Surface Runoff and Lateral Subsurface Flow as a Response to Conservation Tillage and Soil-Water Conditions

D. D. Bosch, T. L. Potter, C. C. Truman, C. W. Bednarz, T. C. Strickland

Abstract. *Conservation tillage has significant potential as a water management tool for cotton production on sandy, drought-prone soils. Plant residue remaining at the soil surface from prior crops serves as a vapor barrier against water loss, reduces raindrop impact energy, slows surface runoff, and often increases infiltration. By increasing infiltration, the potential for greater plant-available water can be enhanced and irrigation requirements reduced. Five years of data were collected to quantify the hydrologic differences between strip till and conventional till production systems. Surface runoff and lateral subsurface flow were measured on six 0.2 ha plots in South Georgia in order to quantify the water-related effects of conservation tillage. Significant differences in surface and subsurface water losses were observed between the conventional and strip tilled plots. Surface runoff from the conventionally tilled plots exceeded that from the strip tilled plots, while subsurface losses were reversed. Surface runoff losses from the conventionally tilled plots exceeded those from the strip tilled plots by 81% (129 mm/year). Shallow lateral subsurface losses from the strip tilled plots exceeded those from the conventionally tilled plots by 73% (69 mm/year). Overall, a net annual gain of 60 mm of water was observed for the strip tilled plots.*

Keywords. *Strip tillage, Water budget, Water conservation.*

Conservation tillage is a management practice designed to reduce soil erosion by leaving 30% or more of the soil surface covered with crop residue following tillage and planting (Galloway et al., 1981). In some cases, conservation tillage has also been shown to increase infiltration (Romkens et al., 1973; Blevins et al., 1990). In situations where plant-available water is limited, either because of poorly distributed rainfall or the lack of an irrigation supply, this practice holds promise as a management tool for cotton production on sandy, drought-prone soils. One of the most commonly applied conservation tillage practices in cotton is strip till, where the soil is left undisturbed from harvest to planting except for narrowly tilled strips into which the seed is planted. Planting directly into a residue cover (no till) or in these narrow strips (strip till) has been shown to reduce erosion and conserve water by enhancing infiltration (Romkens et al., 1973; Langdale et al., 1979; Blevins et al., 1990). Plant residue remaining at the soil surface from prior crops serves as a vapor barrier against evaporative water loss, reduces raindrop impact energy, slows surface runoff, and often increases infiltration (Triplett et al., 1968). By increasing infiltration, the potential for greater plant-available water can be enhanced and irrigation requirements reduced. If crop production is water limited, conservation tillage could potentially increase crop yields.

Conservation tillage used in combination with winter cover crops has a particular benefit for cotton production, which tends to leave little residue on the soil surface after harvest (Mutchler et al., 1985). Conservation tillage systems without the cover crops are not believed to be as effective. Yoo and Touchton (1988) observed reduced runoff and sediment loss from cotton planted following rotilling a winter wheat cover crop when compared to rotill tillage alone and a disk-chisel plow tillage without cover crops. Reduced tillage alone, going from the disk-chisel plow tillage to the rotill tillage without the cover crop, yielded greater runoff and sediment loss than did the disk-chisel tillage without a cover crop (Yoo and Touchton, 1988). For these reasons, conservation tillage cotton production using wheat (*Triticum aestivum* L.) or rye (*Secale cereale* L.) as winter cover crops has gained increased producer acceptance over the past 20 years (Lascano et al., 1994). Lascano et al. (1994) found that wheat residues planted in cotton stubble reduced soil-water evaporation by 38% (from 160 mm to 100 mm) during a 100-day period.

Cotton acreage in Georgia rapidly increased after the successful completion of the boll weevil eradication program. In the early 1990s, cotton acreage in the state increased

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by over four times its acreage in the 1980s (Georgia Agricultural Statistics, 2004). Most of the increases were in the southern portion of the state that lies within the Atlantic coastal plain. While the region normally receives abundant rainfall, it is poorly distributed throughout the year, often leading to drought conditions during the summer growing season. For cotton production in the southeastern U.S., water conservation can mean the difference between a profitable season and an economic loss. Soils in the region can be highly erosive, and the erosion potential is high. Conservation tillage presents a management alternative to bring marginal areas in the region back into production. Because of this, the adoption of conservation tillage has been rapid. Of the cotton production areas in the south, there has been an increase from 6% to 19% from 1990 to 2002 in the cultivated area using strip and no-till farming (CTIC, 2004).

While the potential benefits of conservation tillage are widely recognized, the impact in terms of water conservation and quality varies, depending on numerous factors including soil characteristics, topography, surface cover, pest pressure, agrochemical use, and weather. In some cases, conservation tillage actually leads to increased runoff and agrochemical losses. Soileau et al. (1994) observed greater runoff and sediment losses from three years of conservation tillage on cotton than from a conventional tillage system. Similar findings have been reported for different cropping systems (Lindstrom and Onstad, 1984; Mueller et al., 1984). In many cases the increased runoff observed with the conservation tillage systems has been attributed to increases in soil compaction and bulk density in the upper soil horizons over time (Hussain et al., 1998; Cassel et al., 1995). In some soils, tillage is required in order to alleviate soil compaction caused by consolidation of soil particles by natural processes over time. In part, the soil compaction can be reduced through strip tillage (Raper et al., 1994) and through in-row subsoiling or paratilling (Schwab et al., 2002). Paratilling is a deep tillage technique where the soil below the surface is loosened but the soil is not inverted.

