

DRAINAGE CHARACTERISTICS OF A SOUTHERN PIEDMONT SOIL FOLLOWING SIX YEARS OF CONVENTIONALLY TILLED OR NO-TILL CROPPING SYSTEMS

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ABSTRACT. *Site-specific soil water movement research is needed in order to fully understand chemical movement into subsurface water bodies. Water flow paths depend on soil, climate, topography, and management practices. In this study, we evaluated drainage and drainage hydrographs over a 12-month period from a Southern Piedmont Cecil sandy loam following a combined six years of corn/rye and cotton/rye cropping system under no-till or conventionally tilled treatments. No-till exhibited significantly higher mean and peak drainage rates, drainage in the rising and recession limbs of hydrographs as well as total drainage, and total drainage time, compared to conventional tillage treatments ($P < 0.05$). The recession time constant of the hydrographs, an index of the structural macropore development in the soil above the water table, was significantly less in the no-till than conventional tillage, which indicated that no-till had less tortuous water flow paths. No-till, therefore, enhanced water movement into deeper profiles in a Cecil sandy loam. Additional longer-period data would be useful to further evaluate temporal, environmental, and management factors that affect drainage under no-till. A study of the implications of more drainage in no-till for nutrient and chemical losses in these systems is pending.*

Keywords. *Drainage, Hydrograph, Tillage, No-till, Water quality, Cecil.*

Intensive agricultural land use has led to impairment of water quality in many watersheds (NRC, 1993). The underlying mechanisms for impairment are many and varied. Water movement and chemical transport are associated with a high degree of spatial and temporal variability, making scientific interpretation and characterization difficult (Gish et al., 2001). Modeling solutes under field conditions is complicated due to the presence of preferential flow paths and the input data needed to describe these paths (Steenhuis et al., 2001).

The physical properties of soils play an important role in flow and transport processes. Tillage type has a profound effect on surface and subsurface soil properties that influence water and chemical movement routes and rates, with potential impact on water quality. Tillage effects on soil characteristics are site specific (Shafiq et al., 1994). Hubbard et al. (1994) stated that it was difficult to make generaliza-

tions about tillage effects on soil bulk density, saturated hydraulic conductivity, or moisture retention because the response of the soil to tillage system depended on particle size distribution, climate, and cropping sequence. It is necessary to develop a knowledge base on how tillage affects water movement under particular sets of soil, topography, climate, and management conditions in order to predict potential for chemical transport.

The Southern Piedmont occupies 15.3×10^6 ha in the southeastern U.S. Cecil and closely related soil series occupy two-thirds of the 14.1×10^6 ha that is available for cropping (Langdale et al., 1992). Over a century and half of intensive conventional-tillage cotton, corn, and soybeans production, aided by the highly intensive summer storms, rolling topography, and inherently erodible soils, led to severe erosion problems (Bruce and Langdale, 1996). Farming systems gradually changed in response to this degradation of farming land so that by 1984, 11.7×10^6 ha were devoted to pastures and forests, while row cropping continued on approximately 2.4×10^6 ha (Langdale et al., 1992).

Alternative tillage practices have been explored and tested since the early 1970s throughout the U.S. to ameliorate on-going degradation of croplands. As a result, conservation tillage technology has now become an important component of the farming system. According to the Conservation Technology Information Center (CTIC, 2000), about 20% of the cotton and 58% of the soybeans in the Southeast are now under no-till, a form of conservation tillage. Approximately 37% of crops were planted with conservation tillage in 2000 nationally.

Field studies often provide wide-ranging estimates of effects of contrasting tillage practices on nutrient leaching losses. Much published research has come from the Midwest (Baker, 1992; Gilliam and Hoyt, 1987). Only limited data are

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available for the Southeast. In a review of the impact of conservation tillage on pesticide runoff, Fawcett et al. (1994) found that conservation tillage systems have often but not always increased infiltration and reduced runoff. They also noted that the length of the conservation tillage period affected the establishment of macropores and changes in soil structure and may, therefore, strongly affect water and chemical movement. More rapid leaching of solutes in no-till compared to conventional tillage has been found in some soils (Andreini and Steenhuis, 1990; Dalal, 1989), but other studies have found the reverse (Kanwar, 1991; Shipitalo and Edwards 1993). McCracken et al. (1995) found that $\text{NO}_3\text{-N}$ leaching in a Cecil sandy loam tended to be greater under no-till compared to conventional tillage only when rainfall occurred soon after fertilizer application.

Understanding surface and subsurface hydrologic processes of soils under contrasting tillage practices is one starting point toward understanding the larger issue of the effects of no-till agriculture on water quality. The objective of this article is to compare subsurface drainage from a Southern Piedmont Cecil sandy loam following a combined six years of conventionally tilled and no-till corn/rye and cotton/rye cropping systems.

MATERIALS AND METHODS

EXPERIMENTAL SITE AND SOIL

The experiment was conducted at the USDA-ARS, J. Phil Campbell, Sr., Natural Resource Conservation Center, Watkinsville, Georgia (33° 54' N and 83° 24' W). The site is located on nearly level (0% to 2% slope) Cecil sandy loam (fine, kaolinitic, thermic Typic Kanhapludult) and consists of 12 instrumented, subsurface-drained plots, each measuring 10 m wide \times 30 m long. Each plot is underlain by five 30 m long drain lines spaced 2.5 m apart. Drain lines consist of 10 cm diameter, flexible, slotted PVC pipes installed on a 1% grade. At the lower edge, the depth of each line is 1 m from the soil surface. To exclude subsurface lateral flow from adjacent areas, plot borders are enclosed with polyethylene sheeting that extends from the soil surface to the depth of the drain line. A non-slotted PVC pipe conveys drainage from the five slotted pipes to a tipping bucket for measurement. The subsurface drainage system was originally designed to remove a 25-year, one-day (24 hour) frequency rainfall with a 95% probability of occurrence (Snyder and Thomas, 1983) of between 9 and 12 cm, within a day. This led to the narrow spacing of 2.5 m (J. E. Box, Jr., personal communication). Warm temperate climate, long growing seasons, and ample rainfall are typical characteristics for the area. Some pertinent climate parameters, as given by Hendrickson et al. (1963) and Bruce and Langdale (1996), are as follows. Average daily temperatures range from 23.9°C to 26.7°C in the summer (June–August) and from 4.4°C to 7.2°C in winter (December–February). Mean annual temperature is 17°C. Average frost-free growing season is from 200 to 250 days. Mean annual rainfall is 1252 mm. Mean monthly rainfall is highest (115 to 140 mm) during the winter months, and least (77 to 86 mm) in the fall.

