LONG TERM SEDIMENT YIELD AND MITIGATION IN A SMALL SOUTHERN PIEDMONT WATERSHED

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ABSTRACT

Southern Piedmont lands suffer moderate to severe erosion when farmed under single-crop, conventional till systems consisting of moldboard plowing, disking or harrowing. This is primarily due to high soil erodibility, high energy spring-summer storms, low residue cover, and poor management factors. A winter season with no crop often leaves soil unprotected from rainfall impacts. Conservation cropping systems that minimize tillage and leave a growing crop and crop residues on the surface both in summer and winter protect soil from erosive effects and sustain productivity. In this paper we present and discuss 26-years of soil loss, runoff and residue production data from a 2.71 ha catchment typical of small Southern Piedmont watersheds. The catchment was first managed in conventional tillage system of summer soybean (*Glycine max* (L.) Merrill) and winter fallow from 1972 to 1974. It was then converted to conservation cropping systems of summer soybean, sorghum (*Sorghum bicolor* (L.) Moench), or cotton (*Gossypium hirsutum* (L.)) and winter barley (*Hordeum vulgare* (L.)), wheat (*Triticum aestivum* (L.)), or clover (*Trifolium incarnatum* (L.)) which have continued to the present. Conservation cropping systems had immediate and residual effects in controlling erosion and runoff in both summer and winter. Destructive soil erosion, from high energy storms was significantly reduced. Residue production increased from about 2 Mg ha^{-1} yr^{-1} under conventional tillage to 9.88 Mg ha^{-1} yr^{-1} under conservation cropping systems over 20 years.

Key Words: Soil erodibility, Conservation cropping system, Tillage system, Erosive effect

1 INTRODUCTION

The Southern Piedmont physiographic region in the southeastern United States covers about 16.5 million ha extending 1200 km from southern Virginia to east-central Alabama and lies between the Appalachian Mountains and the southern Coastal Plain (Carreker et al., 1977). The Piedmont slopes southeastward for approximately 250 to 300 km from 350 m above sea level adjacent to the mountains to 100 m above sea level along the southeastern edge. This foothills region is dissected by many streams. The topography is gently rolling, with gentle to moderate slopes on ridge tops and steeper slopes near streams. Valleys are narrow with little alluvial soils. There are abundant surface waters and diverse biological resources (Hendrickson et al., 1963). Average growing seasons vary from 209 to 220 days. Average annual rainfall varies between 1100 and 1400 mm.

Ultisols dominate the landscape of the humid-thermic, southern USA (Perkins et al., 1973).

Of the approximately 14.1 million ha available for cropping in the Southern Piedmont, approximately two-thirds is classified as Typic Kanhapludults of which Cecil is a representative soil series (Langdale et al., 1992a). These soils are deeply weathered and have largely developed in residuum from underlying schist, gneiss and granite. The original surface horizons of most of the Hapludults were loamy sands to sandy loams. They were relatively thin even under mature forests (Davis et al., 1931). Native fertility of the soil is low.

Much of the southeastern USA has been under cultivation for over 250 years (Sojka et al., 1984) and exposed to human-induced erosion. Trimble (1974, 1975), and Dregne (1982) suggested that European

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settlers initiated accelerated soil erosion in the southern USA during the early 1800s. The ensuing 150 years of cotton cultivation caused extensive soil erosion (Trimble, 1974; Langdale et al., 1992b). After soybean began replacing cotton in the late sixties, it became the primary human induced soil erosion stimulus in the south (USDA, 1980; Larson, 1981). Over 86% of the Southern Piedmont is classified by USDA-NRCS (Natural Resource and Conservation Service) as eroded. Less than 0.5% of the land is Class I, which can be cropped with relatively few limitations. About 48% is Class II and III, which can be used for row crops with careful management while about 38% is Class IV and V which are best used for pastures and forests.