Accurate economic and environmental comparisons require accurate assessments of these tillage systems for different soils and cropping systems. There is a continuing need for systematic research to provide growers with the best available information on benefits of different tillage systems so that they can make informed choices which will enhance profitability and sustainability while minimizing adverse environmental impacts. The objectives of this research were:

- To quantify the impact of strip tillage on surface runoff and shallow subsurface lateral flow from plot-sized fields in the southeastern coastal plain.
- To evaluate seasonal variability of water losses.

Materials and Methods

A 1.9 ha parcel on the University of Georgia Gibbs Farm located in Tift County, Georgia, was selected for the study in late 1998. The site was divided into six 0.2 ha plots with a seventh 0.4 ha plot at the top of the hillslope set aside for companion rainfall simulation studies (fig. 1).

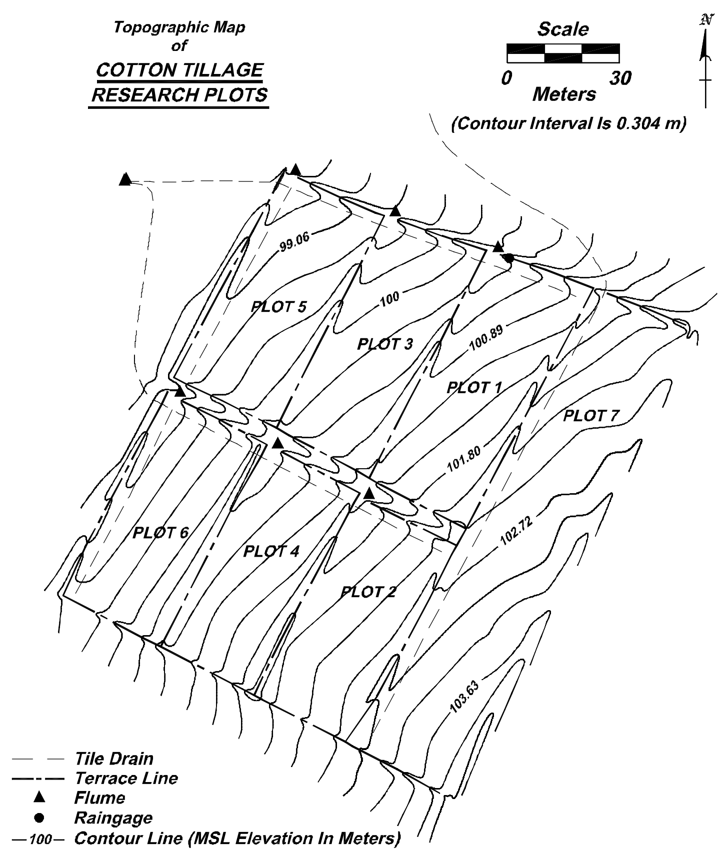

Figure 1. Topographic map of the research plots.

SITE DESCRIPTION

The soil is a Tifton loamy sand with a 3% to 4% slope. The surface soil is well drained, with a sand horizon at the immediate surface extending to approximately 25 cm. The surface horizon is underlain by a loamy sand to a sandy loam, which extends to approximately 50 cm. The subsoil is a sandy clay loam extending to approximately 2 m. Clay fractions increase with depth, varying from 9.5% in the 0-8 cm depth interval to 20% in the 15-30 cm depth interval. The depth to the argillic horizon varies from 25 cm to 50 cm across the plots. Textures of the top 30 cm of the profile vary from 75% to 92% sand. The heavier textured sandy clay loam subsoil in the Tifton soil series has a reduced conductivity and is believed to restrict rooting depth and deep percolation while inducing lateral subsurface flow (Hubbard et al., 1985). Prior research on similar soils indicates that the lateral subsurface flow may be as high as 22% of the annual rainfall (Shirmohammadi et al., 1984). The combined effect of the lateral subsurface flow and percolation to the shallow groundwater is approximately 30% of the annual water budget (Sheridan, 1997).

Plots 1 through 6, with a surface drainage area of approximately 0.2 ha each, were surrounded by 0.6 m high earthen berms. The berms facilitated surface drainage to the northwest corner of each plot (fig. 1). Metal 0.46 m H flumes (Brakensiek et al., 1979) were installed and equipped with Druck pressure transducers and Campbell Scientific data loggers to monitor flow depth. Depth measurements were collected every minute during flow events when the flow through the H flume exceeded a depth of 10 mm. Flow events less than 10 mm in depth were not recorded in order to eliminate erroneous readings due to fluctuations in the transducer reading. The flow depths were converted into flow rates using rating curves for the H flumes (Brakensiek et al., 1979). The transducer readings were checked for accuracy twice a year from 1999 through 2003. Daily and annual flow volumes were calculated using the data. The flow data were screened through inter-plot comparisons and examination of rainfall records. Faulty readings caused by instrument failure and debris in the stilling wells were discarded, and estimates for missing data were derived through comparisons with data from plots with the same tillage. Missing data over the study period were less than 1%.

