Impact of Deep Ripping of Previous No-Tillage Cropland on Surface Soil Properties

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ABSTRACT

The use of continuous no-tillage cropping raises concern about water and nutrient movement into subsoil due to high soil bulk density. Deep ripping (i.e., paraplowing) might be a conservation strategy to loosen surface and subsoil without excessive incorporation of surface crop residues. We initiated a multi-year study comprised of four water catchments (3.1-6.7 acres each) that had previously been under continuous no-tillage cropping for at least 10 years. Two of the water catchments were paraplowed each autumn, but managed otherwise with conservation tillage, similar to the two remaining water catchments. Soil-surface properties were evaluated during the first and second year of the study. Soil bulk density of the surface (20 cm) was significantly lower under paraplowing (1.37 Mg m^{-3}) than under no tillage (1.51 Mg m^{-3}). Soil organic C was significantly greater under paraplowing (10.4 mg g^{-1}) than under no tillage (8.7 mg g^{-1}). Surface residue C was not different between tillage systems in either year. There was no difference in the standing stock of total organic C in residue and soil to a depth of 20 cm between tillage systems in either year. We conclude from these early years of the study that annual paraplowing in combination with conservation tillage management had few negative impacts on soil-surface chemical properties and may have improved soil physical conditions to possibly allow greater water utilization.

KEYWORDS

Bulk density, poultry litter, paraplow, soil organic carbon, total soil nitrogen

INTRODUCTION

Crop management systems can vary greatly in their production potential and impacts on the environment. Tillage is an important management variable that influences long-term sustainability. Restoration of eroded cropland in the southeastern USA has been demonstrated with the development of conservation tillage systems, which limit soil disturbance and allow surface residue accumulation (Langdale *et al*., 1992). Long-term no-tillage management can increase infiltration by increasing soil macroporosity (Edwards *et al*., 1988). Many of the management options for achieving sustainability, however, are regionally specific with variations due to soil type, climatic conditions, and landscape ecology.

Land application of manure provides essential nutrients to crops and helps alleviate waste disposal. Poultry production in the Southern Piedmont is extensive (Census of Agriculture, 1992). Manure is often mixed with bedding material at the end of the production cycle, cleared from confinement housing, and applied as litter (manure plus bedding) to nearby land as a source of nutrients. Depending upon management, however, repeated application of poultry litter could become a source of excessive nutrients (Vervoot *et al*., 1999). Surface application of poultry manure without soil incorporation may potentially cause unwanted nutrient enrichment in surface water runoff, which can be high in the high-rainfall region of the southeastern USA. Of increasing concern is the unbalanced load of P in poultry manure compared with N. Crop production in the southeastern USA benefits greatly from P application, because these soils have a great capacity to fix P, especially in the subsurface clayey horizons. However, little information is available to predict the impact on surface water concentration of P and soil profile distribution of P from poultry manure application to conservation-tilled cropland. Increased density of soil under continuous no-tillage cropping could limit water and nutrient movement into subsoil. Deep ripping, i.e., paraplowing, might be a conservation strategy to loosen surface and subsoil without excessive incorporation of surface crop residues. This loosening of the soil could also enhance water and nutrient storage at lower depths than possible with continuous no tillage.

We evaluated the effect of no tillage compared with paraplowing on surface-soil distribution of bulk density and

IN E. van Santen (ed.) 2002. Making Conservation Tillage Conventional: Building a Future on 25 Years of Research. Proc. of 25th Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Auburn, AL 24-26 June 2002. Special Report no. 1. Alabama Agric. Expt. Stn. and Auburn University, AL 36849. USA.

organic C and N during the first two years of an intended long-term study. Surface water runoff volume and nutrient concentration will be reported in these proceedings by Endale *et al*. (2002). Other aspects of this study that will eventually be reported are agronomics, N cycling of broiler litter, soil-profile distribution of inorganic N and P, ammonia volatilization, water-use efficiency, and fecal-borne pathogen survival and transport.

MATERIALS AND METHODS

This study consisted of four small water catchments [3.1-6.7 acres each (1.3-2.7 ha)] located near Watkinsville, Georgia (33˚ 52' N, 83˚ 25' W). Soils are Cecil sandy loam (fine, kaolinitic, thermic Typic Kanhapludult). These soils are classified as well drained with moderate permeability. Mean annual precipitation is 49" (1250 mm) and temperature is 62 ˚F (16.5 ˚C).

