IMPACT OF DEEP RIPPING OF PREVIOUS NO-TILLAGE CROPLAND ON RUNOFF AND WATERQUALITY

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ABSTRACT

Long-term conservation tillage practices might lead to soil compaction in some soils, altering water and chemical movement and resulting in environmental problems. The problem gets exacerbated where restrictive soil horizons are near or close to the surface. Farming practices are needed that allow a loosening of such natural or human-induced restrictive layers so as to reduce water runoff and associated off-site chemical losses. We have been monitoring surface runoff volume and associated nutrient concentrations since 1998 from four catchments that have been under a no-till cropping system for at least ten years. We paratilled two of the catchments every fall during this experiment to a depth of 12-16 in. We have found that runoff volume is significantly reduced from the catchments that have been paratilled. While the effect of paratilling on nitrate-nitrogen (NO_3-N) and soluble orthophosphate (PO_4-P) loss is not yet clear, losses of iron (Fe) and aluminum (Al) have been higher from the paratilled catchments, suggesting that any surface soil disturbance to a long standing no-till system could lead to immediate disruption of an established equilibrium. An ongoing severe drought reduced the potential data set from the experiment.

KEYWORDS

Conservation tillage, no-till, paraplow, paratill

INTRODUCTION

Large areas of eroded, degraded soils exist in the Southeast because of poor row crop production practices. Trimble (1974), Langdale *et al.* (1992), and others attribute this to intensive tillage practices that decrease soil organic matter content and leave soils vulnerable to the erosive action of intense rainfall. The challenge to restore degraded land to improve productivity, curtail environmental degradation of water and land resources, and develop a favorable and sustainable ecological balance has been met through improved farming systems. Such systems include, among others, converting cropland to pastures and forests and minimizing tillage. Adoption of conservation tillage for major crops such as cotton and soybeans has risen in the Southeast in recent times. According to CTIC (2000), about 20% of the cotton and 58% of the soybeans in the Southeast are now under no-till. Agricultural sustainability is a dynamic concept, however. As new farming systems are put in place to alleviate past problems, their short and long-term impacts need to be understood. This is true in particular due to regional variations in soil type, climate and landscape ecology.

The national drive for increased adoption of conservation tillage practices in US agriculture indicates general acceptance of its economic and environmental benefits. The scientific literature is mixed, however, on the effect of conservation tillage on the hydraulic and physical properties of various soils. Restricted plant rooting due to increased soil density is sometimes reported with no-till planting (West *et al.*, 1996; Griffith *et al.*, 1992). The Cecil soil series has a restrictive sub-surface horizon, which often times lies close to or at the surface due to past erosion. A restrictive horizon coupled with potential compaction from no-till farming could exacerbate environmental problems associated with water and chemical movement.

Pidgeon (1983) described the Paraplow, an implement that can be used to loosen soil without inversion to a depth of 14-16 in. with minimal disturbance of residue on the soil surface. The implement loosens soil by lifting it and dropping it back down with legs or shanks, angled at the side at 45 degrees from the horizontal. The soil fractures along zones of weakness as it is lifted and stays loose with increased storage and conductivity after it is dropped back. A disc coulter is used ahead of the each leg to reduce soil surface disturbance and cut previous crop residue. West *et al*. (1996) made distinctions between the "Paraplow", where the legs are attached to a moldboard frame at 20" spacing, and the "Paratill", where the legs are mounted on a square toolbar frame with variable spacing. The Paraplow and Paratill are available in four, six, and eight-leg models (West *et al*., 1996). Pidgeon (1983) found that the Paraplow increased water infiltration while preserving residue cover.

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The objective of this study was to evaluate surface water runoff volume and associated nutrient and mineral concentrations from a long-standing no-till cropping system on a Cecil soil with or without paratilling.