A 15 cm (i.d.) tile drain was installed at 1.2 m depth across the slope between the lower boundary of plot 7 and the upper berm of plots 1 and 2 (fig. 1). The drain was designed to intercept lateral subsurface flow originating on plot 7 and redirect it away from other plots lower in the slope. To capture lateral subsurface flow originating on the remaining plots, two separate loops of the 15 cm drain tile were installed at 1.2 m depth surrounding plots 1, 3, and 5 and plots 2, 4, and 6 (fig. 1). A 0.24 m HS flume was installed at each tile drain outlet to measure flow and to provide a point for manual water sample collection (fig. 1). Depth measurements were collected every 5 min during any measurable flow. The flow depths were converted into flow rates using rating curves for the flumes (Brakensiek et al., 1979). Readings were checked and adjusted if necessary twice a year from 1999 to 2003.

During periods of tile flow, manual flow measurements were made two times per week by recording the time required to fill 1 L bottles. These flow measurements were compared to the flow measurements collected with the pressure transducer / data logger system. Any periods of questionable flow readings were screened out and replaced with the manual flow measurements. These questionable flow readings were likely caused by faulty instrumentation, debris in the stilling wells, or the somewhat coarse sensitivity of the pressure transducers used for the tile flow measurements (approximately 1 mm). Over the five-year period, less than 1% of the pressure transducer readings were discarded and replaced with the manual measurements.

Precipitation data were collected with a tipping bucket rain gauge located 10 m from plot 1. One-minute precipitation data were collected during rainfall events. Additional climatic information was available from a University of Georgia weather station located on the farm. Runoff data collection, surface and subsurface tile flow, began on 18 March 1999 and ran through 31 December 2003. Precipitation data were collected from 1 January 1999 through 31 December 2003.

MANAGEMENT

Plots 1, 3, 5, and the upslope portion of plot 7 were placed in conventional tillage, while plots 2, 4, 6, and the downslope portion of plot 7 were strip tilled. Cotton was planted in 1999, 2000, 2001, and 2003, and peanuts were planted as a rotation in 2002. The conventionally tilled plots were chisel plowed to 20 cm approximately three weeks before planting, followed by a disk harrowing to 8 cm to form the beds for planting. A subsoiler was used on the strip tilled plots to create a narrow 15 cm strip for planting with tillage to 20 cm. Planting, fertilization, and pesticide treatment on all of the plots were identical. Following cotton harvest, the cotton stalks were mowed to 5 cm. All cotton and peanut residue was left on the soil surface in all plots. All plots were planted with a rye grain cover crop each fall (approximately December 1). The cover crop was killed in the spring prior to planting (approximately April 1). The cover crop on the conventionally tilled plots was killed by disk harrowing, while the cover on the strip tilled plots was killed by spraying with herbicide. Both the conventional and the strip tilled plots were paratilled to approximately 45 cm on 1 November 2002. The paratilling was done to increase the porosity in the strip tilled plots and to relieve compaction. Some soil disturbance also occurred on the strip tilled plots during peanut harvest.

Fertilizer and pesticide applications and crop management practices were in accordance with the University of Georgia recommendations. All plots received 4.5 Mg ha^{-1} of poultry litter each spring, one month prior to planting, except in 2003 when it was determined through soil tests that no pre-plant fertilization was necessary. Irrigation was used to supply plant water needs not met by precipitation. The plots were irrigated with a cable-tow system in 1999. A solid set irrigation system was established in the spring of 2000. During the growing season, farm managers irrigated all plots on an as-needed and equal basis. The cotton and the peanuts were planted in early May and harvested in late September.

RESULTS AND DISCUSSION

PRECIPITATION

Precipitation was below the area long-term yearly average for the first four years of the study and slightly above average for 2003. Precipitation for the five-year period varied from a low of 886 mm in 2001 to a high of 1246 mm in 2003

Table 1. Monthly precipitation totals for the site from 1999 to 2003 and long-term averages for the area.

	1999 (mm)	2000 (mm)	2001 (mm)	2002 (mm)	2003 (mm)	Long-Term Average (mm)[a]
January	112	92	47	89	8	131
February	50	56	13	43	106	124
March	39	131	267	113	242	134
April	28	34	35	80	85	88
May	65	6	39	18	36	87
June	222	50	155	72	154	119
July	89	110	97	196	152	130
August	62	67	61	74	249	106
September	108	281	100	92	71	81
October	46	21	35	130	75	56
November	29	103	19	140	29	82
December	65	90	20	99	42	101
Annual total	915	1042	886	1145	1246	1237

[a] Bosch et al., 1999.

(table 1). Monthly precipitation totals were below normal for January, February, April, May, and December for all five years (fig. 2). March precipitation totals in 2001 and 2003 were nearly two times the long-term average (table 1). The most extreme periods in terms of precipitation excess were observed in September of 2000 (3.5 times the long-term average) and in August of 2003 (2.5 times the long-term average). Similar to the long-term average precipitation patterns, the greatest precipitation generally occurred from June through September.

Surface Runoff

Annual plot runoff, expressed as a percentage of rainfall, varied from 3% to 56% (table 2). In all years, annual surface runoff from the conventionally tilled plots was greater than that from the strip tilled plots (fig. 3). Annual surface runoff totals from the two tillage systems were found to be statistically different at the 95% confidence interval using paired t-tests. Considerable year-to-year variability was observed. During the years of lowest precipitation, from 1999 to 2001, less runoff occurred. The greatest deviations between the two tillage methods were observed in 2001 (19%) and in 2003 (18%) when the greatest precipitation occurred. Over the five-year period, the average surface runoff from the conventionally tilled plots was 29% (288 mm) of the precipitation, while from the strip tilled plots it was 16% (159 mm). This equates to a difference of 129 mm of infiltrated water per year.