The Cecil soil series generally consists of deep, well drained, moderately permeable soils. These soils are deeply weathered and have largely developed in residuum from underlying schist, gneiss, and granite. The profile is general-

ly acidic, and pH decreases with depth. The soil at the research site was described by Bruce et al. (1983) in a pit within 50 m of the plots. They described a brown sandy loam Ap horizon about 20 cm thick, a red sandy clay loam to clay loam BA horizon about 5 cm thick, and a red clay Bt1 horizon about 75 cm thick, followed by a red clay Bt2 horizon and a loam to clay loam BC horizon, both about 30 cm thick. The C horizon is a loamy saprolite. Saturated hydraulic conductivities decreased from 18 to 20 cm h^{-1} in the Ap to 0.2 cm h^{-1} just below the Bt1. As a result, a perched water table can be present at the lower Bt1 during rainfall events and cause pipe drain flow.

TILLAGE AND FERTILIZER TREATMENTS

The experiment had multiple objectives and was laid out as a split plot design in randomized blocks with three replications. The main plot treatment was tillage [conventional tillage (CT) or no-till (NT)], and the sub-plot treatment was type of nitrogen fertilizer [ammonium nitrate or poultry litter]. The CT consisted of a 30 cm deep chisel plowing, to break possible hard pans, followed by a 1 to 2 passes of disc harrowing to a depth 20 cm, and a subsequent disking to 8 cm to smooth the seed bed. The only tillage operation in the NT was the use of a coulter disk for planting. Tillage treatments had been in place since the spring of 1991. We focus on tillage effects only in this article.

CROPPING SYSTEM AND OPERATION

The cropping system that started in the spring of 1994 consisted of cotton (May–November) followed by rye grown as a cover crop (November–May). Cultivars were Hy Gainer for rye and Stoneville 474 for cotton. Rye was planted in mid-November and remained under 0.3 m tall until March. There was accelerated growth after that, and rye height reached 1.2 to 1.5 m in early May. Rye was chemically killed two weeks before planting of cotton. Planting date for cotton during this research was 14 May 1997, and harvesting was on 4 November 1997. From spring of 1991 to spring of 1994, corn was grown with or without a winter rye cover crop, with the same tillage treatments (McCracken et al., 1995).

RECESSION TIME CONSTANT

Youngs (1985) and Dougherty et al. (1995) presented a theoretical background for analysis of drainage recession hydrographs in terms of parameters that include the drainable porosity, or specific yield, and how this might be used practically to distinguish soil structures produced as a result of different soil management treatments, such as tillage.

The equation of Dougherty et al. (1995) has the form:

$$\frac{aK(t-t_0)}{SD} = \ln\left(\frac{Q_0}{Q}\right) \quad (1)$$

where Q_0 is the drain flow rate at time t_0 , with time zero taken as the time at peak drainage rate. The quantity SD/aK , (the reciprocal of that in eq. 1), which has dimensions of time, can be regarded as a “recession time constant” (RTC). It is defined by the hydraulic conductivity (K) below the water table, the specific yield (S), and the drain half spacing (D). The specific yield depends on the water retention properties of the soil above the water table, and hence on the soil structure. The RTC is a measure of how quickly the water table falls from a given height for a given drain spacing. A

large RTC indicates a tortuous flow path with a large number of fine pores that release water slowly, while a small RTC indicates more water release through larger and more connected pores, a situation that no-till promotes. Dougherty et al. (1995) noted that the RTC could be used to characterize the effect on soil structure of tillage treatments, if the drain geometry is the same for each treatment and there is no difference in subsoil conditions. These situations are true for this study. The RTC was obtained from the slope of the regression line of the plot of $\ln(Q)$ against time of the recession limb of the hydrograph, with time 0 taken as the time at peak drainage rate.

DATA ACQUISITION AND ANALYSIS

Drainage data for this article cover the period 3 May 1997 to 9 May 1998. Drainage was measured with tipping buckets calibrated to tip every 3 L of flow. Periodic checks were made on this calibration and estimated drainage was adjusted accordingly, which was not often. The buckets were recalibrated to 3 L at the end of each season. An encapsulated reed switch arrangement attached to the buckets and integrated with a CR10X (Campbell Scientific Inc., Logan, Utah) recorded total drainage tips every hour at each plot. Rainfall, at 15-minute intervals, was acquired from a Georgia Automated Environmental Monitoring Network weather station (Hoogenboom, 1996) located at the research site. Analysis was based on unit time (1 hour) both for rainfall and drainage. Exceedance probabilities of various parameters for rainfall and drainage hydrographs were established by first developing frequency distributions for each parameter. Box plots were generated for various drainage hydrograph parameters using SigmaPlot 5.0 (SPSS Inc. Chicago, Ill.). Excel (Microsoft Corporation, Redmond, Wash.) was used to generate descriptive statistics of hydrograph parameters and to determine each RTC by regression of observed $\ln(Q)$ against time. The reciprocal of the slope of the regression line gives the RTC.

There were 30 drainage events, each with one or more closely following drainage hydrographs as a result of varying rainfall intensities during the event. A total of 41 drainage hydrographs were deciphered this way. For some events, hydrographs overlapped so closely that it was not possible to make a distinct separation. Consequently, in analyzing the various drainage parameters, 30 to 41 events of that parameter were considered appropriate. For example, we chose to consider the 30 events with combined hydrographs for total drainage. In analyzing each hydrograph in terms of its components, we used up to 41 hydrographs. The rainfall analysis was also based on the 41 events that led to these 41 hydrographs. We used only 31 of the 41 hydrographs for RTC analysis because in the others it was either difficult to assign the starting point (peaks of hydrograph had long curvatures), or the tail end was truncated too much by the following hydrograph.

