years, reconsolidation of soil occurred with time under conventional tillage (CT) at 12-20 and 20-30 cm depths (Figure 1).

Whether cover crops were grazed by cattle or left ungrazed had little effect on soil bulk density in CT or in no tillage (NT), except at the last sampling event 4.5 years after initiation (Figure 1). At the last sampling, soil bulk density was greater under grazed than ungrazed cover crops under NT, but only at 0-3 cm depth. Further evaluation of these systems is warranted to better define the long-term effects of cattle grazing on soil bulk density in these two tillage systems.

Surface-soil organic C and N fractions (0-6 cm depth) were always greater under NT than under CT in both grazed and ungrazed cropping systems (Table 1). Cover crop management had no effect on particulate organic C and potential N mineralization. Soil microbial biomass C and potential C mineralization were greater under grazed than ungrazed cover crop management under NT, but not under CT.

Table 1. Soil organic C and N fractions at a depth of 0-6 cm at the end of 2.5 years of management with different tillage and cover crop systems.

Tillage	Cover crop	POC	SMBC	CMIN	NMIN
		Mg ha^{-1}		kg ha^{-1} 24 d^{-1}	
CT	Grazed	2.03	0.43	387	25
CT	Ungrazed	2.09	0.49	403	24
NT	Grazed	7.29	0.86	782	52
NT	Ungrazed	6.59	0.68	617	51
$LSD_{0.05}$		0.97	0.05	53	11

CT is conventional tillage and NT is no tillage.
POC is particulate organic carbon, SMBC is soil microbial biomass carbon, CMIN is potential carbon mineralization, and NMIN is potential nitrogen mineralization.

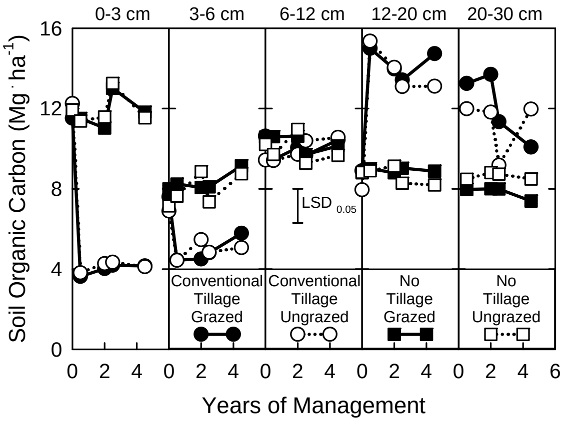

Figure 3. Stock of soil organic C at five soil depths as affected by time of management under different tillage (conventional and no tillage) and cover crop (grazed or ungrazed) systems.

Soil organic C was initially highly stratified with depth following 20 years of perennial pasture (Figure 2). Following moldboard plowing of pasture, soil organic C became more uniformly distributed within the surface 30 cm. Stratification ratio of soil organic C (0-6 cm / 20-30 cm) at the end of 2.5 years of management was 1.7 and 2.2 under grazed and ungrazed cover crop management with CT and was 5.5 and 4.9 under grazed and ungrazed cover crop management with NT. The LSD $_{P=0.05}$ was 0.8 so the differences between cover crop management systems were not significant, but resulted in a significant interaction between tillage and cover crop management. Deposition of animal-processed cover crop forage as dung on the soil surface may have contributed to the tendency for greater stratification ratio of soil organic C with grazing under NT.

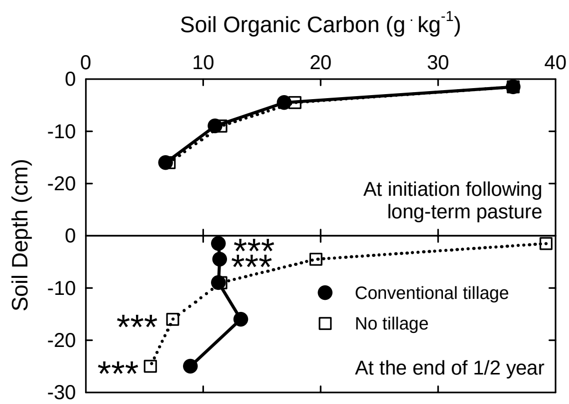

Figure 2. Depth distribution of soil organic C as affected by management under conventional and no tillage.

Soil with higher stratification ratio of soil organic C has the capacity to (1) withstand traffic (as evidenced by the relatively effective preservation of porosity near the surface with NT as compared with CT in Figure 1), (2) retain a greater portion of nutrients in soil in organically bound and readily mineralizable forms, and (3) preserve water quality by reducing water runoff and sediment loss (Franzluebbers, 2008).

