SOIL RESPONSES UNDER INTEGRATED CROP AND LIVESTOCK PRODUCTION

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ABSTRACT

Integration of crops and livestock could be either detrimental or beneficial to soil properties, depending upon timing and intensity of animal traffic and initial condition of the soil surface. We evaluated the surface-soil properties of a Typic Kanhapludult in Georgia during the first three years of an experiment evaluating the effect of tillage [conventional (CT), conservation (NT)], cropping system (summer grain-winter cover, winter grain-summer cover), and cover crop utilization (none, grazed) variables. With initially high soil organic C (SOC) due to previous pasture management, depth distribution of SOC became widely divergent between CT and NT following cropping management. Soil bulk density during the first year was reduced with CT, but soil became reconsolidated below 12 cm, similar to that under NT. Soil penetration resistance was greater under NT than under CT, but larger differences occurred with low soil water content than with high soil water content. Ponded infiltration was lower under NT than under CT with low antecedent soil water content, but higher under NT than under CT with high antecedent soil water content. The interaction of tillage management with antecedent soil water content on penetration resistance and water infiltration indicates that long-term tillage effects on soil physical quality will be partly influenced by timing and intensity of tractor and cattle traffic loads. Although CT management could alleviate negative influences on 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. A longer term investigation is warranted to verify or strengthen these interpretations.

INTRODUCTION

Soil organic matter is a critical component in maintaining soil quality in the southeastern USA. Pastures are known to improve soil organic C and N, which leads to retention of organically-bound nutrients and improved water relations. Cropping systems that are appropriate in this region under conditions of high soil organic matter have not been evaluated since much of the cropland has been stripped of soil organic matter from previous degradative cropping practices.

The impact of grazing animals on the environment is more often than not viewed as negative. A large portion of the land area in the southeastern USA is devoted to pasture production of cattle. Our previous work 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., 2001b). However, the role of grazing animals in pasture-crop rotations does not have to be limited to the medium- or long-term pasture phase alone. Cover crops following grain or fiber crops can be an excellent source of high quality forage to be utilized in mixed-use farming operations, which have the potential for adoption throughout the southeastern USA. A potential impact of animals grazing cover crops, however, could be compaction due to trampling, as was observed in two soils under relatively low soil organic matter conditions (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 could alleviate negative animal trampling effects.

A long-term pasture-crop rotation experiment was established in 2002 to determine the influence of tillage, cropping system, and cover crop management on productivity and environmental quality in the Southern Piedmont. Preliminary crop and animal productivity responses were reported in Franzluebbers and Stuedemann (2004).

Our objective was to quantitatively evaluate three management factors (tillage, time of cover cropping, and cover crop management) for their impacts on soil physical, chemical, and biological properties. The factorial arrangement of treatments allowed us to isolate interactions among management factors, which should lead to a better understanding of the processes controlling productivity and environmental quality. Other objectives during the course of this multi-year project will be to (1) quantify the responses in plant and animal productivity due to tillage management under cropping systems that include grazing cattle and high cropping intensity, (2) quantify the relative stability of plant production during winter versus summer growing seasons, (3) quantify cattle productivity and performance during short-term grazing alternatives to perennial pastures, and (4) evaluate the interrelationships among soil, plant, and animal properties following adoption of land management systems, which may uniquely alter soil organic matter dynamics and plant and animal productivity.