Parametric significance tests for this kind of data set are not appropriate (Dougherty et al., 1995). The hydrographs cannot be considered as replicates because the rainfall amounts, durations, and intensities that produce drainage are different. Data were, therefore, analyzed using the Wilcoxon option of the non-parametric procedure of SAS (SAS, 1998). All significant differences are reported at $P \leq 0.05$.

RESULTS

RAINFALL

There were 67 rainfall events of 5 mm or above during the study period. Thirty of the rainfall events led to drainage. Rainfall was considered as one event if drainage continued between the rain pulses. Figure 1 shows exceedance probabilities for rainfall amount, duration, and average and maximum intensities. The 25, 50, and 75 percentile values are indicated by the intersecting horizontal and vertical dashed lines. The middle half of the rainfall events that led to drainage was between 22 and 52 mm (fig. 1A). Rainfall duration equaled or exceeded 7 hr in 75% and 27 hr in 25% of the events (fig. 1B). Average rainfall intensity varied between 1.5 and 4 mm hr⁻¹ in the middle half of the events (fig. 1C). Maximum intensity exceeded 7.5 mm hr⁻¹ in 75% of events and about 15 mm hr⁻¹ in 25% of events. Four of the 12 months of the study period were the 5th or less wettest months over a 60-year period. The ranking for another four of the 12 months was from the 12th to the 14th wettest. Therefore, the drainage system had to handle some above-normal rainfall events during the study period.

DRAINAGE EVENTS

The observed drainage patterns were grouped into five general types, as shown in figure 2. Nine events were of type 1, eight of type 2, four of type 3, three of type 4, and six of type 5. In type 1, there was one drainage hydrograph in response to one rain event or pulse. There was also one drainage hydrograph in type 2, but in response to a second pulse of rain only. In type 3, there were two drainage hydrographs in response to two rain pulses following each other, but the first hydrograph was dominant. There were also two drainage hydrographs in type 4 in response to two rain pulses following each other, but the second hydrograph was dominant. The hydrographs overlapped in some cases. Type 5 showed three or more overlapping hydrographs in response to a pulsating but long-lasting rain event. The peak flows in one or more of these type 5 hydrographs were similar between CT and NT.

Figures 3 to 6 show box plots for various parameters of these drainage events and hydrographs. The "whiskers" show the 10th and 90th percentiles. The boxes bound the 25th and 75th percentiles. The means are shown as dashed lines and the medians as solid lines. Values outside this range are shown as dots. Figure 7 shows the exceedance probabilities of the ratio NT/CT for various parameters of these drainage events and hydrographs.

DRAINAGE AMOUNT AND DURATION FOR RISING AND RECESSON LIMBS OF HYDROGRAPHS

Forty-one hydrographs were analyzed for drainage amount and duration of the rising and recession limbs. Figures 3A and 3B show drainage amount, and figures 4A and 4B show drainage duration. The rising and recession limb drainage amounts were highly skewed in both CT and NT. But skewness in CT was 1.5 to 2 times more than in NT, and kurtosis was 3 to 4 times more. Drainage amount was significantly higher from NT than from CT in both the rising and recession limbs. The mean of the ratio NT/CT for drainage amount was 3.4 for the rising limb and 2.7 for the recession limb. The ratio was greater than 1 in about 85% of the cases (fig. 7A).

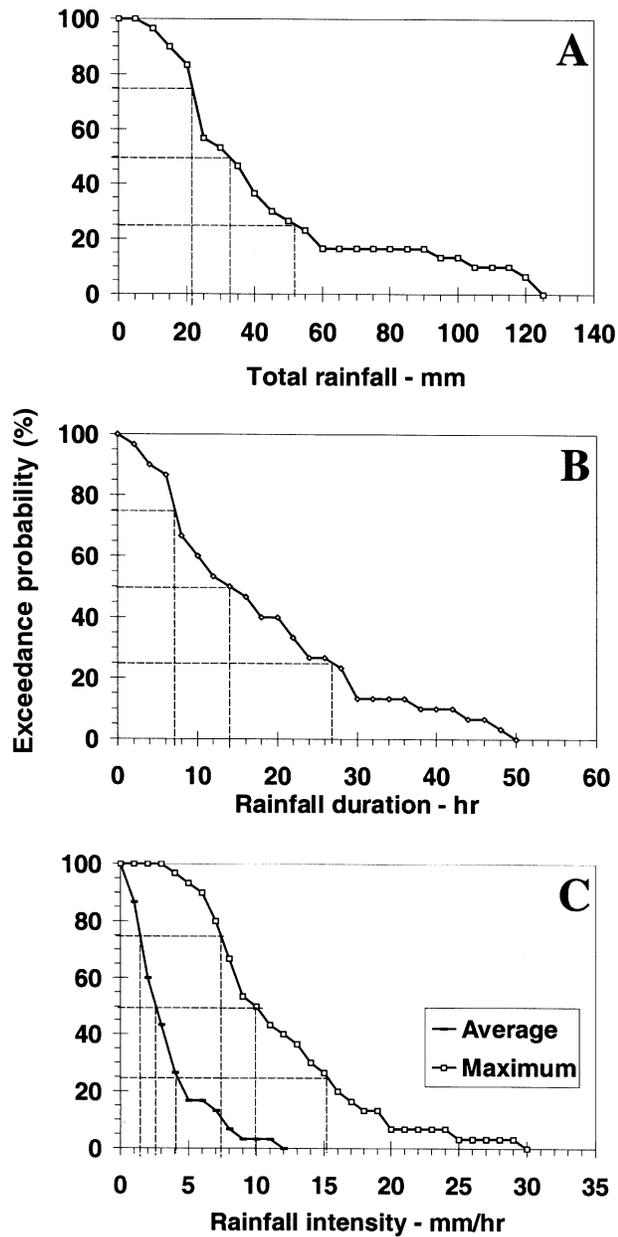


Figure 1. Exceedance probability for rainfall events: (A) total rainfall, (B) rainfall duration, and (C) rainfall intensity. The 25%, 50%, and 75% probabilities are indicated by intersecting horizontal and vertical dotted lines.