MATERIALS AND METHODS

Background, Site and Soil

The study site is located at the USDA-ARS, J. Phil Campbell Sr. Natural Resource Conservation Center near Watkinsville, GA (83°24' W and 33°54' N). The Center has a rich history of research into abating soil erosion problems in the Southern Piedmont land resource area (Hendrickson and Barnett, 1963; Adams and Dawson, 1964; Carreker *et al*., 1977; Langdale and Moldenhauer 1995; Endale *et al*., 2000). As part of this effort, the four catchments used in this research were established in 1972. The research has produced a wealth of information into infiltration and runoff, soil and chemical loss, and residue management and dynamics in response to management of such summer crops as soybeans, grain sorghum, millet, corn and cotton under conventional and conservation tillage, with fallow and such cover crops as barley, wheat, rye, and crimson clover.

The four catchments designated as P1, P2, P3, and P4 have areas of 6.69, 3.19, 3.11 and 3.46 acres, respectively. P3 and P4 are immediately adjacent to each other and are separated by 1.8 and 2.3 miles from P2 and P1, respectively. The catchments represent common land forms of the Southern Piedmont. Cecil sandy loam soil (fine, kaolinitic, thermic, Typic Kanhapludults) dominates the catchments. Typic Kanhapludults cover approximately two-thirds of the 34.8 million acres available for cropping in the Southern Piedmont (Langdale *et al*., 1992). The Cecil soil series generally consists of deep well-drained and moderately permeable soils. Saturated hydraulic conductivity of the Bt horizon is < 0.4 in. hr^{-1}, while for horizons above it can reach 6-8 in. hr^{-1}. Mean annual precipitation is 49 in. and temperature is 62°F. The spring-summer cropping season coincides with the season of high rainfall energy.

Slopes on P3 and P4 range from 1.5 to 3% and both have had a grass waterway bisecting them to channel runoff towards measuring flumes. Slopes on P1 and P2 range from 2 to 7% and P1 also has had a grass waterway. There has not been a grass waterway on P2. All grass waterways were incorporated into the catchments at the start of this research. The top of the Bt horizon generally lies within 20 in. of the surface in all catchments.

P1 has been under a continuous doubled cropping conservation cropping system since 1975. The other three had been managed under both conventional and conservation tillage prior to 1990 but only conservation tillage since.

Arrangement

We began this study in 1998. P1 and P3 were left in continuous no-till while P2 and P4, which have also been under no-till, were paratilled in mid to late October or November of each year to 12-16 in. depth. Summer crops were Maize (*Zea mays*) in 1999, pearl millet (*Pennisetum glaucum*) in 2000, and grain sorghum (*Sorghum bicolor*) in 2001. Winter cover 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 tests with inorganic N-P-K, as well as broiler litter in July 2000, July 2001, and December 2001 at 1.1 ton $acre^{-1}$. We will refer to P2 and P4 as PT (paratilled) and P1 and P3 as N-PT (non-paratilled) catchments.

Each catchment is instrumented with an automated system that measures rain and runoff and collects discrete water samples over the runoff event. Samples were kept refrigerated on site until collected for analysis. Composite samples were sent to the University of Georgia in Athens, GA for analysis of minerals, and nitrate and phosphate. Rain and runoff data were downloaded form data loggers after the events and processed for statistical analysis with the General Linear Models Procedure of SAS (SAS Inst., 1989).

PRELIMINARY RESULTS

Runoff prior to paratillage

Runoff from seven storms immediately prior to the start of paratilling is presented in Table 1. Runoff is expressed in cubic feet per acre for direct comparison between catchments, since the areas of P2 to P3 differ slightly and P1 has about twice the area of the others. Considering runoff events above 5 ft^3 $acre^{-1}$, P3 and P4 had runoff from six of the seven storms while P2 had four, and P1 three. Volumetric accuracy of runoff below 5 ft^3 $acre^{-1}$ is not certain. We were unable to measure one of the three events for P1 because of equipment malfunction. The two catchments that were later paratilled (P2, P4) had higher runoff compared to the other two. Runoff from P4 was 1.4 to 3.6 times that from P3 except for the event of 04/05/98, where it was about 28 times. P2 had higher runoff than P3 for three of the events. A linear regression of runoff in response to rainfall showed an R^2 value of 0.84 for P3 and 0.87 for P4. Although runoff between P1 and P2 appear similar, recall that P1 has twice the area.