MATERIALS AND METHODS

Previous History

The experiment was located at the J. Phil Campbell Sr. Natural Resource Conservation Center in Watkinsville GA on Cecil sandy loam (fine, kaolinitic, thermic Typic Kanhapludult). A set of 18 experimental paddocks (1.7 acres each) were previously arranged as six cattle grazing treatments in three blocks. Previous treatments included low (120-30-60 lb N-P_2O_5-K_2O/acre/yr) and high fertilization rates (300-75-150 N-P_2O_5-K_2O/acre/yr) imposed upon four grass variables [‘Kentucky-31’ tall fescue (*Festuca arundinacea* Schreb.) with low and with high endophyte infection, ‘Johnstone’ tall fescue with low endophyte infection, and ‘Triumph’ tall fescue with low endophyte infection]. Previous treatments were part of a long-term experimental design initiated in 1981 to study tall fescue-endophyte effects on cattle productivity, performance, and other miscellaneous animal response variables until 1997. Fertilization was terminated prior to 1998 and forage grazed on an *ad hoc* basis thereafter. Pasture growth during the past five years without fertilization was expected to remove any differences among paddocks in residual inorganic soil N. All paddocks were limed (1 ton/acre) immediately prior to termination of the tall fescue. The 18 experimental paddocks were regarded as an excellent starting point for the proposed research because soil organic matter was at a high level (Franzluebbers et al., 1999) and grazing infrastructure was mostly in place at the site (fencing, gates, shades, mineral feeders, watering troughs, and animal handling facility).

Experimental Design and Management

The experimental design of the current investigation consisted of a completely randomized design with a split-plot arrangement within main plots. Main plots were a factorial arrangement of (a) tillage and (b) time of cropping and split plots within main plots were (c) cover crop management. Main plots were replicated four times. Grazed plots were 0.5 ha (1.1 acre) in size and ungrazed plots were 0.2 ha (0.6 acres). Two paddocks remained in perennial pasture to serve as uncropped controls.

Tillage management was with (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. Conventionally tilled plots were broken from sod with a moldboard plow to a depth of 25 to 30 cm (10 to 12") and disk plowed to approximately 15 cm (6") thereafter.

Cropping systems included (1) winter grain cropping [wheat (*Triticum aestivum* L.); November planting and May harvest] with summer cover cropping [pearl millet (*Pennisetum glaucum* (L.) R. Br.; June planting and October termination] and (2) summer grain cropping [grain sorghum (*Sorghum bicolor* (L.) Moench; May-June planting and October harvest] with winter cover cropping [cereal rye (*Secale cereale* L.); November planting and May termination]. ‘Tifleaf 3’ pearl millet was drilled in 6.75"-wide rows under CT and 7.5"-wide rows under NT at a rate of 14 lb/acre on 12 June 2002, at 13 lb/acre on 26 June 2003, and 15 lb/acre from 22-23 June 2004. 'Pioneer 83G66' grain sorghum was drilled in 13.5"-wide rows under CT and 15"-wide rows under NT at a rate of 5 lb/acre from 13-14 June 2002, at 6 lb/acre from 2-5 June 2003, and 6 lb/acre from 18-19 May 2004. Due to poor stand of sorghum in 2002, especially under NT, portions of plots were replanted on 17 July 2002. Ammonium nitrate was spread on sorghum and millet at 44 lb N/acre on 18 June 2002, on sorghum at 46 lb N/acre on 12 June 2003, on millet at 40 lb N/acre on 9 July 2003, on sorghum at 43 lb N/acre on 18 June 2004, and on millet at 45 lb N/acre on 19 July 2004. Sorghum was harvested for grain from 15-22 November 2002, 17-20 October 2003, and 5-6 October 2004. Wheat was drilled in 7.5"-wide rows at a rate of 106 lb/acre on 28 November 2002 (‘Crawford’), at 82 lb/acre (CT) and 116 lb/acre (NT) from 4-6 November 2003 (‘518W’), and at 106 lb/acre (CT) and 110 lb/acre (NT) from 10-16 November 2004 (‘Coker 9663’). Rye was drilled in 7.5"-wide rows at a rate of 111 lb/acre on 2 December 2002 (‘Hy-Gainer’), at 94 lb/acre (CT) and 111 lb/acre on 5 November 2003 (‘Hy-Gainer’), and at 103 lb/acre (CT) and 118 lb/acre (NT) from 10-16 November 2004 (‘Wrens Abruzzi’). Ammonium nitrate was spread on wheat and rye at 47 lb N/acre on 25 February 2003, at 36 lb N/acre on 20 February 2004, and at 45 lb N/acre on 3 March 2005. Wheat was harvested for grain from 11-19 June 2003 and 3-4 June 2004.