The four water catchments were managed separately under various forms of cropping and forage production since 1972. Two water catchments (P1 and P2) were separated by 0.5 mile. The other two water catchments (P3 and P4) were immediately adjacent to each other and separated from P1 by 2.3 miles and from P2 by 1.8 miles. Prior to this experiment, all water catchments were managed with no tillage for at least 10 years. Since the autumn of 1998, the four water catchments were managed together as described in the following. Two water catchments (P1 and P3) were allowed to continue under continuous no tillage and the other two water catchments (P2 and P4) were converted to no tillage planting of all crops with autumn paraplowing following harvest of the summer crop. Paraplowing depth was *ca.* 12-16" (30-40 cm). Summer crops were maize (*Zea mays*) in 1999, pearl millet (*Pennisetum glaucum*) in 2000, and grain sorghum (*Sorghum bicolor*) in 2001. Winter crops were crimson clover (*Trifolium incarnatum*) on P2 and P3 and rye (*Secale cereale*) on P1 and P4 in 1998/1999, barley (*Hordeum vulgare*) in 1999/2000, and rye in 2000/2001. Crops were fertilized according to soil testing with inorganic N-P-K, as well as with broiler litter in July 2000, July 2001, and December 2001 at 1.1 ton acre^{-1} (2.48 ± 0.25 Mg ha^{-1} application^{-1}).

Soils were collected from each water catchment in five zones, which served as pseudoreplicates for analyses. The five zones represented a central waterway and the four corner sections of each water catchment. Within each zone, eight sites separated by 50' (15 m) were sampled and composited. At each site, surface residue was collected from 64 sq. in. (20 x 20 cm) areas by first removing green plant material above 1.5"-height (4 cm) and then collecting all surface residue to ground level by cutting with a battery-powered hand shears. Following surface residue removal, a soil core [1.6" diam (4.1-cm diam)] was sectioned into depths of 0-1.2, 1.2-2.4, 2.4-4.7, and 4.7-7.9" (0-3, 3-6, 6-12, and 12-20 cm). Surface residue was dried at 158˚F (70 ˚C) for several days, ground to <1/32" (1 mm), and analyzed for total C and N with dry combustion. Soil was dried at 131˚F (55 ˚C) for 3 days, initially passed through a sieve with openings of 3/16" (4.75 mm) to remove stones, a subsample ground in a ball mill for 5 minutes, and analyzed for total C and N with dry combustion. Soil bulk density was calculated from the total dry weight of soil and volume of coring device.

Standing stock values of soil organic C and total soil N to a depth of 7.9" (0-20-cm depth) were calculated based on the density and volume of each soil depth section. Stratification ratios of soil properties were calculated based on the weighted concentration of a soil property at a depth of 0-6 cm divided by the concentration of that property at a depth of 12-20 cm.

Data were analyzed for variance due to tillage systems within each depth using the general linear models procedure of SAS (SAS Institute Inc., 1990). Differences among tillage systems were considered significant at $P = 0.1$.

RESULTS AND DISCUSSION

Soil bulk density was significantly lower under paraplowing (PP) than under no tillage (NT) at all soil depths to 20 cm in February 1999 (Table 1). Soil samples from February 1999 were collected *ca.* 4 months following the first paraplowing operation in this experiment. The vertical breaking action of the paraplow tool had a strong loosening effect on soil density. Except for no difference between tillage systems at a depth of 0-3 cm, soil bulk density in February 2000 responded similarly to tillage management as during the sampling in February 2000. Although paraplowing reduced soil bulk density, compaction of soil under NT was not excessive. Soil bulk density >1.7 Mg m^{-3} might be expected to hinder root growth of many plants. The protective layer of surface residue and accumulation of surface soil organic matter were very likely important long-term attributes that helped to alleviate excessive surface-soil compaction with continuous NT.

Soil organic C and total soil N concentrations were greater under PP than under NT at depths of 3-6 and 6-12 cm during sampling in 1999 and 2000 (Table 1). Some surface residue incorporation with paraplowing likely contributed to this tillage effect. Soil organic C and total soil N at a depth of 0-3 cm were also greater under PP than under NT in 1999, but not significantly different between tillage systems in 2000. Perhaps the more frequently that paraplowing is employed, the more disturbed the plow layer will become, which could eventually result in a decline in soil organic matter pools. This temporal effect

Table 1. Surface-soil properties as affected by tillage system during the first and second year. Paraplowing was in November 1998 and 1999. NT is continuous no tillage and PP is conservation tillage with autumn paraplowing.