Soil organic C stock following long-term pasture was 9.5 ± 1.8 Mg C ha^{-1} in each of the sampling depths (Figure 3). Following moldboard plowing, soil organic C stock was reduced dramatically in the 0-3 and 3-6 cm depths with a concomitant increase in soil organic C stock in the 12-20 and 20-30 cm depths. Therefore, inversion tillage appeared to have simply redistributed soil organic C within the soil profile. However, there was a trend for declining soil organic C stock at lower depths under CT with time. In fact, the stock of soil organic C to a depth of 30 cm became divergent between CT and NT during the course of 4.5 years at an equivalent rate of 0.51 Mg C ha^{-1} yr^{-1}; a value very similar to the mean rate of soil organic C sequestration for the entire southeastern USA region (Franzluebbers, 2005). Extension of this research for a longer period of time will be of key interest in obtaining a better estimate of soil organic C changes with differences in tillage and cover crop management.

As noted previously in this study, soil penetration resistance was affected by antecedent water content (Franzluebbers and Stuedemann, 2008b). Soil penetration resistance was 38 ± 18% greater in dry soil (0.12 ± 0.03 m^3 m^{-3}) than in wet soil (0.21 ± 0.03 m^3 m^{-3}) at a depth of 0-10 cm, was 119 ± 24% greater in dry than in wet soil at a depth of 10-20 cm, and was 157 ± 34% greater in dry than in wet soil at a depth of 20-30 cm (Table 2).

Table 2. Soil penetration resistance at three soil depths in dry and wet soil conditions as affected by tillage and cover crop management.

Tillage	Cover crop	Water content	Soil depth (cm) 0-10	10-20	20-30
		m^3 m^{-3}	---------- Joules	----------	
Dry soil conditions (4 events in 2004 and 2005)					
CT	Grazed	0.116	119	246	290
CT	Ungrazed	0.113	84	261	337
NT	Grazed	0.121	151	248	296
NT	Ungrazed	0.124	139	313	394
$LSD_{0.05}$		0.040	58	183	294
Wet soil conditions (6 events in 2003, 2004, and 2005)					
CT	Grazed	0.197	104	115	124
CT	Ungrazed	0.196	62	111	118
NT	Grazed	0.215	102	133	133
NT	Ungrazed	0.219	90	131	137
$LSD_{0.05}$		0.031	36	32	33

CT is conventional tillage and NT is no tillage.

Under dry soil conditions, penetration resistance was greater under NT than under CT at a depth of 0-10 cm (Table 2). No other differences in penetration resistance occurred under dry conditions. Greater soil penetration resistance under NT than under CT also occurred under wet conditions, but only at a depth of 10-20 cm.

Under wet soil conditions, penetration resistance was greater under grazed than under ungrazed cover crop management at a depth of 0-10 cm (Table 2). No difference in penetration resistance due to cover crop management occurred below 10 cm depth. Therefore, grazing of cover crops had a detrimental effect on surface-soil strength under wet conditions (P = 0.04), but only a trend for detrimental effect under dry conditions (P = 0.23).

Similar to the results reported previously for penetration resistance, single-ring water infiltration was also affected by antecedent soil water content (Franzluebbers and Stuedemann, 2008b). Water infiltration rate during four events under relatively wet conditions (0.19 $\pm$ 0.03 m^3 m^{-3}) was only 69 $\pm$ 24% of that during three events under relatively dry conditions (0.11 $\pm$ 0.03 m^3 m^{-3}) (Table 3).

Table 3. Single-ring water infiltration in dry and wet soil conditions as affected by tillage and cover crop management.

Tillage	Cover crop	Water content	Macropore filling	Infiltration rate
		m^3 m^{-3}	mm	mm min^{-1}
Dry soil conditions (4 events in 2004, 2005, and 2006)				
CT	Grazed	0.098	22	7.6
CT	Ungrazed	0.110	26	7.9
NT	Grazed	0.106	25	6.5
NT	Ungrazed	0.131	35	6.6
$LSD_{0.05}$		0.047	18	4.4
Wet soil conditions (3 events in 2003, 2004, and 2005)				
CT	Grazed	0.181	24	4.0
CT	Ungrazed	0.186	29	6.1
NT	Grazed	0.199	12	3.1
NT	Ungrazed	0.205	26	6.5
$LSD_{0.05}$		0.057	18	2.4

CT is conventional tillage and NT is no tillage.

Under dry soil conditions, there were no differences in soil water content, macropore filling, or water infiltration rate due to tillage or cover crop management systems (Table 3). However under wet soil conditions, macropore filling tended to be (P = 0.12) and water infiltration rate was greater (P < 0.01) when cover crops were left ungrazed than when grazed. The reduced capacity to take in water under grazed management, especially under wet soil conditions, was consistent with the greater surface-soil penetration resistance observed under grazed than ungrazed cover crop management under wet soil conditions (Table 2).