Cover crops were managed to assess the impact of grazing cattle on crop production as (1) without cattle by mowing (CT) and mechanical rolling (NT) at maturity and (2) stocking with cattle for 60-90 days to consume available forage produced. Cover crops were stocked with yearling Angus steers in Summer 2002 (initial weight 578 ± 48 lbs) and in Spring 2003 and with cow/calf pairs in Summer 2003 (initial cow weight 1107 ± 88 lbs and initial calf weight 370 ± 33 lbs), Spring 2004, Summer 2004, and Spring 2005. Ungrazed cover crops were grown until 2-4 weeks prior to planting of the next crop and either (1) mowed prior to conventional tillage operations or (2) mechanically rolled to the ground in the no-tillage system.

Each grain and cover crop received a top-dressing application of ammonium nitrate shortly after planting and no other fertilizer amendment. The basal application of N assured early plant growth and development with further growth dependent upon the mineralization of stored nutrients in soil organic matter. Extractable P and K concentrations in the surface 3 inches of soil were greater than 100 mg P $\cdot$ kg^{-1} soil and 400 mg K $\cdot$ kg^{-1} soil (Schomberg et al., 2000), levels considered adequate for crop production.

Soil Sampling and Analyses

Soil was sampled in May 2002 and in November/December 2002, 2003, and 2004. Soil was sampled at depths of 0-3, 3-6, 6-12, and 12-20 cm in May 2002 and additionally at 20-30 cm depth thereafter. A composite sample of 8 cores in grazed plots and 5 cores in ungrazed plots was collected with a 4-cm diameter probe following surface residue collection from a 0.04 m^2 area at each subsampling location. Soil was dried at 55 °C for $\geq$3 days and passed through a 4.75-mm screen to remove large stones. Soil bulk density was determined from the total dry weight prior to sieving and volume of coring device. A subsample was ground in a ball mill for analysis of total C and N with dry combustion. Soil microbial biomass C was determined from 25- to 65-g subsamples following rewetting of dried soil using a chloroform fumigation-incubation technique (Jenkinson and Powlson, 1976; Franzluebbers et al., 1996). Mean-weight diameter of water-stable aggregates was determined by summing the dry-weight components of four aggregate sizes (1-4.75, 0.25-1, 0.053-0.25, and <0.053 mm) following immersion of a 100-g subsample in water and oscillated for 10 minutes at a 20-mm stroke length with a frequency of 31 cycles/minute (Kemper and Koch, 1966; Franzluebbers et al., 1999).

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 0.23 cm-diameter cone with a 30° tip. The number of strikes required to reach a depth of 10, 20, and 30 cm was recorded. Each strike contained the equivalent kinetic energy of 14.5 J. Penetration resistance was determined in four locations of each grazed plot and in two locations of each ungrazed plot on 9 May 2003, 5 August 2003, 9 October 2003, 7 May 2004, 27 July 2004, and 22 October 2004. Soil water content was determined at a depth of 0-20 cm with time-domain reflectrometry from the average of five measurements within a 2-m radius of each penetrometer sampling.

Water infiltration was determined from the linear rate of water intake during 1 hour within a 30-cm diameter steel ring inserted approximately 4 cm into the ground. Water was supplied with a Mariotti system and volume of water recorded every 10 minutes. Linear regression was used to determine rate of water infiltration. Accounting for a 5-cm head of water, the intercept from the linear regression allowed estimation of air-filled macroporosity. Infiltration was determined from two locations in each grazed and ungrazed plot on 15 October 2003, 3 May 2004, 27 July 2004, and 20 October 2004. Soil water content was determined in the same manner as described earlier.

Significance of difference in soil properties among management systems was assessed with the general linear model procedure of SAS and non-linear relationships of penetration resistance and water infiltration with antecedent soil water content.