Over the whole period, total rainfall producing the runoff events was 17.2 in. Runoff in cubic feet per acre per inch of rain amounted to 239 for P1, 274 for P2, 244 for P3, and 379 for P4. P2 had 15% more runoff than P1, and P4 had 38% more runoff than P3.

Table 1. Total runoff for plots 1-4 from seven storms in 1998 before paratillage started. P1 and P2 had barley, P3 had clover, and P4 had rye during this period

Date	Rainfall	P1	P2	P3	P4
	inches	----------- ft^3 $acre^{-1}$ -----------			
01/07/1998	2.10	431	542	90	187
01/22/1998	0.87	<5	<5	<5	129
02/03/1998	4.67	†	2059	1716	2759
03/08/1998	4.81	3670	2085	1995	2744
04/05/1998	2.48	<5	<5	6	176
05/03/1998	1.24	<5	<5	143	509
05/08/1998	1.02	<5	13	246	<5

†Not determined due to equipment malfunction

Runoff after paratillage

Runoff from nine storm events after paratilling started is presented in Table 2. The effect of paratilling in reducing runoff is clear. Since P3 and P4 are adjacent to each other and about the same size, the comparison between them is more meaningful. Whereas before paratilling P4 had more runoff than P3 from storms of about 1 to 5 inches, runoff was less for all events of similar magnitude after paratilling. P3 had runoff of 178-1077 ft^3 $acre^{-1}$ from four of the storms, whereas P4 had minimal runoff from these same storm events. The high correlation between rainfall and runoff before paratilling for P4 disappeared after paratilling. The 6.5 in. storm of July 24, 2001 represents a 1 in 50 to 100 year storm and is considered an extreme event. Rainfall that produced the nine, runoff events amounted to 23.6 in. Runoff in cubic feet per acre per inch of rain was 345 for P1, 350 for P2, 442 for P3, and 241 for P4. P2 had just 2% more runoff than P1, down from 15% of the earlier period. But this time P4 had 55% less runoff than P3.

Variance between runoff amounts was high, and the data were, therefore, log-transformed for statistical analysis. Log-means of runoff from P2 and P4 were not statistically significant from those P1 and P3 before paratillage (P = 0.79), but were significantly lower after paratillage (P = 0.06).

Water quality

We do not have a 'before and after' comparative water quality data as that for the runoff, but results of analysis for NO_3-N, PO_4-P, Fe, and Al from seven of the nine post-paratill sampling are presented in Fig. 1 as box plots. We did not run analysis of varience as a statistical test on these. We had samples from the very low flows that showed high concentration of especially Fe and Al. These might bias statistical tests, but nevertheless are included in Fig. 1. Mean concentration for each parameter is indicated by dotted lines inside each box in Fig. 1.

Mean soluble orthophosphate (PO_4-P) concentration from the PT catchments was about half that of N-PT catchments. Variance was higher from N-PT (9.5 for P1 and 34 for P3) than the PT catchments (2.3 for P2 and 0.28 for P4). One of our hypotheses in this experiment, namely that paratilling will induce/encourage less offsite transport of phosphorus, appeared to be correct.

The effect of paratillage is not apparent on the distribution for NO_3-N concentration in Fig. 1. Almost all concentrations were below 10 ppm (mg $liter^{-1}$), an index often used as an indicator for possible environmental problems. The largest concentration occurred during the extreme event of July 24, 2001 (5.6 to 10.5 ppm).