Trimble (1974) showed that accelerated soil erosion subsided in the Southern Piedmont about 1967. These positive results coincided with the application of soil-erosion research reported by Copley (1944), Adams (1949), Baver (1950), and Beale et al. (1955). The Southern Piedmont was one of ten original sites for national soil erosion experiments stations in the early 1930. The J. Phil Campbell Senior, Natural Resource Conservation Center was established in 1937 as a regional soil and water conservation research site. In the early years, runoff plots were established and monitored to produce data later used in development of the Universal Soil Loss Equation (Williams et al., 1981; Langdale and Shrader 1982). The location was also the site of early research efforts with mulch tillage and cropping systems (Hendrickson et al., 1963).

Southern Piedmont lands suffer moderate to severe erosion when farmed under single-crop conventional tillage systems because of highly erosive storms associated with the udic-thermic climate, and the highly erodible nature of Typic Kanhapludult soils (Langdale et al., 1979a, 1985b). In a 1940-1959 study, soil erosion from a conventionally tilled cotton averaged 45 Mg ha^{-1} yr^{-1} (Barnett and Hendrickson, 1960; Langdale et al., 1992b). About 21% of the 1,250 mm yr^{-1} of rainfall was partitioned into runoff. On average, there were 11 storms annually with intensity greater than 127 mm hr^{-1} that contributed 25% of the rainfall, 56% of the runoff, and caused 86% of the soil loss. Most of these high-intensity storms occurred in June, July and August during the cotton growth season.

Buol (1973), Barnett (1976), and Wischmeier and Smith (1978) have documented the inherent erosive nature of Ultisols that appears to be related to low organic matter content, weak structure, and low permeability caused by intensive weathering. Low inherent soil fertility and clayey or acid sub-soils with high Al concentration in many Ultisols exaggerate soil erosion problems (Langdale and Shrader, 1982). Larson (1981) and Langdale and Shrader (1982), have related properties such as poor aggregation, low soil carbon, low infiltration and low crop yield to eroded soils. Bruce et al. (1986, 1988), showed that rewetting of the plant root zone declines significantly as soil carbon declines with accompanying increase of clay content in Ap soil horizons.

Erosion on Southern Piedmont soils remains a problem without application of sound conservation practices (Carreker et al., 1977; Langdale et al., 1979b). Large quantities of crop residue improves soil carbon and water stable aggregates consequently improving the water regime for crop production (Bruce et al., 1990a, 1990b; Langdale et al., 1987, 1990). Conservation tillage technology for cotton production was not available prior to 1960 but rapidly advanced during the 1970s and 1980s with development of herbicides and new planting equipment. Crop rotation options with cotton were limited to summer annuals. Compared with practices in other regions, conservation practices including tillage, have evolved quite differently in the Southern Piedmont because of the region_s thermic-humid climate and eroded Ultisols (Langdale et al., 1985a, 1992a).

Research was started in 1972 in a small catchment at the USDA-ARS, Watkinsville, GA, to evaluate sediment and herbicide transport in runoff from a Piedmont watershed. The study was conducted cooperatively between the USDA-Agricultural Research Service and Environmental Protection Agency (Smith et al., 1978). After 3 conventionally tilled soybean crops (summer soybean, winter fallow), management converted to conservation cropping systems consisting of double-crop conservation tillage rotations (summer: sorghum, soybean or cotton; winter: barley, wheat or clover) which have been maintained since. The objective of this paper is to summarize 26-years of runoff and sediment data and show impacts of the contrasting cropping systems on long-term runoff and sediment losses and residue production.

2 STUDY METHODS AND DESCRIPTION

The research catchment _P1' was established during the spring and summer of 1972 on 2.71 ha at the USDA-ARS J. Phil Campbell Senior, Natural Resource Conservation Center, Watkinsville, GA (83° 24' W longitude and 33° 54' N latitude). Slopes range from 2 to 7 percent. The catchment consists of three soil types: a gravely Cecil sandy loam (clayey, kaolinitic thermic Typic Kanhapludults), with 2 to 6 percent slopes, is dominant; a similar soil but with thinner solum, a gravelly Pacolet sandy loam, occurs on a small area on the 5 to 7 percent slopes; and a Starr sandy loam occupies the lower portion of the catchment on 2 to 4 percent slopes.