Soil depth		Feb 1999			Feb 2000		
Inches	cm	NT		PP	NT		PP
Soil bulk density, Mg m^{-3}							
0-1.2	0-3	1.18	***	0.98	1.03		1.01
1.2-2.4	3-6	1.46	***	1.27	1.44	***	1.26
2.4-4.7	6-12	1.63	***	1.46	1.58	***	1.42
4.7-7.9	12-20	1.61	**	1.50	1.61	***	1.49
0-7.9	0-20	1.53	***	1.38	1.49	***	1.36
Soil organic C, mg g^{-1}							
0-1.2	0-3	21.6	**	26.9	24.7		23.3
1.2-2.4	3-6	11.3	**	14.9	13.1	*	16.5
2.4-4.7	6-12	6.6	*	8.7	7.6	*	9.4
4.7-7.9	12-20	4.8	†	6.1	5.3		6.2
0-7.9	0-20	8.2	*	10.3	9.2	†	10.5
Total soil N, mg g^{-}							
0-1.2	0-3	2.33	*	2.69	2.72		2.38
1.2-2.4	3-6	1.21	**	1.52	1.37	†	1.64
2.4-4.7	6-12	0.64	*	0.81	0.73	*	0.88
4.7-7.9	12-20	0.43		0.50	0.49		0.53
0-7.9	0-20	0.82	*	0.97	0.92		1.00
C:N ratio of soil organic matter, g g^{-1}							
0-1.2	0-3	9.5	**	10.2	9.3	*	10.1
1.2-2.4	3-6	9.6	†	9.9	9.9		10.2
2.4-4.7	6-12	10.5		10.8	10.7		10.7
4.7-7.9	12-20	11.2		12.5	11.0		11.8
0-7.9	0-20	10.1	†	10.7	10.1		10.6

†, *, **, *** indicate significant differences between tillage systems within a year at $P = 0.1$, $P = 0.05$, $P = 0.01$, and $P = 0.001$, respectively.

will be evaluated in years to come. Taken to a depth of 0-20 cm, soil organic C and total soil N were significantly greater under PP than under NT in February 1999 (Table 1). This analysis on a gravimetric basis was counteracted by the significantly lower soil bulk density with PP than with NT resulting in no significant difference in the stock of soil organic C and total soil N on a volumetric basis between tillage systems in either 1999 or 2000 (Table 2). The position within a water catchment had a significant effect on the stock of soil organic C (Fig. 1) and total soil N. Waterways were in a central position within the catchment, such that historical water and sediment movement would have been preferentially flowing through this zone, thereby depositing organically enriched surface soil and residues.

Surface residue C, although numerically lower under PP than under NT in both years, was not significantly different between tillage systems in either 1999 or 2000 (Table 2). However, surface residue N was significantly lower under PP than under NT in 1999, but not different in 2000. Surface residue C averaged 12 ± 1% of the total standing stock of C to a depth of 20 cm. Surface residue N averaged 6 ± 2% of the total standing stock of N to a depth

Table 2. Surface residue and soil organic C and N stocks as affected by tillage system during the first and second year. Paraplowing was done in November 1998 and 1999. NT is continuous no tillage and PP is conservation tillage with autumn paraplowing.

	Feb 1999			Feb 2000	
Component	NT		PP	NT	PP
C stocks, g m^{-2}					
Surface residue	382		337	377	336
Soil (0-6 cm)	1228	*	1340	1319	1323
Soil (6-20 cm)	1259		1485	1396	1521
Soil (0-20 cm)	2487		2825	2715	2844
Total (residue + soil)	2869		3162	3092	3180
N stocks, g m^{-2}					
Surface residue	23	*	15	11	13
Soil (0-6 cm)	131		135	141	133
Soil (6-20 cm)	118		131	131	138
Soil (0-20 cm)	249		266	272	271
Total (residue + soil)	271		281	283	284

* indicates significant difference between tillage systems within a year at P = 0.05.