The duration of drainage for the rising and recession limbs (fig. 4A and 4B) was not statistically different between NT and CT. The mean for the rising limb was 4.5 hr for both NT and CT. The median for the ratio NT/CT was 1.0 (fig. 7B). For the recession limb, the means were 25.5 and 26.7 hr for CT and NT, respectively. The ratio NT/CT for time to recess was greater than 1 in about 85% of the cases (fig. 7B), which means that NT took a little longer to recess, although this did not prove significant. The unit hour used for measurement and analysis may have been too coarse to bring out differences. The data were less skewed than for drainage amount, and both skewness and kurtosis were similar between CT and NT.

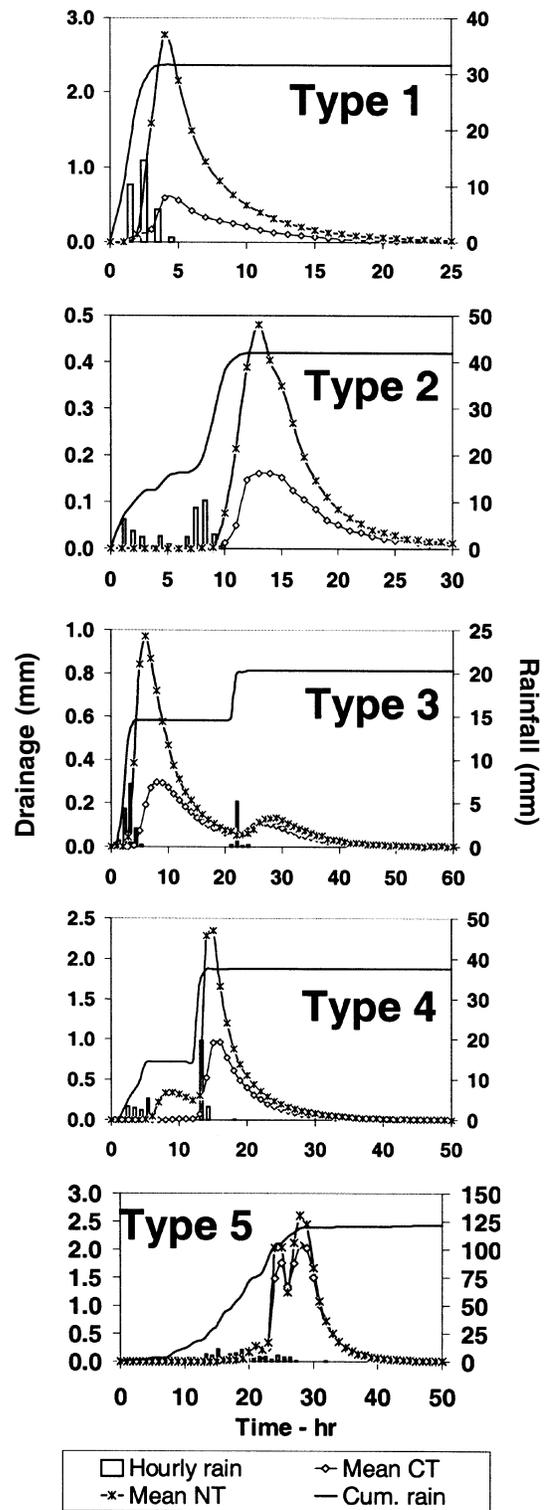


Figure 2. The five types of classification for drainage hydrographs.

TOTAL DRAINAGE AMOUNT AND DURATION

Total drainage amount and duration were analyzed for the 30 events with one or more hydrographs each. Results are shown in figures 3C and 4C. NT had significantly higher total drainage than CT. The mean was 7.6 mm for CT and 15.0 mm for NT. The ratio NT/CT was greater than 1.0 in about 90%

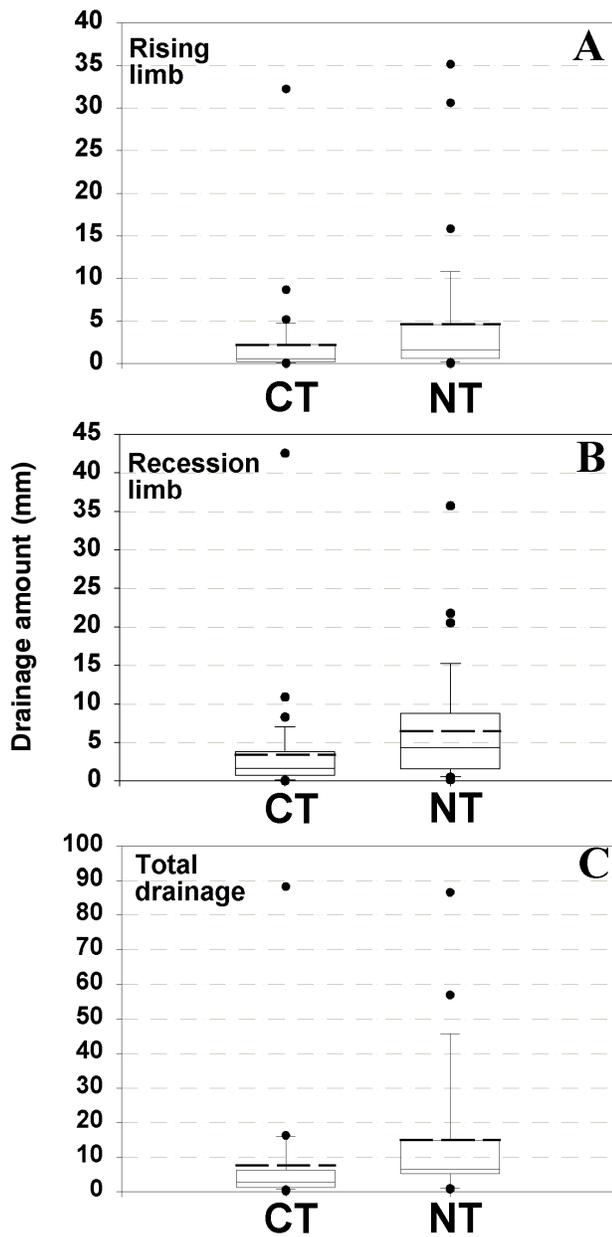


Figure 3. Box plot for conventionally tilled (CT) and no-till (NT) drainage amount: (A) for the rising limb of hydrographs, (B) for recession limb of hydrographs, and (C) for total drainage. The “whiskers” show the 10th and 90th percentiles. The boxes bound the 25th and 75th percentiles. The means are shown as dashed lines and the medians as solid lines. Values outside this range are shown as dots.

of the events (fig. 7A), and the mean of the ratio was 2.8. On average, 12.5% of the total rainfall was partitioned into drainage in CT, while 27.6 % was partitioned in NT (fig. 5A). The ratio NT/CT for partitioning of rain into drainage was greater than 1.0 in about 90% of the events (fig. 7C). There was one extreme drainage event of about 87 mm (fig. 3C) from both CT and NT following a 29-hour rainfall event of 123 mm, the highest rainfall during the study period. Skewness and kurtosis were similar to the rising and recession limb drainage.