Flow was gauged with a 0.762 m (2.5 ft) stainless steel H-flume and a FW-1 water level recorder (U.S. Hydrology Staff, 1962). A motorized slot traversing through the nappe was used to sample runoff for sediment concentration and quantity. Products of runoff volume and sediment concentration during an event were summed to get sediment yield. Rainfall was measured with a recording rain gauge.

From July 1972 to October 1974, the catchment was cropped conventionally to soybean-fallow similar to systems used by soybean farmers in Southern Piedmont at the time (Langdale and Leonard 1983). Soybeans were grown in 0.91 m (36-in) rows approximately parallel to topographic surface contours. Soil was disked and rotary tilled (0.15 m) and then chiseled (0.20 m). A contra-rotating tine tiller was used to incorporate herbicides. A gully formed during this conventional tillage phase of the study on part of the catchment. The gully was renovated by establishing an 11-m wide (0.32 ha) fescue (*Festuca arundinacea* Schreb.) grassed waterway in October 1974 (Langdale et al., 1979a). This waterway was also used for farmer technology transfer.

Table 1 Tillage and cropping systems on research catchment 'P1'

Cropping		Crop		Tillage	
System	Period	Summer	Winter	Summer	Winter
1	Jul. 1,1972 - Oct. 21, 1974	Soybean	None	Disk harrow	None
2	Oct. 22, 1974 - May 31, 1977 1976	Grain Sorghum	Barley	NT-Coulter	NT-drill
3	Jun.1, 1977 - Nov. 5, 1980	Soybean	Wheat	CIRC	NT-drill
4	Nov. 6, 1980 - May 14, 1984	Grain Sorghum	Clover	CIRC	NT-drill
5	May 15, 1984 - Nov. 14, 1985	Soybean	Wheat	CIRC	NT-drill
6	Nov. 15, 1985 - Oct. 23, 1988	Grain Sorghum	Clover	CIRC	NT-drill
7	Oct. 24, 1988 - Oct. 30, 1990	Soybean	Wheat	CIRC	NT-drill
8	Oct. 31, 1990 - Oct. 1, 1993	Forage Sorghum	Clover	CIRC	NT-drill
9	Oct. 2, 1993 - May 24, 1995 19957	Soybean	Barley	CIRC	NT-drill
10	May 25, 1995 - Oct. 28, 1996	Soybean	Clover	CIRC	NT-drill
11	Oct. 29, 1996 - May 10, 1998	Cotton	Barley	CIRC	NT-drill

NT-Coulter stands for no-till coulter; NT-drill stands for no-till planter; CIRC stands for conservation tillage with coulters and in-row chisel NT-NNN

Conservation cropping systems began during 1974-1975 winter crop year. Table 1 presents the eleven systems used from 1972 to 1998. The first conservation croping system (System 2, Table 1) used a fluted-coulter no-till planter for grain sorghum and small grains drill for barley. Poor soil penetration by fluted-coulters made planting soybeans following small grains impractical. Also large quantities of crop residues were difficult to sever with coulters alone (Langdale and Leonard,1983; Langdale et al., 1983). In-row chisel tillage equipment was used beginning with system 3. It helped to break up the restrictive Bt horizon that often limited plant root growth as well as water movement because of higher clay content and lower saturated hydraulic conductivity than surface horizons (Radcliffe et al., 1989). In-row chiseling improved planting of soybeans and led to further reductions in runoff and soil loss. General operation consisted of fall planting of small grains or seeding of crimson clover with a grain drill and summer planting of sorghum, soybeans or cotton with a four row planter. The great advantage of conservation cropping systems is the yearly production and retention of crop residue on the soil surface which influences soil properties that favor less runoff and sediment loss (Bruce et al., 1995). Between 1975 and 1994, an average of 9.88 Mg ha^{-1} $yr^{-1}$of crop residue was produced. Total crop residue production did not exceed 2 Mg ha^{-1} yr^{-1} under the conventional tillage system.