Table 3. Stratification ratio (0-6 cm / 12-20 cm) of soil properties as affected by tillage system during the first and second year. Paraplowing was done in November 1998 and 1999. NT is continuous no tillage and PP is conservation tillage with autumn paraplowing

	Feb 1999			Feb 2000	
Component	NT		PP	NT	PP
Soil bulk density, Mg m^{-3}	0.82	*	0.75	0.77	0.76
Soil organic C, mg g^{-1}	3.3		3.4	3.4	3.3
Total soil N, mg g^{-1}	3.9		4.2	3.9	3.9
C:N ratio, mg g^{-1}	0.9		0.8	0.9	0.9

* indicates significant difference between tillage systems within a year at P=0.05.

of 20 cm. Surface residues C and N in either of these conservation tillage management systems were a significant portion of the total C and N of the near surface budget. This differs considerably with conventional tillage systems, in which surface residue C and N are often <1% (Franzluebbers *et al*., 1999).

The C:N ratio of soil organic matter increased gradually with depth in both tillage management systems during both years (Table 1). The C:N ratio of soil organic matter at a depth of 0-3 cm was significantly greater under PP than under NT in 1999 and 2000. Differences in the C:N ratio of soil organic matter between tillage systems were often not significant at lower depths. The C:N ratio of surface residue was 25 ± 7 among tillage systems and sampling dates. This ratio is similar to that reported for 13 crop and pasture management systems from the same geographic region on similar soils (27 ± 8) (Franzluebbers *et al*., 2000).

Stratification of soil bulk density during the sampling in February 1999 was the only property measured with a significant difference between tillage systems (Table 3). The lower stratification ratio under PP than under NT suggested that total soil porosity (i.e., the inverse of bulk density) was improved more under PP than under NT. Stratification ratios of soil organic C and total soil N were 3.7 ± 0.4 among tillage systems and sampling dates. These ratios are intermediately

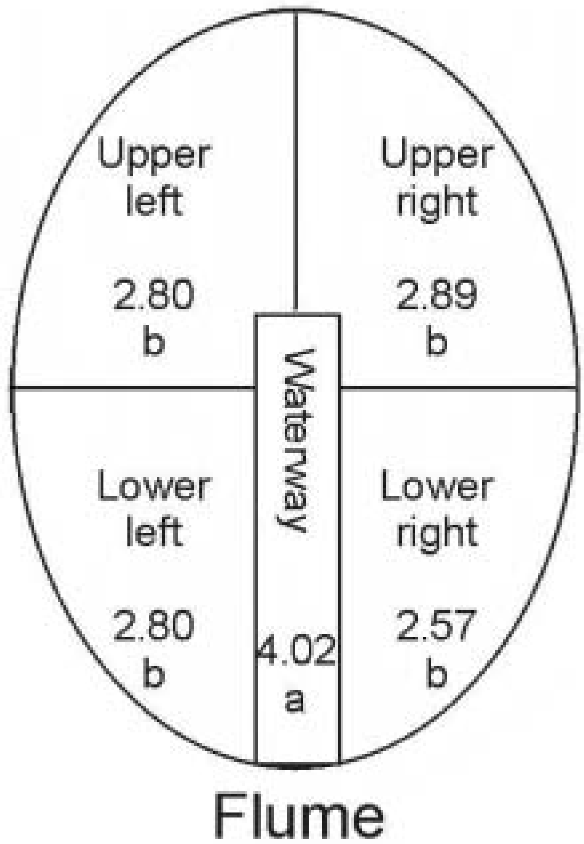

Fig. 1. Stock of organic C (kg m^{-2}) in surface residues and soil to a depth of 20 cm in February 1999 as affected by position within a water catchment. The diagram schematically represents the relative positions of each zone, as each watershed was shaped differently. Values followed by a different letter are significantly different at $P = 0.05$.

high on a theoretical scale that has been proposed to assess soil ecosystem functioning (Franzluebbers, 2002). The fact that paraplowing did not reduce the stratification ratio of soil organic C and total soil N suggests that this operation may not be detrimental to soil quality or ecosystem functioning. The energy requirements of paraplowing are not minor. Yet the benefit of paraplowing on increasing total soil porosity without destroying surface soil organic matter should be considered as a possible option to improve soil water-plant relations and possibly reduce water runoff concentration of nutrients.

CONCLUSIONS

This early evaluation of annual deep ripping (i.e., paraplowing) with conservation tillage compared with continuous no-tillage cropping suggests that soil physical conditions could be improved with deep ripping and that surface residue and soil organic C and total soil N could be maintained without significant degradation. We intend to evaluate these treatments in this experimental setup for at least five years.

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