Concentrations shown in Fig. 1 for Fe and Al are interesting and telling. The Cecil soil series is high in Fe (red color) and Al oxides in subsurface horizons, which had been exposed in many landscapes in the Southern Piedmont due to past erosion. The graph clearly shows that disturbance of the soil surface even in long standing conservation systems can lead to a disruption of the established equilib-

Table 2. Total runoff for plots 1-4 from nine storms after paratillage started. The Cropping system was rye except for: 02/01/1999 clover on P2 and P3, 01/10/2000 all barley, and 07/24/2001 all sorghum.

Date	Rainfall	P1	P2	P3	P4
	inches	----------- ft^3 $acre^{-1}$ -----------			
02/01/1999	3.64	110	98	874	11
01/10/2000	2.15	5	2	279	<5
12/06/2000	2.91	114	109	1077	<5
03/03/2001	1.75	<5	5	242	<5
03/12/2001	1.68	<5	7	179	<5
03/15/2001	1.83	477	125	1106	238
03/20/2001	1.73	15	58	469	85
03/29/2001	1.41	<5	<5	6	<5
07/24/2001	6.56	7436	7885	6213	5356

rium. Although the figures include samples from the very low flows, all runoff from P4 was visually higher in sediment and brown to red in color. P1 has been under continuous double cropped conservation system since 1975 with no surface disturbance other than during no-till planting. Mean Fe loss from P1 was only 0.7 ppm compared to 10.3 from P2 and 21.6 from P4. The variance was only 0.25 for P1 but was high to very high for P3 and P4. Mean Fe concentration from P3 was 5.2 ppm with a variance of 9.7. The history of P3 includes cultivation through the 1980s and before.

The pattern for concentration of Al in runoff water was similar to that of Fe. The highest mean concentration was from P4 (45.3 ppm) followed by P2 (17.4 ppm). Variance was highest from these two catchments. Mean Al concentration from P1 was 1.5 ppm and the variance was 0.96. P3 had a mean Al concentration of 9.7 ppm and a variance of 43.3.

DISCUSSION

We consider these results preliminary not only because of the short period of the study so far, but also because the period has coincided with the drought that had gripped the Southeast since mid-1998. Analysis of monthly rainfall data from 1937 to 2001 showed that annual rainfall varied from 33.7 to 72.3 in. with a mean of 49.1 and a median of 50.2 in. Year 2000 was the 6th driest on record with annual rainfall of 36.1 in., followed by year 2001, which was the 19th driest with 42 inches. Year 1999 was the 21st driest with 43.1 in. annual rainfall. The pattern was similar for the fall,