3 RESULTS AND DISCUSSIONS

There was a dramatic difference in runoff and soil loss between the conventional tillage period (CTP) and the conservation cropping systems period (CCSP). Not only were runoff and soil loss reduced during the CCSP, but these were consistently low across systems 2 to 11. Total runoff during 2.5 years of CTP was 451 mm compared to 549 mm during 24 years of the CCSP (Figure 1). Total soil loss through the flume was 58293 kg ha^{-1} (129.25 kg $ha^{-1}mm^{-1}$ runoff) during CTP. Near equal quantities dropped out behind the flume. But, total soil loss during CCSP was only 983 kg ha^{-1} (1.79 kg $ha^{-1}mm^{-1}$ runoff). This excludes system 10 (25 May 95 to 28 Oct. 96) for which there were no soil loss data. Soil loss per unit of runoff varied from zero to no more than 2.6 kg ha^{-1} mm^{-1} runoff for individual cropping systems of the CCSP. Cropping systems 5 and 6 had no soil loss. The period proved relatively dry with a total runoff of only 0.96 mm recorded in only three of the 54 months.

The ten largest soil loss events caused by one day storms varied between 990 and 17198 kg soil ha^{-1}, all occurred during the CTP, and accounted for 81.7% of the total soil loss during the whole period. These losses were associated with 6.3% of runoff events, 8% of runoff causing storms and 26.6% of total runoff. The next ten largest soil loss events from individual daily storms varied between 355 and 976 kg soil ha^{-1}, also occurred during the CTP, and accounted for 12.2% of the total soil loss. These soil losses were associated with 6.3% of runoff events, 4.8% of runoff causing rain and 10.2% of total runoff.

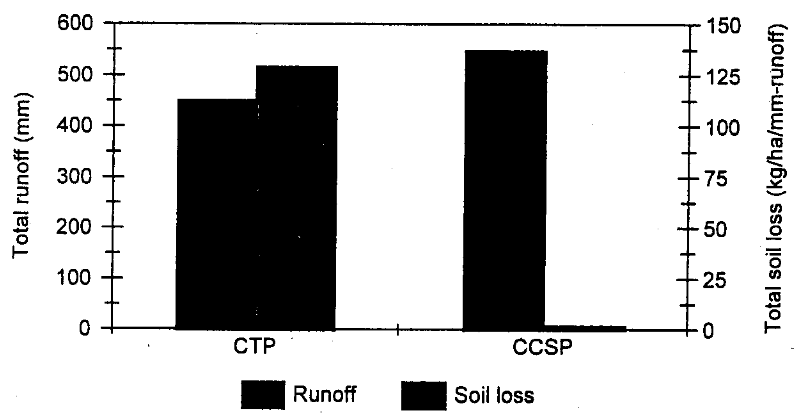

Fig. 1 Total runoff and soil loss during the 2.5 years conventional tillage period CTP, and 24-years conservation cropping systems period CCSP

Most erosion during conventional tillage is caused by storms with a rainfall greater than or equal to 100 mm, or an erosion index (EI) greater than or equal to 1,000 MJ_mm $(ha\cdot h)^{-1}$ (Langdale et al., 1992b). One such storm (May 28, 1973, 100 mm, 1050 MJ_mm $(ha\cdot h)^{-1}$) accounted for 29.5% (17198 of 58293 kg ha^{-1}) of the total soil loss during CTP. This storm occurred a few days following primary tillage and soybean emergence. Langdale et al. (1992b) characterize it as typifying erosion risks associated with 170 years of conventional tillage cotton and soybean in Southern Piedmont. In contrast, another similar storm occurred on December 14, 1972 (110 mm, 785 MJ_mm $(ha \cdot h)^{-1}$) but caused soil loss of only 136 kg ha^{-1}. The contrast arose because of a soybean residue cover of 1.4 Mg ha^{-1} during the second storm (Langdale et al., 1992b).