Results And Discussion

Soil Organic C and Microbial Biomass

Soil organic C (SOC) concentration was initially very high at the soil surface and declined rapidly with depth (Fig. 1). There were no differences in SOC between tillage systems before treatment implementation, indicating an equal starting point for this long-term comparison. At the end of one year of cropping, SOC under NT remained highly stratified with depth, similar to that at initiation. Under CT however, SOC became relatively uniformly distributed due to moldboard plowing that inverted soil within the surface 30 cm and subsequent disk tillage that mixed residues throughout the tillage layer. Similar SOC results were obtained at the end of two years of cropping. Although SOC was removed from the soil surface with CT, SOC concentration became enriched lower in the plow layer relative to that under NT.

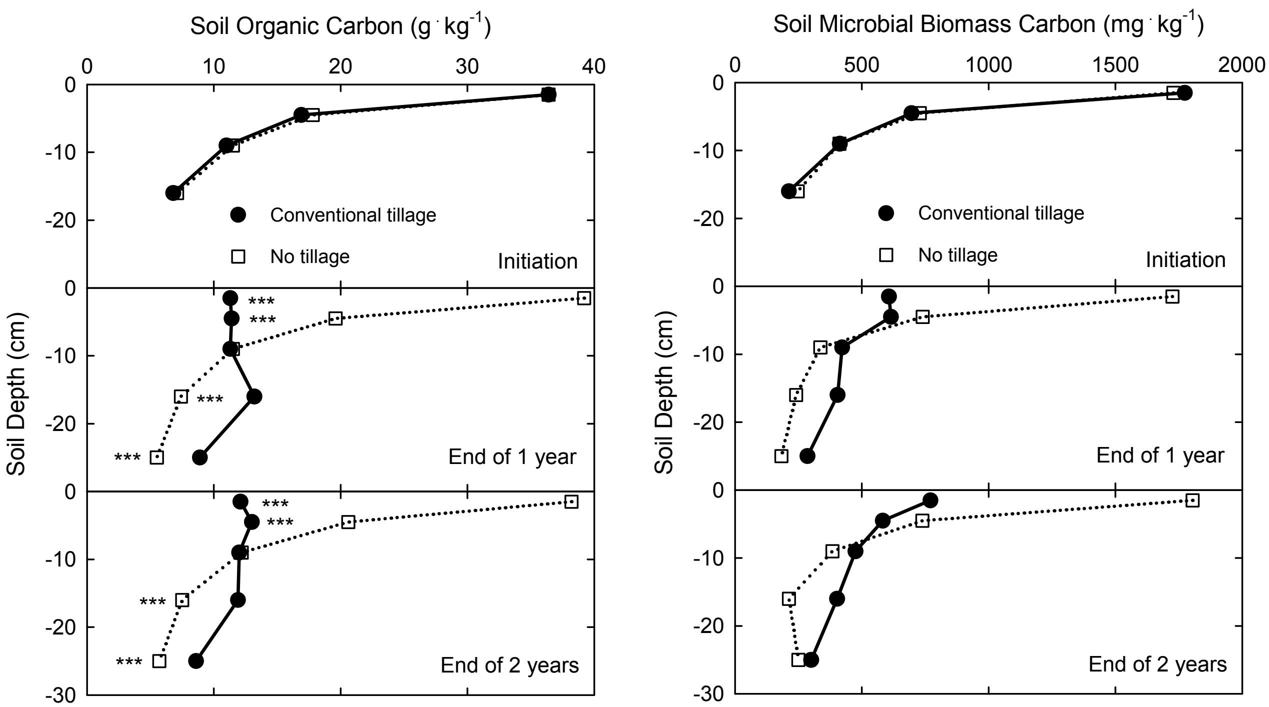

*Figure 1. Soil organic C and microbial biomass C concentration with depth as affected by tillage management and year of sampling. *** denotes significance between tillage means within a depth at P = 0.001. Statistical evaluation was not available for soil microbial biomass C.*