Total drainage time (fig. 4C) varied from 4.2 to 80.5 hr in CT and from 16.5 to 87.4 hr in NT. The mean total time was 38.2 hr for CT and 44.1 hr for NT. In 85% of the events, the

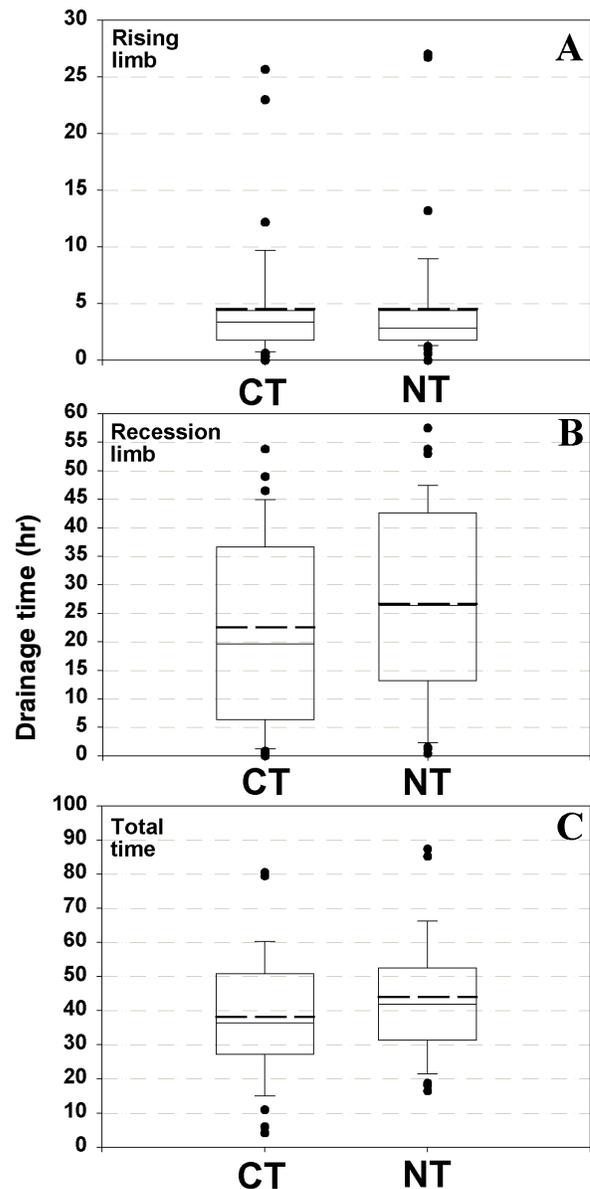


Figure 4. Box plot for CT and NT drainage time: (A) for the rising limb of hydrographs, (B) for recession limb of the hydrographs, and (C) for total drainage. The “whiskers” show the 10th and 90th percentiles. The boxes bound the 25th and 75th percentiles. The means are shown as dashed lines and the medians as solid lines. Values outside this range are shown as dots.

ratio NT/CT for total drainage time was greater than 1.0 (fig. 7B). The difference between CT and NT was significant ($P = 0.05$). Skewness and kurtosis were similar to the rising and recession limb drainage time.

MEAN AND PEAK DRAINAGE RATES

Mean and peak drainage rates are shown in figures 5B and 5C, and the ratio NT/CT is shown in figure 7C. Mean and peak drainage rates were significantly higher from NT (0.4 and 1.3 mm hr^{-1}) than from CT (0.2 and 0.6 mm hr^{-1}). The ratio NT/CT was greater than 1.0 for about 85% of the events considered. Skewness was 2.6 and 2.1 and kurtosis was 6.0 and 4.3 for mean drainage rate for CT and NT, respectively. The equivalent values for peak drainage rate were, respectively, 4.6, 1.9, 24.1, and 4.9. The middle half of the data had