Runoff in 2002, the year during which peanuts were grown, varied from the other years during which cotton was grown. During 2002, surface runoff from the strip tilled plots was 46% less than the runoff observed from the conventional plots (270 mm versus 498 mm, table 2). For the other four years, the difference between the runoff observed from the conventionally tilled plots and that observed from the strip tilled plots averaged 33% (148 mm from strip till versus 220 mm from conventional till, table 2). For just the four years during which cotton was grown, the average surface runoff from the conventionally tilled plots was 27% of the precipitation, while it was 13% of the precipitation for the strip tilled plots. The precipitation received in 2002 was 1145 mm, similar in volume to the 1042 mm observed in 2000 (table 1). However, the average runoff from all of the plots was 30% of the precipitation in 2002 versus just 11% in 2000 (table 2). Some of the difference may be explained by differences observed in the seasonal precipitation patterns, primarily differences in the July precipitation (table 1). In 2000, 110 mm was observed in July, whereas 196 mm was

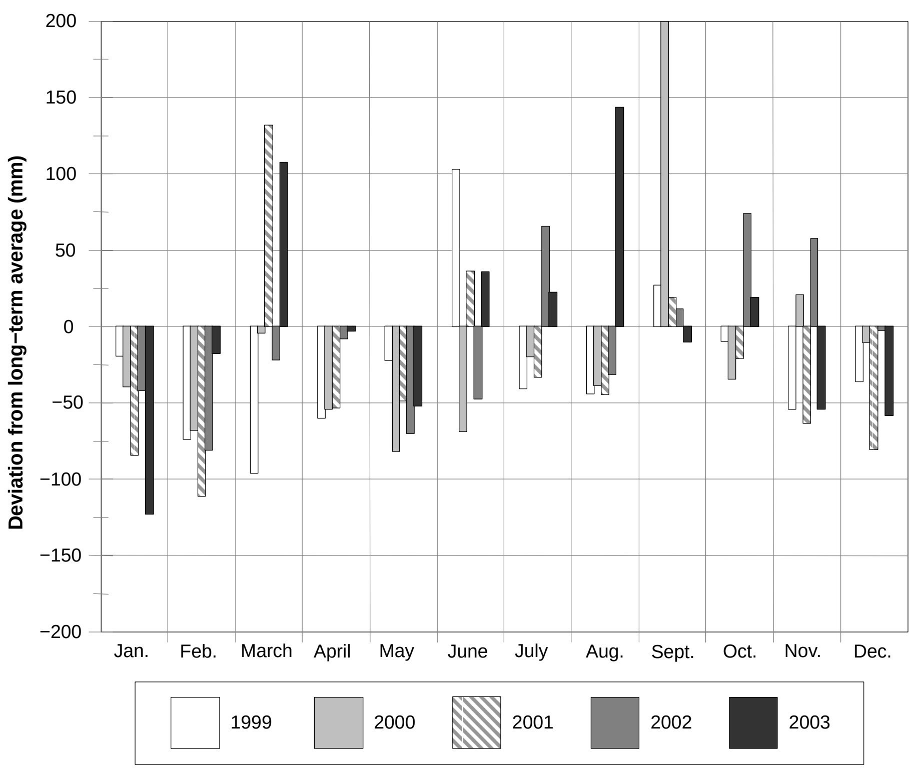

Figure 2. Deviation from long-term average monthly precipitation from 1999 to 2003.

Table 2. Surface runoff totals presented as mm from the plot and as a percentage of the annual precipitation.

	1999		2000		2001		2002[a]		2003		Average	
	mm	%	mm	%	mm	%	mm	%	mm	%	mm	%
Plot 1 (conventional)	88	12	153	15	510	33	701	45	317	56	349	35
Plot 2 (strip)	79	11	36	3	353	7	255	31	231	20	157	16
Plot 3 (conventional)	97	13	125	12	395	19	521	34	120	42	262	26
Plot 4 (strip)	53	7	56	5	305	9	332	27	201	27	165	16
Plot 5 (conventional)	176	24	234	22	283	34	273	25	144	22	253	25
Plot 6 (strip)	109	15	70	7	249	14	224	22	34	18	155	15
Average of conventional till	120	17	171	16	396	29	498	35	194	40	288	29
Average of strip till	80	11	54	5	302	10	270	26	155	22	159	16
Average of all plots	100	14	112	11	349	19	384	30	175	31	224	22

[a] Peanuts were grown in 2002, cotton in all other years.

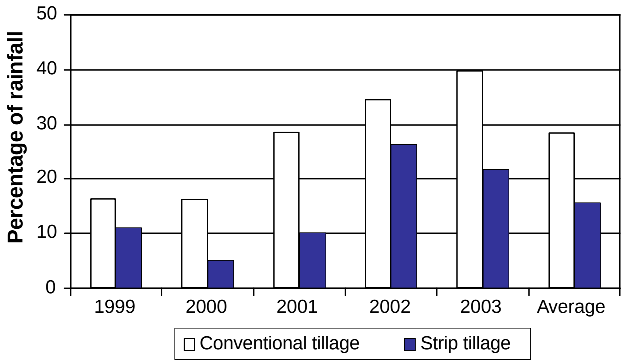

Figure 3. Average surface runoff as a percentage of rainfall for the conventionally tilled and strip tilled plots.

observed in July of 2002. This led to greater observed runoff in July of 2002. However, based on this limited observation, it appears that the potential for surface runoff from peanuts exceeds that for cotton and that the effects of the strip tillage were reduced for the peanut crop.