Soil microbial biomass C followed a similar development pattern in response to time of sampling and tillage management as occurred for SOC (Fig. 1). Soil microbial biomass C was 3.9 $\pm$ 0.9% of SOC, somewhat lower than percentages reported using similar measurement techniques in another study in Georgia (6.7 $\pm$ 0.5%; Franzluebbers et al., 1999) and from cropping systems in eastern Texas (5.1 $\pm$ 0.7%; Franzluebbers et al., 1995), but more similar to soils in northern Alberta and British Columbia (3.3 $\pm$ 0.8%; Franzluebbers and Arshad, 1996). The portion of SOC as soil microbial biomass C is often interpreted as an index of biologically active soil organic matter. Higher values suggest aggrading management influence under similar environmental conditions. Available data suggests that the portion of SOC as soil microbial biomass C is higher in warmer than in cooler climate zones and in drier than in wetter climate zones (Franzluebbers et al., 2001a). These same climatic conditions are also reflected in soil depths, where surface soil layers tend to be warmer and drier on average than deeper layers, and have the highest portion of SOC as soil microbial biomass C.

Soil Bulk Density and Penetration Resistance

Soil bulk density following long-term pasture and prior to this cropping experiment was relatively low at the soil surface (1.1 Mg/m^3) and increased dramatically with depth to about 6 cm, at which point maximum bulk density occurred ($\sim$1.5 Mg/m^3), similar to lower depths (Fig. 2). With initial moldboard plowing of pasture, soil bulk density was reduced during the first year, but returned to high values below 12 cm in later years. Tillage operations following the breaking of sod were limited to approximately the surface 15 cm, which led to reconsolidation without subsequent mechanical loosening in the 12 to 30 cm zone. Under NT, soil bulk density did not appear to change with time compared to the initial pasture condition. Maintenance of the low bulk density at the soil surface with NT was likely possible only with the high concentration of SOC present. Subsequent animal and equipment traffic did not cause any further obvious compaction to soil.

Soil penetration resistance was highly related to antecedent soil water content at the time of sampling (Fig. 3). Soil water content averaged across sampling events was 0.171 m$^{3/}$ m^3 under

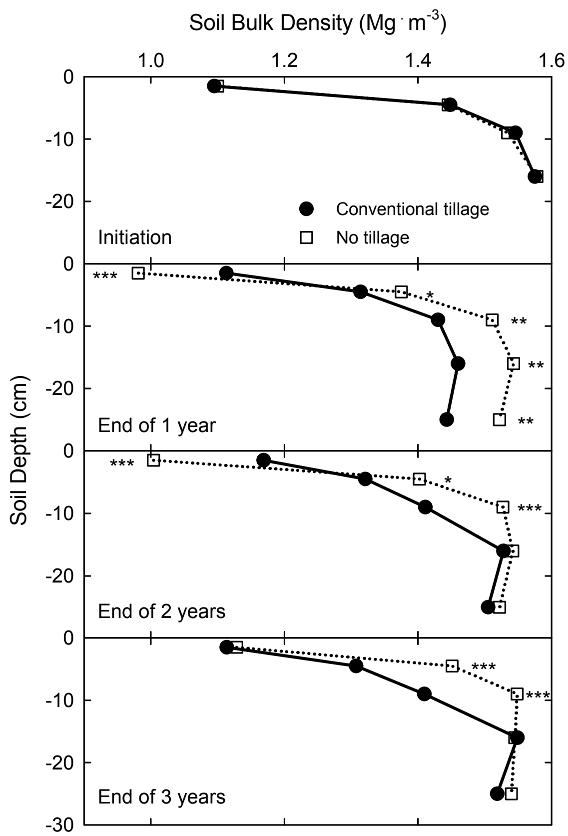

*Figure 2. Soil bulk density with depth as affected by tillage management and year of sampling. *, **, and *** denote significance between tillage means within a depth at P = 0.1, 0.01, and 0.001, respectively.*