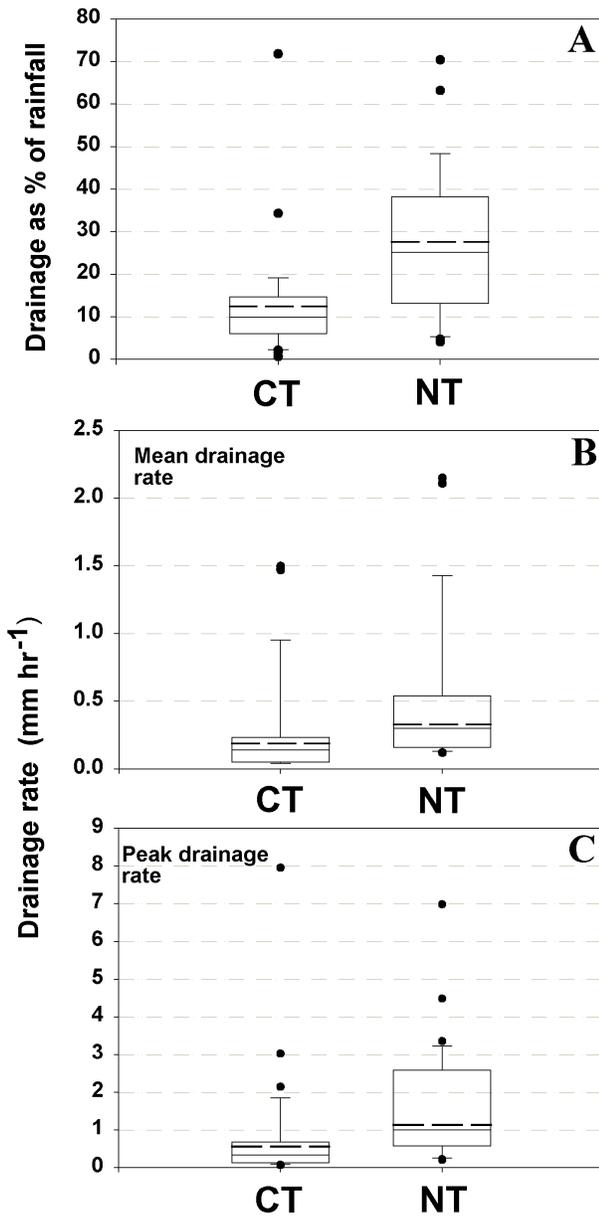


Figure 5. Box plot for CT and NT total drainage as percent of: (A) total rainfall, (B) mean drainage rate, and (C) peak drainage rate. The “whiskers” show the 10th and 90th percentiles. The boxes bound the 25th and 75th percentiles. The means are shown as dashed lines and the medians as solid lines. Values outside this range are shown as dots.

a narrower range in CT than in NT but was centered toward the low end of the drainage rate scale for both tillage systems.

TIME FOR DRAINAGE TO START, AND BETWEEN PEAK RAINFALL AND DRAINAGE RATES

The time for drainage to start following the start of rainfall (fig. 6A) varied from 1 to 35 hours. The mean was 8.5 hr for CT and 8.0 hr for NT. The time ratio NT/CT was less than 1.0 for about 65% of the events (fig. 7D), which means that NT tended to start drainage slightly ahead of CT. However, these differences were not significant.

Peak rainfall rates were often followed by peak drainage rates in both CT and NT. The mean time was 5.6 hr for CT and 4.8 hr for NT (fig. 6B). Although means were not statistically different, the time was often shorter in NT (faster

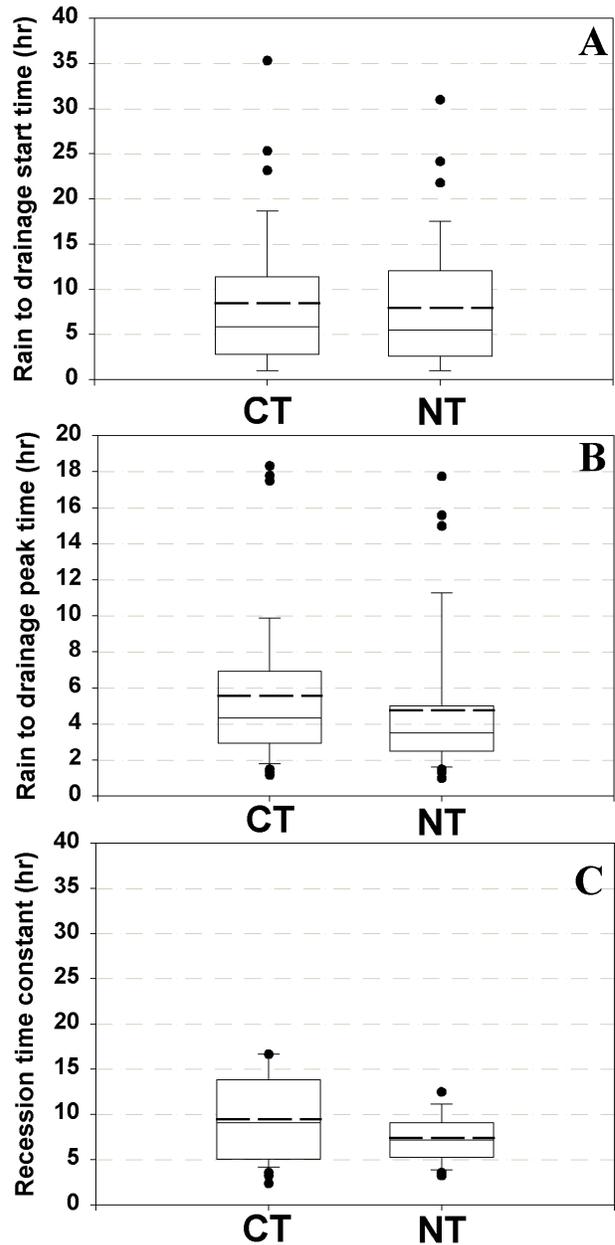


Figure 6. Box plot for CT and NT of: (A) time between start of rain and drainage, (B) time between rain and drainage peak rates, and (C) recession time constant. The “whiskers” show the 10th and 90th percentiles. The boxes bound the 25th and 75th percentiles. The means are shown as dashed lines and the medians as solid lines. Values outside this range are shown as dots.

response; fig. 7D). Statistical differences might have surfaced if the time of measurement and analysis was less than one hour.

RECESSION TIME CONSTANT

We evaluated 31 hydrographs for the recession time constant. As already pointed out, not all hydrographs are suitable for such analysis (or many of the other analyses) because of too much overlap of two or more of the hydrographs. The mean coefficient of determination (R^2) for the regression of $\ln(Q)$ against time was about 0.97. The reciprocal of the slope of the regression line gives the RTC. The mean RTC was 9.49 for CT and 7.41 for NT (fig. 6C).