Cotton was grown for the first time during this study in the summer of 1997 (system 11). The grassed waterway was also converted to the crop rotation at that time because of negligible soil losses from the catchment over the long CCSP. There was also poor residue production with the barley crops grown prior to and after the cotton. There was practically no yield from barley the second winter. These factors. appear to have increased runoff (160 mm) and soil loss (344 kg ha^{-1}) for this system compared to the other systems of the CCSP. Virtually all the runoff and soil loss occurred during the cotton and subsequent barley growing periods divided equally.. These values are still low compared to potential values from conventional tillage systems.

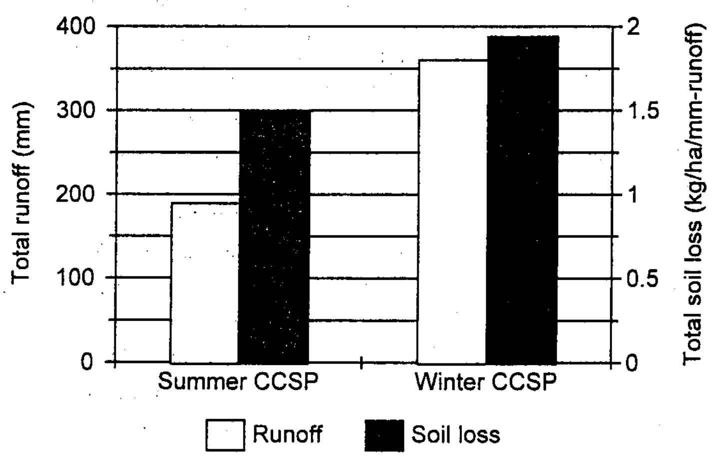

Fig. 2a Total runoff and soil loss for summer and winter of the 2.5-years conventional tillage period CTP

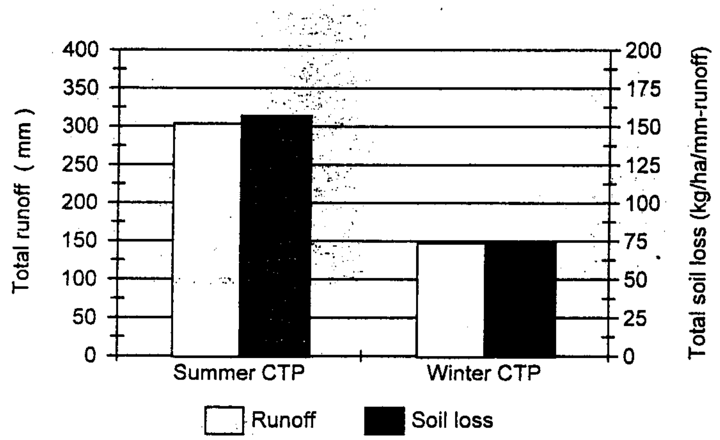

Fig. 2b Total runoff and soil loss for the summer and winter of the 24-years conservation cropping systems period CCSP

Total runoff and soil loss per unit of runoff for summer and winter periods of the CTP and CCSP are presented in Figures 2a and 2b. Note that the scales of the secondary-Y axis (soil loss) of these two graphs are different. About 67 percent of the runoff and 81.5 percent of the soil loss under CTP occurred in the summer when soybean was growing. The rest occurred in the winter when soybean stubble and residue covered the soil surface and no other crop was growing. But during the CCSP period, only 34.4 percent of the total runoff and 28.7 percent of the total soil loss occurred in the summer. Total soil loss per unit of runoff for summer was double that for winter (156.84 versus 73.25 kg ha^{-1} mm^{-1} runoff) during CTP. Erosion was extremely low and there was not much difference between total summer and winter losses per unit runoff during CCSP (1.5 versus 1.94 kg ha^{-1} mm^{-1} runoff). Langdale and Leonard (1983) have reported the shift of peak runoff events from the summer to midwinter months under conservation cropping systems. Under conventional tillage, poor summer soil surface physical conditions (crusting , etc.,) lead to higher runoff. In conservation cropping systems soil becomes saturated during the winter and more water infiltrates during the summer.

The amount of the precipitation that produced runoff and that which was partitioned to runoff also showed contrast between the CTP and CCSP. During CTP, 16.5 percent of the total rainfall and 25.8 percent of runoff causing rainfall was partitioned to runoff. The equivalent values during the CCSP were 2.0 and 11.3 percent respectively (Figure3).