As illustrated by the runoff data from 2003 for plots 1 and 2, the seasonal pattern of the runoff closely followed the precipitation patterns (fig. 4). The greatest runoff occurred during March and again from June through August. Despite a fairly dense canopy produced by the winter cover crop, the plots still can yield considerable runoff during the heavy rainfall periods typically observed in March. This is likely due to saturated soil-water conditions and a lack of available storage in the soil profile during this period. At this time of the year, when both the conventionally tilled and the strip tilled plots contained a cover crop to adsorb rainfall energy, the runoff patterns from the two tillage methods are similar (fig. 4). From June through August, the crop canopy develops, evapotranspiration increases, and the profile dries out, resulting in a decreased runoff potential (fig. 4). Less similarity is observed between the two different tillage systems during the summer months. Runoff from the strip tilled plots is considerably less than that from the conventionally tilled plots, presumably due to the litter on the soil surface of the strip tilled plots, which reduces rainfall energy and enhances infiltration (table 2).

Seasonal patterns and tillage differences were further examined by dividing the data into four climatic periods: January through March, April through May, June through August, and September through December. These divisions

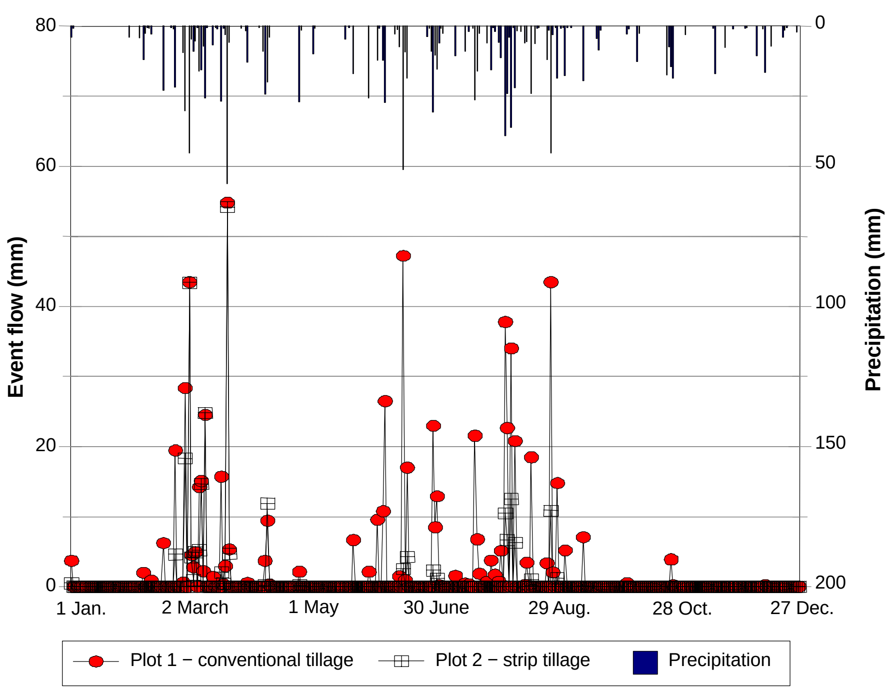

Figure 4. Surface runoff (mm) from plots 1 and 2 in 2003.

were obtained by examining long-term precipitation patterns and finding the periods with the greatest expected precipitation (table 1). Similar climatic periods were used by Bosch et al. (1999), who found that rainfall during the June through August period is typically the greatest, while rainfall during the period from September through December is typically the least. Rainfall from June through August typically occurs in short duration, intense storms, while rainfall from January through March typically occurs in longer duration, less intense storms (Bosch et al., 1999).

Seasonally averaged runoff data, calculated as the average daily runoff from the three conventionally tilled and the three strip tilled plots during these climatic periods, were plotted to compare the two tillage systems (fig. 5). While the conventionally tilled plots generated greater runoff than did the strip tilled plots throughout the entire calendar year, the difference was greater during the months of June through August than it was for the other periods of the year. In addition, for equivalent volume rainfall events, more runoff was generated from the conventionally tilled plots during the summer months than was generated during the spring months (fig. 5).

A linear regression of the average daily runoff volumes as a function of daily precipitation volume was performed for the four climatic periods selected (table 3). Runoff from the conventionally tilled plots was greater than that from the strip tilled plots for all seasons ($\alpha = 0.01$). Surface runoff patterns from the conventionally tilled plots only were statistically different ($\alpha = 0.01$) for each season. Runoff patterns from the strip tilled plots were statistically different ($\alpha = 0.01$) in all seasons except from June to August and from September to December. The greatest runoff potential occurs from the conventionally tilled plots in the period from June to August, when 45% of the precipitation can be expected to run off the plots. In contrast, just 21% of the precipitation can be expected to run off the strip tilled plots during this same period.