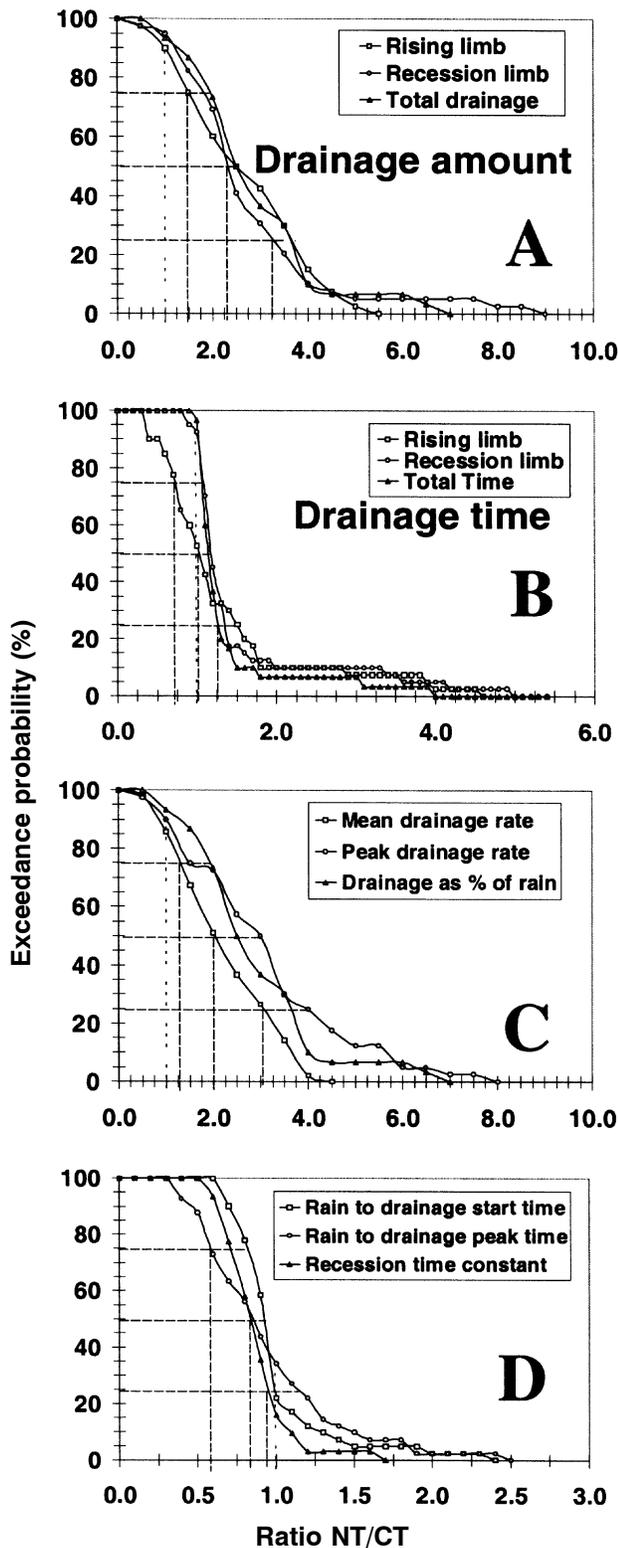


Figure 7. Exceedance probability for the ratio NT/CT for various drainage parameters: (A) drainage amount, (B) drainage time, (C) mean and peak drainage rates, and percentage partitioning of rain to drainage, and (D) time between start of rain and drainage, time between peak rain and drainage rates, and recession time constant.

These differences are considered significant ($P = 0.05$). The standard error was 0.83 for CT and 0.46 for NT. The RTC ratio NT/CT was less than 1.0 in about 80% of the events

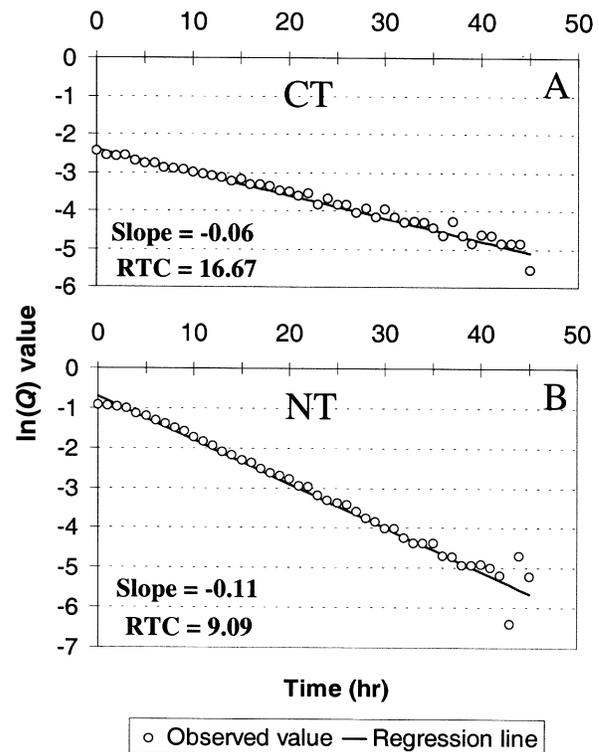


Figure 8. Graph of $\ln(Q)$ vs. time for: (A) conventional tillage (CT), and (B) no-till (NT) for the drainage event of 19 to 21 January 1998. Q is mean hourly drainage (mm); RTC is recession time constant.

analyzed (fig. 7D), which indicates generally a faster drainage response of NT, as expected. The middle half of the data were between 5 and 9 for NT and between 5 and 14 for CT. Figure 8 shows an example of the $\ln(Q)$ vs. time relationship and the regression line used to calculate the RTC. The example is for the 17th drainage event, which occurred between 19 and 21 January 1998.

DISCUSSION

HYDROGRAPHS

Hydrographs are common tools for analysis of surface water flow, but discussion of the analysis and use of drain hydrographs is rather limited in the literature. Drain hydrographs help to visualize the characteristic of the drainage system as well as the dynamics of water in the unsaturated profile above the water table, which can be affected by agricultural management systems. The five types of drain hydrographs presented in figure 2 give a good visual representation of the consequence of CT and NT on drainage. The area between the NT and CT graphs represents the extra drainage from NT. Except in type 5 and the second hydrograph of type 3, this area appears to equal or exceed the area under the CT graph. The NT graphs are more pointed and have higher peaks, which indicates faster and greater response to rainfall. In some instances, drainage occurred from NT but not from CT (type 4, first hydrograph). The closeness of the hydrographs in type 5 is probably an indication that, under long sustained rainfall, the soil profile in both CT and NT gets saturated (excess surface water running off) to the extent that the hydraulic head driving flow into the drains becomes about the same. It also indicates that

the drainage system, which is similar in both CT and NT, appears to handle the high flows equally well in both. In all the other types, where peak flows are two or more times higher in NT than CT, the hydraulic head in CT, it appears, stays below that of NT, both because less water enters and moves through the soil in CT and because the drainage system is able to remove the incoming flow without the build up of head. Closely spaced drains are designed to react to rainfall within hours. For wider-spaced drains, there can be a longer time before drains start flowing after rain. This will change the dynamics of water flow in the profile and the nature of the hydrographs.