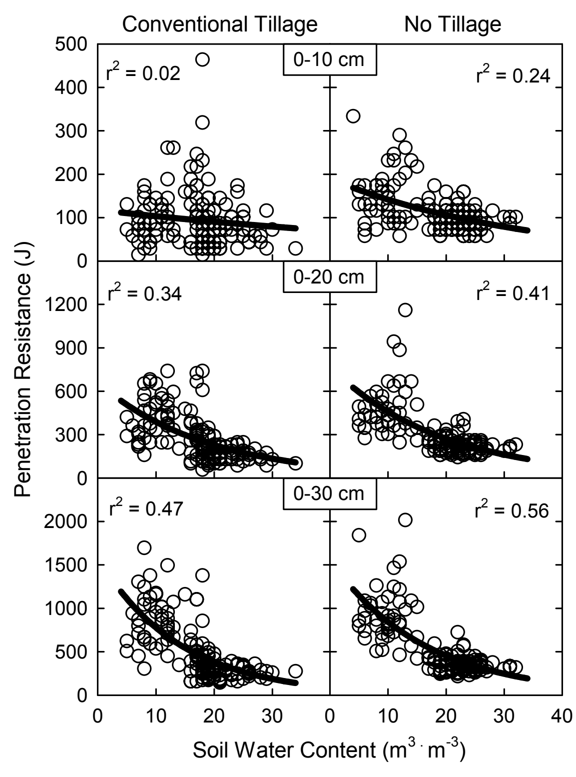

Figure 3. Penetration resistance of soil in relationship to soil water content as affected by tillage management and depth of sampling. Regression lines represent the best fit to the equation: $Y = a\ e^{-b\ SWC}$, where a and b are derived constants and SWC is soil water content.

CT and 0.184 $m^{3/} m^3$ under NT ($P < 0.001$). Despite the higher soil water content under NT, penetration resistance was greater ($P < 0.05$) under NT than under CT at all three sampling depths (i.e., 113 vs. 94 J at 0-10 cm, 316 vs. 278 J at 0-20 cm, and 544 vs. 508 J at 0-30 cm). Maximum absolute difference in penetration resistance between tillage systems occurred at the driest soil water content. Therefore when dry, soil under NT would likely be more resistant to root penetration than under CT, a situation that could be partly overcome by the high surface residue condition under NT to maintain higher soil water content than under CT. Statistically, most significant differences in penetration resistance between tillage systems occurred at higher soil water content ($\geq$0.20 $m^{3/} m^3$). Overall, difference in penetration resistance between tillage systems was relatively small. Busscher et al. (1997) previously demonstrated a strong relationship between penetration resistance and soil water content on Coastal Plain soils.

Although the effect of cover crop management was not strong, soil penetration resistance tended to be greater under grazed than ungrazed cover crops under CT (292 vs. 248 J at 0-20 cm depth). Under NT, penetration resistance averaged 308 J with grazing and 338 J when ungrazed at a depth of 0-20 cm. Although these results are preliminary, it appears that grazing of cover crops would be more detrimental to penetration resistance under CT than under NT. More data are needed to verify this conclusion.

Soil Aggregation and Infiltration

Mean-weight diameter of soil aggregates was greatly affected by tillage management during the first year of CT (Fig. 4). With CT, soil aggregates became less stable and formed smaller units, resulting in smaller mean-weight diameter of water-stable aggregates. Less stable aggregates would eventually lead to (1) SOC loss through more rapid oxidation, (2) fewer macropores to allow rapid water infiltration, and (3) surface crust development that could prevent seed germination and rainfall percolation.

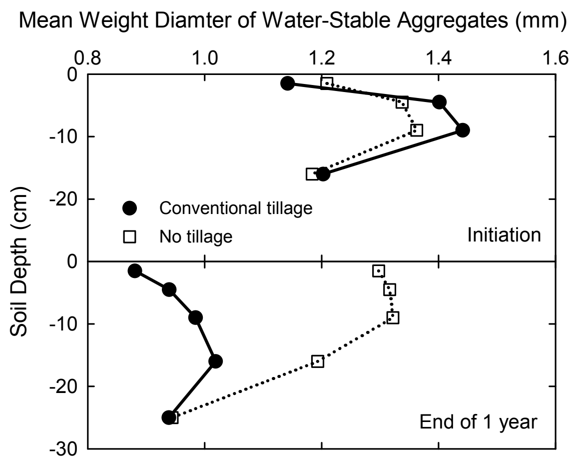

Figure 4. Mean-weight diameter of soil with depth as affected by tillage management and year of sampling. Statistical analysis was not yet available.