Surface soil (0-3 cm depth) at the end of 2.5 years of management had a greater (P < 0.01) portion as water-stable macroaggregates (>0.25 mm) under NT than under CT (0.71 vs. 0.65 g g^{-1}). Cover crop management did not affect the portion of soil as water-stable macroaggregates, nor did it affect macroaggregate stability and mean-weight diameter stability (Franzluebbers and Stuedemann, 2008b). Macroaggregate stability [0.85 vs. 0.96 $g_{(wet)}$ $g^{-1}_{(dry)}$ under CT and NT, respectively] and mean-weight diameter stability [0.78 vs. 0.94 $g_{(wet)}$ $g^{-1}_{(dry)}$ under CT and NT, respectively] were likely influenced by the amount of surface residue C content (0.07 vs. 0.72 Mg ha^{-1} under CT and NT, respectively), as well as by the content of surface-soil organic C and N fractions (Table 1).

CONCLUSIONS

Surface-soil conditions at initiation of this long-term cropping system experiment were of high quality due to the immediate history of long-term perennial pasture. The high content of surface-soil organic matter following perennial pasture contributed greatly to the magnitude and direction of temporal change in soil responses. Compared with initially degraded cropland from a long history of clean cultivation that would have led to significant accumulation of soil organic matter with adoption of conservation tillage and relatively little change with continuation of conventional tillage (e.g., Terra et al., 2005; Novak et al., 2007), the results in this study were more of gradual increase in organic matter with NT and decline with CT.

High concentration of surface-soil organic C and N fractions contributes to water-stable aggregates and potentially to a more conducive soil to receive rainfall. Although surface runoff and soil loss were not determined in this study, they would have been expected to be greater in clean-tilled soil exposed to intensive rainfall impact and cattle trampling. Several studies in the literature have documented the positive impact of surface residue and soil organic matter accumulation on reducing soil loss from water erosion (reviewed in Franzluebbers, 2008). Curiously, even though soil loss was reduced with NT in other studies, water runoff reduction did not always occur (Sharpley et al., 1992; Edwards et al., 1993; Sharpley and Smith, 1994). Results in this study with single-ring infiltration devices also suggested that water infiltration may not always be enhanced with NT compared with CT (Table 3). However, to fully evaluate hydrologic characteristics, measurements must be made in water catchment studies to define reasonable boundaries and flow patterns within the landscape. Single-ring infiltration measurements were used only as an indicator of hydrologic function. The point measurements did indicate that cattle grazing of cover crops during wet periods led to increased soil strength and reduced water infiltration. Interestingly though, soil bulk density measurements did not exhibit a strong suggestion for surface soil compaction with grazing. Longer term evaluation appears necessary to obtain greater consistency among these measures.

Alleviation or avoidance of surface-soil compaction with animal traffic appears to have been achieved through different mechanisms. With uniformly distributed soil organic matter concentration in the plow layer and low residue content at the soil surface in CT systems, alleviation of compaction from animals was through periodic loosening and incorporation of crop residues with disk tillage. With highly stratified depth distribution of soil organic matter and high residue content at the soil surface in NT systems, avoidance of compaction from animals was from the low density, spongy nature of the residue cover + high soil organic matter at the soil surface itself. Animal traffic over this protective surface cover may have helped to incorporate organic matter with the mineral soil below. This biological mixing process would have been a likely reason for the greater soil microbial biomass and mineralizable C observed in NT surface soil with grazing compared with no grazing of cover crops (Table 1).

Retention of surface-soil organic C and N fractions is also important for sequestration of soil organic C as a means to mitigate greenhouse gas emissions. Although inversion tillage initially redistributes most of the existing soil organic C within the plow layer, placement of organic C deeper in the soil profile does not appear to be a viable long-term strategy for soil C sequestration, at least in the low-activity clayey subsoils of the southeastern USA. Data presented here indicate that organic C placed below 12-cm depth is mineralized relatively rapidly and would require repeated application to maintain the elevated level. However, the organic matter addition at depth would have to come at the expense of surface-soil organic matter buildup. In a regional land-use survey in the southeastern USA, data in Causarano et al. (2008) suggested that stratification ratio of soil organic C (0-5 cm / 12.5-20 cm) was predictive of total organic C sequestered in the surface 20 cm of soil.

Almost all soil quality indicators favored the selection of NT as a superior management system over that of CT. Whether cover crops were grazed or not resulted in no difference in some soil quality indicators (e.g., bulk density, total and particulate soil organic C, potential N mineralization, and water-stable aggregation), but there were also some indicators that were enhanced with grazing relative to no grazing (e.g., soil microbial biomass and mineralizable C) and some indicators that were reduced with grazing (e.g., penetration resistance and water infiltration under wet soil conditions only). Grazing of cover crops also provides significant economic return to farmers (Franzluebbers and Stuedemann, 2007), as well as potentially positive impacts on resource efficiency and environmental protection (Russelle et al., 2007), and therefore, should be considered further as a potential conservation management approach to enhance the applicability and productivity of conservation tillage systems (e.g., NT). More long-term research is needed to fully evaluate the implications of such intensive, integrated crop-livestock systems on changes in soil quality (in specific) and environmental quality (in general).

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