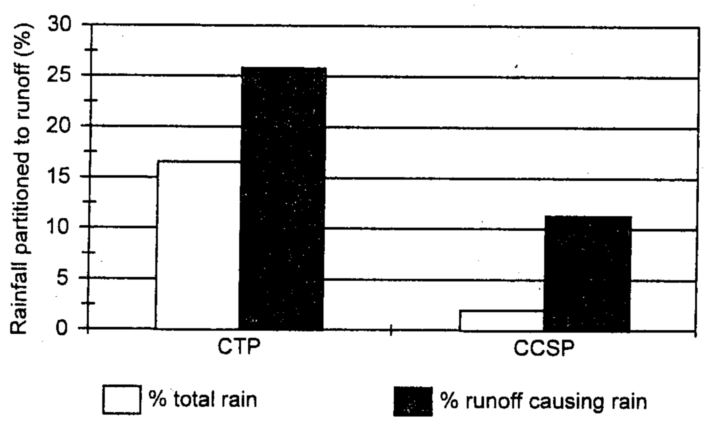

Fig. 3 Partitioning of rainfall into runoff during the 2.5-yr conventional tillage period CTP and 24-years conservation cropping system period CCSP

4 SUMMARY AND CONCLUSIONS

The high erodibility of the dominant Southern Piedmont soils coupled with the region's high energy storms result in unacceptably high erosion rates from conventionally tilled one crop per year systems. Many years of plot-to-watershed size studies across a wide range of landscapes and soil textures have shown that erosion is reduced through dissipation of raindrop kinetic energy by surface residues or growing cover crops. Conservation cropping systems are a management tool which leaves protective crop residue on the soil surface, thereby providing for less exposure of soil to the erosive effects of raindrops, and over time, builds up residue that leads to surface properties that favor protection and enhancment of the soil resource. The Southern Piedmont continues to benefit from conservation cropping systems in combating effects of severe erosion that occurred during decades of conventionally tilled row-cropping. In designing conservation cropping systems in Southern Piedmont, the region's unique features must be taken into account. These include: mild winters, that allow 2 crops per year but also promote weed, pest and diseases; prevalence of soil hardpans that lead to root penetration problems; low soil water storage; and intensive rainfall.

Improvements have occurred because of the expansion of expertise in use of double cropping, cover crops, and residue management practices that minimize tillage, and reduced erosion in the southeast. Breakthroughs that facilitated this include:

1. Introduction of fluted coulters for small grain residue management,
2. Commercially successful in-row subsoil-planting equipment that controlled soil erosion and runoff

on up to 7% slopes,

3. Improved weed control options including new herbicides and new applicators, and
4. Realization of distinctly different nature of conservation tillage in the southeast.

While coulters and subsoil-planting equipment have been around a long time, their integration into sound application of soil and crop science might be considered innovative in this context.

Scientists at the J. Phil Campbell Senior, Natural Resource Conservation Center utilized and improved on these innovations to quantify their effect on soil erosion from a 2.71 ha typically small Southern Piedmont watershed under a double-cropped conservation tillage systems.

The major conclusions after 26 years are:

- Double cropped conservation cropping system following conventional tillage cropping immediately reduced runoff and soil erosion.
- Conservation cropping system was essential to successfully combat accelerated erosive effects of high-energy storms following conventional tillage.
- Residue of 9.88 Mg ha^{-1} yr^{-1} of was produced over 20 years under conservation cropping systems. The residue modified surface soil properties that allowed more infiltration and therefore less runoff. Residue production did not exceed 2 Mg ha^{-1} yr^{-1} under conventional tillage system.
- The in-row chisel tillage (systems 3 to 11) was more effective in reducing runoff than fluted coulter tillage (system 2) in catchment 'P1'.

Conclusions are based on research at a particular Southern Piedmont location. As pointed out, success with conservation tillage depends on designing appropriate strategies based on environmental, cultural and management resources and constraints of a particular location.

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