As stated earlier, the drainage system in this research was narrowly spaced to remove water fairly fast, even prior to 1991 when the tillage treatments were started. Radcliffe et al. (1996) noted that an identical set up adjacent to these plots was designed closer than normal to minimize travel time in the saturated zone. However, Radcliffe et al. (1996) also stated that, in the adjacent subsurface-drained plots, the soil above the drain pipes was compacted during backfilling to address the concern that this disturbed area could act as preferential flow path. We believe the same occurred in these plots. Three rainfall events matched the design rainfall amount during the 12 months period of this study: 10.4 cm (25 September 1997), 12.1 cm (26 October 1997), and 9.2 cm (24 December 1997).

HYDROGRAPH ANALYSIS

The analysis of the hydrographs indicated that NT had significantly higher mean and peak drainage rates, drainage in the rising and recession limb, and overall total drainage than CT. Drainage lasted longer in NT, too. Since the hydraulic head above the drain pipes is a driving force for pipe drainage flow, NT had more water moving to the water table through the soil surface and subsurface. We hypothesize that this was the result of a higher infiltration rate in NT, because of greater residue at the soil surface combined with macropore flow, as many studies indicate. In a long-term tillage experiment near Griffin, Georgia, with the same soil series as these experiment sites, Radcliffe et al. (1988) found higher infiltration in no-till. Removing the top 0.2 cm of litter, organic matter, and soil from the no-till plots sharply reduced the infiltration rate. Adding straw mulch to the conventional tillage plots increased the infiltration rate. Radcliffe et al. (1988) concluded that most of the difference in infiltration between no-till and conventional tillage in short-term rainfall events was because of surface crusting. At the same site, Hargrove et al. (1988) showed that rooting was more extensive in NT plots than in CT plots, despite the greater compaction under the soil surface. This indicated that macropores penetrated the compacted zone in no-till and provided a path for root growth. Such macropores could also convey water to the lower soil profile. Later, Golabi et al. (1995) looked for evidence of macropores in these same Griffin plots and found that no-till had 40% more macropores than conventional tillage. They also found that 1% to 15% of the cross-sectional area of the no-till was stained with macropore flow.

RECESSION TIME CONSTANT

The recession time constant varied from 2.4 to 16.7 in CT and from 3.2 to 12.5 in NT. Dougherty et al. (1995) reported

RTC values in the range 3.8 to 20.5 from 800 m² plots in clay soils with mole drains at 0.5 depth and 3 m spacing under non-inverting tine tillage. The RTC values were higher and ranged from 19.7 to 42.8 where tractor-drawn plowing that inverted the soil to 0.2 m depth was done. Under this latter condition, soil compaction and smearing of the soil at the base of the plow layer restricted the rate of downward movement of water. In our research, RTC values were 5 or less in about 20% of the events, with little difference between NT and CT, although the overall RTC was significantly lower in NT than in CT. These low values indicate fast responses. It is not clear why RTC values were similar between CT and NT in this range. Differences emerged between treatments at higher RTC values. Given the close drain spacing and the possibilities of some macropores in CT, some of the low RTC values are perhaps to be expected. In the regression of $\ln(Q)$ vs. time, the starting time (t_0) perhaps should be moved further down the recession curve to reflect the greater influence of the tail part of the recession curve, which lasts longer and has a more gradual slope than the part immediately following peak flow rate, especially in NT. The peaks of the hydrographs in CT had more curvature, and the starting point (t_0) of the analysis could be placed in any number of locations. Further study is required on this topic.

IMPLICATIONS

The literature reports widely varying effects of contrasting tillage practices on water movement and nutrient leaching losses. Under the prevailing environmental conditions of this research, we found that no-till enhanced water movement into and through the soil, as evidenced by the faster mean and peak drainage rates as well as larger drainage amount, compared to conventional tillage. The consequence of this in terms of chemical losses has not been investigated here. Macropore-induced preferential water flow does not necessarily always mean more chemical leaching (Golabi et al., 1995). In fact, the opposite might be true if surface-applied chemicals enter the soil matrix by diffusion before the onset of a large rain following application. Once in the matrix, the chemicals may be bypassed by water flowing in the macropores. In these soils, NO₃-N leaching tended to be greater under no-till compared to conventional tillage only when rainfall occurred soon after application, as reported by McCracken et al. (1995). Nevertheless, understanding the nature of the soil water flow in any cropping system is a prerequisite for making judgements about potential non-point-source pollution and designing possible best management practices to combat it. Site-specific research is required because factors that influence water movement have a spatial and temporal variability. One drawback to large-scale field research relying on actual environmental conditions (in contrast to simulated research) is that the spectrum of independent variables necessary to evaluate a dependent variable is not necessarily readily available, and the research has to cover long periods to generate these variables.

CONCLUSIONS

The effect of tillage on water movement needs to be studied under site-specific conditions. The Southern Piedmont presents a unique set of environmental conditions that include soils, topography, climate, and farming systems.

Increased adoption of conservation tillage is a recent phenomenon in the region. Measurement and analysis of drainage over a 12-month period from a Cecil sandy loam, the dominant soil series in the region, following a combined six years of a corn/rye and cotton/rye cropping system under contrasting tillage treatments showed that surface soil properties that affect infiltration and water movement into deeper soil profiles have diverged. No-till had more water moving to the water table through the soil surface and subsurface, which provided additional hydraulic head above the drain pipes, the driving force for pipe drainage. As a result, drainage peaked higher, included more volume, and lasted longer from no-till than from conventional till. The use of the recession time constant (RTC) as an index of the structural macropore development was partially validated based on the smaller mean RTC value from no-till, which indicates more water release through larger and more connected pores. The question remains, however, why in about 20% of the cases, at the smallest end of the scale, the difference in RTC was minimal between no-till and conventional tillage. More analysis is required. The implication of all of this for nutrient and chemical movement into and through the soil is a subject for further study, since more nutrient and chemical movement does not necessarily always follow increased drainage. Additional longer-period data is also required to cover the spectrum of environmental factors that come into play in such a study.

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