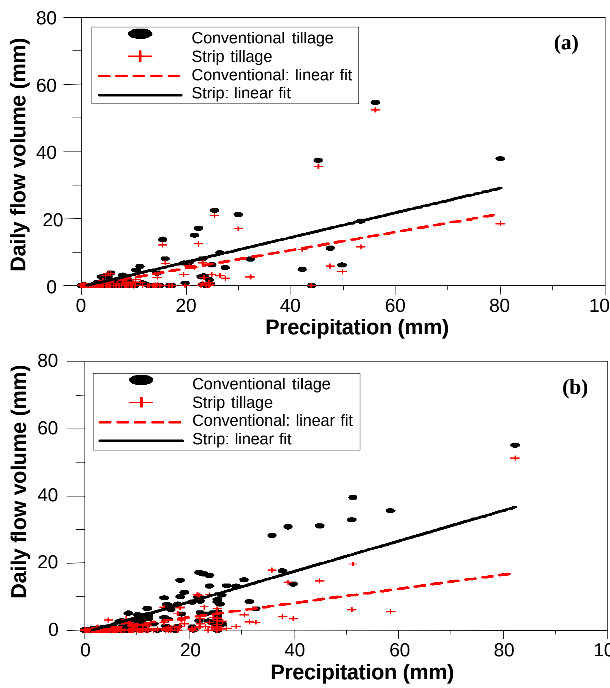

Figure 5. Average daily flow volume as a function of precipitation for the periods from (a) January through March and (b) June through August from the conventionally tilled and strip tilled plots from 1999 through 2003.

Peak surface runoff rates observed from the conventionally tilled plots were up to five times greater than those observed from the strip tilled plots when runoff occurred. During individual runoff events, surface runoff volumes were up to ten times greater from the conventionally tilled plots than from the strip tilled plots.

Lateral Subsurface Flow

Lateral subsurface flow from the strip tilled plots was consistently greater than lateral subsurface flow from the conventionally tilled plots (table 4). The deviation between the two was the greatest in the years with the largest rainfall totals (2002 and 2003). Shallow lateral subsurface losses from the strip tilled plots exceeded those from the conventionally tilled plots by 73%. Over the period of the study, a difference of 346 mm was observed between the lateral subsurface flow from the strip tilled plots versus that from the conventionally tilled plots, or an average of 69 mm per year.

As expected, subsurface tile flow closely followed the periods of greatest precipitation and the lowest evapotranspiration (fig. 6). During the summer, when evapotranspiration rates are the greatest, subsurface losses were reduced due to greater available storage in the soil profile. In general, peak daily outflow from the strip tilled plots exceeded the observed peaks from the conventionally tilled plots, as did the flow durations. All plots were paratilled in 2002. The paratilling was done on all plots prior to receiving 140 mm of rainfall in November 2002. During this month, 153 mm of water drained from the strip tilled plots, while 103 mm drained from the conventionally tilled plots. A portion of this drainage was caused by precipitation received in October 2002, which also received fairly high rainfall (130 mm). The November totals were equivalent to 63% of water drained that year for the strip tilled plots and to 66% of the water drained from the conventionally tilled plots. The combination of the peanut crop and the paratilling appeared to make the strip tilled plots more susceptible to subsurface water losses.

Table 3. Slope of the regression curve for the average daily runoff data (mm) as a function of daily precipitation volume (mm).

	Conventional Tillage		Strip Tillage	
Period	Slope[a]	SEC[b]	Slope[a]	SEC[b]
January-March	0.37 a	0.015	0.27 d	0.014
April-May	0.12 b	0.007	0.05 f	0.007
June-August	0.45 c	0.013	0.21 g	0.011
September-December	0.28 d	0.012	0.20 g	0.011

[a] Slope coefficients were tested for statistical difference; coefficients followed by the same letter are not significantly different at the 99% confidence interval.

[b] SEC = standard error of the coefficient.

Table 4. Shallow lateral subsurface runoff totals presented as a percentage of annual precipitation.

	1999 (%)	2000 (%)	2001 (%)	2002 (%)	2003 (%)	Average (%)
Conventional Tillage	2	6	12	14	12	9
Strip Tillage	6	10	18	21	23	16

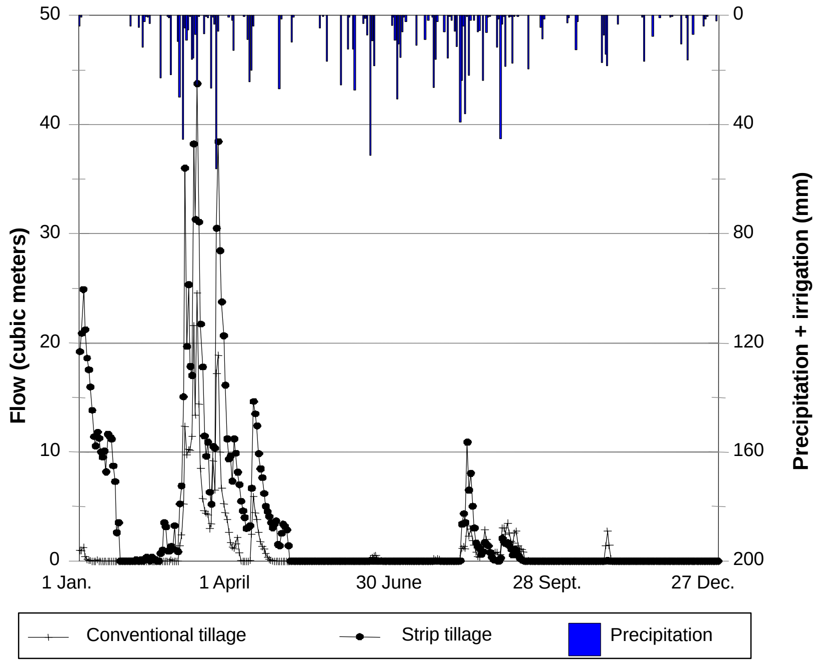

Figure 6. Daily subsurface tile flow volume and daily precipitation observed in 2003 for the conventionally tilled and strip tilled plots.