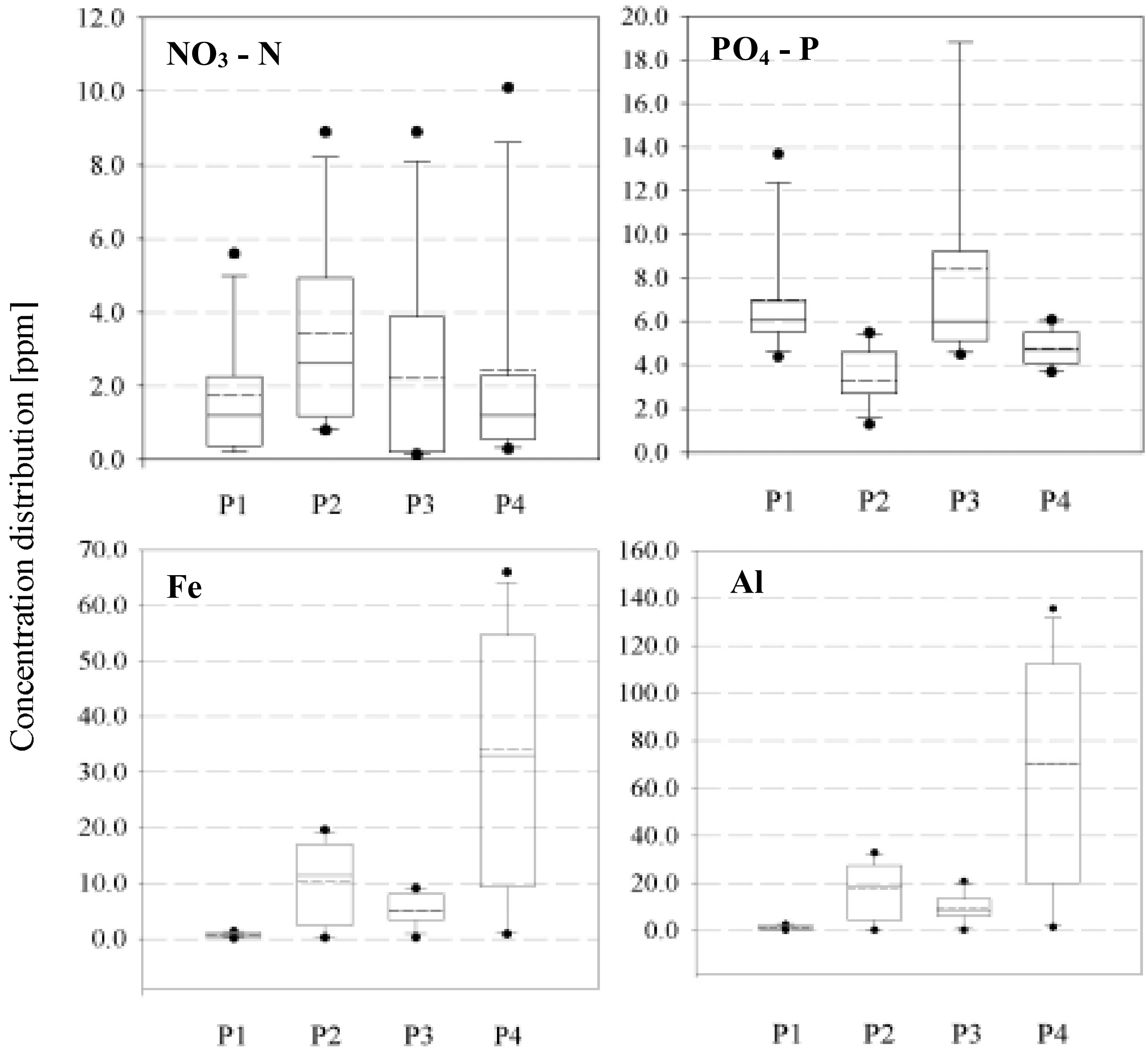

Fig. 1. Distribution of concentrations of NO_3-N, PO_4-P, Fe and Al in ppm (mg liter^{-1}) from seven runoff events, following start of paratillage. Each box shows the 25th percentile, median, and 75th percentile. Whiskers show the 10th and 90th percentiles. Outliers beyond these limits are shown as dots. Means are shown as dotted lines inside boxes.

winter, and spring seasons for periods when the summer crop is harvested and the cover crop has not developed full canopy. Optimum soil moisture is important during paratilling to minimize unnecessary and unintended disturbance of the soil surface. Drier conditions will result in production of larger clods, while wetter conditions could cause plant residue to cling to the cutting edge of the plow and force soil to collect on the surfaces. This problem may have caused rougher surface conditions in P4 that might have lead partly to some of the high Fe and AL losses indicated in Fig. 1. Franzluebbers *et al*. (2002) discuss the effect of paratilling no-till fields on surface-soil distribution of bulk density and organic C and N from this experiment.

CONCLUSIONS

Mean runoff from two small-sized Southern Piedmont catchments with at least ten years of conservation tillage cropping history became less ($P = 0.06$) after paratillage to 12-16 in depth started. The runoff before paratillage started was higher and similar to catchments with similar cropping history that were not paratilled ($P = 0.79$). Loss of the minerals iron and aluminum through runoff was higher from the two paratilled catchments compared to the two others that continued no-till with no paratillage. Paratillage may also have reduced the off-site loss of phosphorus to some degree. The experiment coincided with a period of drought that reduced the expected seasonal rainfall and runoff events, and these results are, therefore, considered preliminary.

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