Steady-state water infiltration and air-filled macroporosity were also negatively related to antecedent soil water content (Fig. 5). Steady-state water infiltration tended to be lower under NT than under CT under relatively dry soil conditions, but higher under NT than under CT under wetter soil conditions. These results indicate a dominating influence of antecedent soil water conditions on additional water infiltration. These results also indicate that tillage management can modify water infiltration, but that tillage interacts with antecedent soil water content. The timing of tractor and cattle traffic operations during the year could greatly impact the development of physical soil quality in the long-term.

As an estimate of air-filled macroporosity, the initially rapid water infiltration that created a positive intercept (b) in the equation: $Y = m \cdot X + b$, was influenced by antecedent soil water

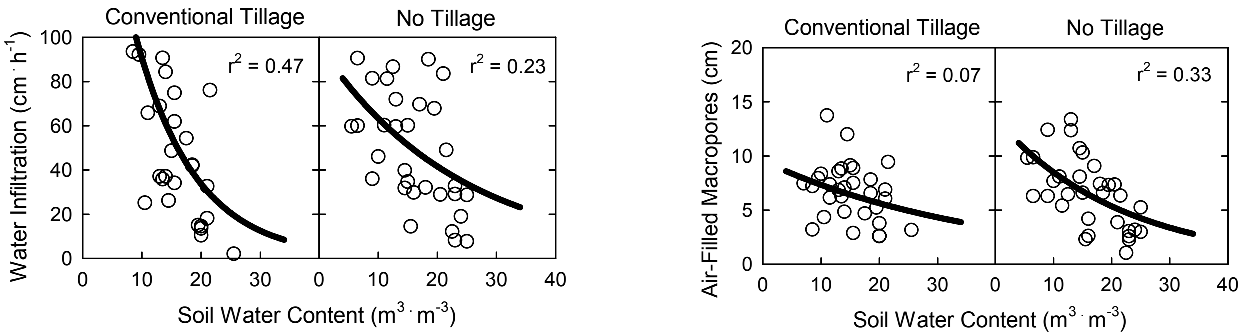

Figure 5. Steady-state water infiltration from 10 to 60 minutes and initial rapid infiltration during the first 10 minutes of ponded percolation representing air-filled macroporosity in relationship to soil water content as affected by tillage management.

content, but also by tillage management (Fig. 5). Air-filled macroporosity tended to be higher under NT than under CT at relatively dry soil condition and lower under NT than under CT at wetter soil condition. These results illustrate that soil water content is an important factor for understanding the impact of tillage system and cover crop management on soil physical condition that develops with time. The timing of tractor and cattle traffic during the year could greatly impact the development of soil physical quality in the long-term.

SUMMARY AND CONCLUSIONS

Crop management following termination of long-term pasture resulted in significant changes in soil properties during the first three years. Termination of pasture with moldboard plowing and subsequent disking (CT) for seedbed preparation led to relatively uniform distribution of SOC and soil microbial biomass C within the plow layer. Termination of pasture with herbicide and subsequent NT management of crops maintained a highly stratified distribution of organic matter in soil. Although CT loosened soil initially throughout the plow layer (0-30 cm), soil at lower depths became reconsolidated after the first year, resulting in less dense soil with CT compared with NT only at a depth of 3-12 cm thereafter. Mean-weight diameter of water-stable aggregates was greatly reduced with CT during the first year after pasture termination. Penetration resistance and steady-state water infiltration were highly related to antecedent soil water content. Tillage system interacted with antecedent soil water content, such that firmer soil and lower water infiltration occurred at low soil water contents, but differences between tillage systems were minimal at wetter soil water contents. Whether cover crops were grazed by cattle or left unharvested for biomass input had relatively minor effects on soil properties, but additional analyses are being conducted to strengthen this conclusion. Although there were indications that soil organic matter, microbial biomass, and soil aggregation could be retained with long-term NT management following rotation with long-term pasture, other soil physical properties (i.e., bulk density, penetration resistance, and water infiltration) indicated equal or poorer conditions for crop growth potential than with CT management, at least during the first three years.

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