Water Balance

Over the five-year study period, total water loss from the conventionally tilled plots exceeded total losses from the strip tillage plots by 6% of the precipitation, or 60 mm of the water that the plots received per year (table 5). The net water gain (water not lost in either surface runoff or lateral subsurface flow) was greatest in 2001, when 13% of annual precipitation, or 115 mm, was gained in the soil profile (table 5, fig. 7). The least difference was observed in 2002, the year when peanuts were planted and the plots were paratilled (fig. 7). On the average, over the peak growing season from June to August, there would be a net annual gain of 82 mm in water in the strip tilled plots. Since the profile is rarely saturated during this period, no water loss via lateral subsurface flow would be expected during this time.

Summary and Conclusions

These results indicate that strip till systems can potentially increase plant-available water through enhanced infiltration. The net annual water gain observed in this study averaged 60 mm, or 6% of the observed rainfall. Surface runoff from the strip tilled plots was 81% less than surface runoff from the conventionally tilled plots. However, this increase in available water was offset by increases in lateral subsurface flow from the strip tilled plots. A 73% increase in lateral subsurface flow was observed from the strip tilled plots. The increase in lateral subsurface flow occurred primarily during the months from January through March, when antecedent moisture conditions are typically the greatest and evapotranspiration the least. Lateral subsurface flow losses during the summer growing season were small. During the months from June through August, a net average gain of 82 mm in infiltrated water was observed for the strip tilled plots. This net water gain could potentially reduce irrigation requirements for strip till systems and result in an economic savings. In several years, this difference would have offset a large portion of the irrigation requirements for these plots (table 5).

These results were obtained for the two dominant row crops in the region, cotton and peanuts. Four years of observations on cotton indicated significant reductions in surface runoff and increases in plant-available water. The limited observations made for peanuts indicated there may also be water quantity and quality advantages for this crop. Similar results have been observed in studies on several other agronomic crops, including corn (Romkens et al, 1973) and wheat (Baumhardt and Lascano, 1996). While further

Table 5. Water balance information for the study plots.

Year	Rain (mm)	Irrigation (mm)	Total Water (mm)	Surface Runoff: Conv. Tillage (% of rain)	Surface Runoff: Strip Tillage (% of rain)	Lateral Subsurface Flow: Conv. Tillage (% of rain)	Lateral Subsurface Flow: Strip Tillage (% of rain)	Total Water Loss: Conv. Tillage (% of rain)	Total Water Loss: Strip Tillage (% of rain)
1999[a]	915	67	982	17	11	2	6	19	17
2000	1042	106	1148	16	5	6	10	22	15
2001	886	229	1115	29	10	12	18	41	28
2002	1145	178	1323	35	26	14	21	49	47
2003	1246	25	1271	40	22	12	23	52	45
Five-year average	1047	121	1168	29	16	9	16	38	32

[a] 1999 flow data starts on 18 March 1999; all other years were based on the entire calendar year.

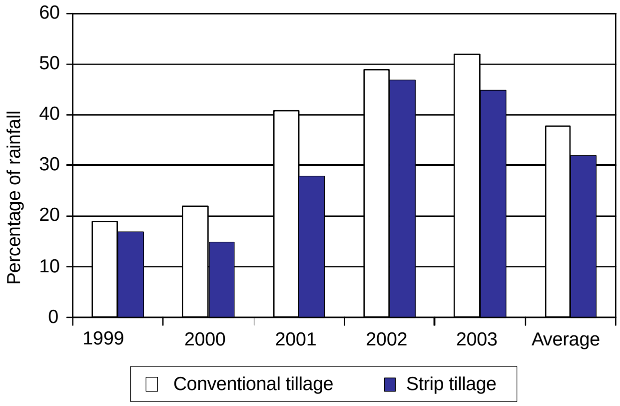

Figure 7. Average annual total water loss (surface and subsurface) as a percentage of annual rainfall for the conventionally tilled and strip tilled plots.

research may be necessary, the hydrologic benefits of strip tillage observed in this study would likely translate to other agronomic crops grown in the region as well, particularly those with greater water requirements.

The reduced surface runoff is expected to have environmental benefits due to a reduced potential for sediment, nutrient, and pesticide losses in surface runoff. In addition, soil carbon is typically increased through strip till and no till systems by leaving greater fractions of plant residue on the soil surface and reducing residue decomposition by minimizing tillage and residue incorporation (Allmaras et al., 2000). Yields from the strip tilled plots were typically similar to those from the conventionally tilled plots (C. Bednarz, 2004, personal communication). Coupled with the possible reduction in irrigation requirements, there may be greater incentive for converting conventional till systems to conservation till systems in the region. However, our results also indicate that conversion to strip till systems increases the probability of chemical losses due to percolation out of the root zone. Increases in infiltration during periods with little or no available water storage in the profile leads to increased water losses out of the bottom of the root zone. Soluble chemicals remaining in the profile following the growing season could be lost during this process. Conversion to strip till systems may require careful management of nitrogen and certain soluble pesticides to prevent these losses.

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References

Allmaras, R. R., H. H. Schomberg, C. L. Douglas Jr., and T. H. Dao. 2000. Soil organic carbon sequestration potential of adopting conservation tillage in U.S. croplands. *J. Soil and Water Conservation* 55(3): 365-373.

Blevins, R. L., W. W. Frye, P. L. Baldwin, and S. D. Roberston. 1990. Tillage effects on sediment and soluble nutrient losses from a Maury silt loam soil. *J. Environ. Quality* 19(4): 683-696.

Baumhardt, R. L., and R. J. Lascano. 1996. Rain infiltration as affected by wheat residue amount and distribution in ridged tillage. *SSSA J.* 60(6): 1908-1913.

Bosch, D. D., J. M. Sheridan, and F. M. Davis. 1999. Rainfall characteristics and spatial correlation for the Georgia coastal plain. *Trans. ASAE* 42(6): 1637-1644.

Brakensiek, D. L., H. B. Osborn, and W. J. Rawls. 1979. *Field Manual for Research in Agricultural Hydrology.* Agricultural Handbook 224. Washington, D.C.: USDA.

Cassel, D. K., C. W. Raczkowski, and H. P. Denton. 1995. Tillage effects on corn production and soil physical conditions. *SSSA J.* 59(5): 1436-1443.

CTIC. 2004. Conservation Technology Information Center. Available at: www.ctic.purdue.edu/.

Galloway, H. M., D. R. Griffith, and J. V. Mannering. 1981. Adaptability of various tillage-planting systems to Indiana soils. Coop. Ext. Serv. Bulletin AY210. West Lafayette, Ind.: Purdue University.

Georgia Agricultural Statistics. 2004. Washington, D.C.: USDA National Agricultural Statistics Service. Available at: www.nass.usda.gov/ga/.

Hubbard, R. K., C. R. Berdanier, H. F. Perkins, and R. A. Leonard. 1985. Characteristics of selected upland soils of the Georgia Coastal Plain. ARS-37. Washington, D.C.: USDA Agricultural Research Service.

Hussain, I., K. R. Olson, and J. Siemens. 1998. Long-term tillage effects on physical properties of eroded soil. *Soil Science* 163(12): 970-981.

Langdale, G. W., A. P. Barnett, R. A. Leonard, and W. G. Fleming. 1979. Reduction of soil erosion by the no-till system in the Southern Piedmont. *Trans. ASAE* 22(1): 82-86, 92.

Lascano, R. J., R. L. Baumhardt, S. K. Hicks, and J. L. Heilman. 1994. Soil and plant water evaporation from strip-tilled cotton: Measurement and simulation. *Agron. J.* 86(3): 987-994.

Lindstrom, M. J., and C. A. Onstad. 1984. Influence of tillage systems on soil physical parameters and infiltration after planting. *J. Soil and Water Conservation* 39(2): 149-152.

Mueller, D. H., R. C. Wendt, and T. C. Daniel. 1984. Soil and water losses as affected by tillage and manure application. *SSSA J.* 48(4): 896-900.

Mutchler, C. K., L. L. McDowell, and J. D. Greer. 1985. Soil loss from cotton with conservation tillage. *Trans. ASAE* 28(1): 160-163.

Raper, R. L., D. W. Reeves, E. C. Burt, and H. A. Torbert. 1994. Conservation tillage and traffic effects on soil condition. *Trans. ASAE* 37(3): 763-768.

Romkens, M. J. M., D. W. Nelson, and J. V. Mannering. 1973. Nitrogen and phosphorous composition of surface runoff as affected by tillage method. *J. Environ. Quality* 2(2): 292-295.

Schwab, E. B., D. W. Reeves, C. H. Burmester, and R. L. Raper. 2002. Conservation tillage systems for cotton in the Tennessee Valley. *SSSA J.* 66(3): 569-577.

Sheridan, J. M. 1997. Rainfall-streamflow relations for coastal plain watersheds. *Applied Eng. in Agric*. 13(3): 333-344.

Shirmohammadi, A., W. G. Knisel, and J. M. Sheridan. 1984. An approximate method for partitioning daily streamflow data. *J. Hydrology* 74(3-4): 335-354.

Soileau, J. M., J. T. Touchton, B. F. Hajek, and K. H. Yoo. 1994. Sediment, nitrogen, and phosphorus runoff with conventional- and conservation-tillage cotton in a small watershed. *J. Soil and Water Cons.* 49(1): 82-89.

Triplett, G. B., Jr., D. M. Van Doren, Jr., and B. L. Schmidt. 1968. Effect of corn (*Zea mays* L.) stover mulch on no-tillage corn yield and water infiltration. *Agron. J.* 60(1): 236-239.

Yoo, K. H., and J. T. Touchton. 1988. Surface runoff and sediment yield from various tillage systems of cotton. *Trans. ASAE* 31(4): 1154-1158.