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EFFECTS OF TILLAGE AND RESIDUE MANAGEMENT ON RUNOFF AND EROSION

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ABSTRACT

Numerous studies have shown the benefits of no-till (NT) cropping systems at reducing erosion. Quantitative information is needed on how residue contributes to erosion control and the impacts of converting NT systems back into conventional-till (CT) systems and vice versa. The objective of this study was to use long-term CT and NT plots to elucidate the effects of residue and tillage on runoff and erosion. Rainfall simulations were conducted on 13 plots in year 1 and 11 plots in year two. Plots had an average slope of 5.6% on a Grenada silt loam (Glossic Fragiudalf) soil. Rainfall was applied to a 3.7 m by 10.7 m area within plots at a rate of 65 mm/h for one hour under natural antecedent soil-water conditions (dry run), followed by a 0.5 h simulation four hours later (wet run), and another 0.5 h application 30 minutes later (very wet run). Runoff and soil loss were adjusted for variations in rainfall to the prescribed application rate and soil loss was further adjusted for difference in slope among plots. NT systems exhibited greater runoff than CT systems, however, sediment losses were greater for CT. Initial response to residue removal was an increase in runoff and erosion for both systems. The second year of residue removal did not affect runoff but caused substantially higher sediment losses particularly for plots with a history of NT. The lack of carry-over in beneficial NT propoerties resulted in NT systems having similar erosion rates as CT systems by the subsequent year of residue removal. This work demonstrates that residue management can be more important than the tillage system for erosion control.

INTRODUCTION

Soil losses by erosion from U.S. cropland have been estimated to be between 2 to 6.8 billion tons per year (Trimble and Crosson 2000). Soil loss rates in the loess hills of the Mississippi River Valley (MRV) are among the highest in the US with erosion rates of 28.9 t/ha/yr (Langdale et al. 1995). No-till cropping systems have been shown to reduce soil loss to less than 3 t/ha/yr reported by McGregor and Mutchler (1992). Murphree and McGregor (1991) reported losses as high as 11.7 t/ha/yr for a relatively flat watershed in the Mississippi Delta under conventional tilled soybean.

The impact of no-till on runoff is not as clear as the impact on erosion. Because soil under no-till is left practically undisturbed, macropores formed by biological activity and structural development are not destroyed. Preferential flow through continuous macropores can increase the infiltration, thereby reducing runoff (Edwards et al. 1988a, 1988b). It is generally accepted that NT results in increased infiltration (Radcliffe et al.1988; Felsot et al. 1990; Freebairn et al. 1989; Kanwar et al. 1995) due to preferential flow down macropores. Since flow velocity is related to particle detachment, runoff rate is a key factor to erosion control (Yu et al. 2000). While erosion may be reduced by as much as 80 to 90% with no-till, runoff maybe reduced only slightly; 10% reduction reported by Meyer et al. (1999). Many studies have found no differences in runoff between no-till and conventional tillage yet soil losses were reduced.

The reduction in erosion with no-till has been attributed to crop residue left on the surface (Foster and Meyer 1977; McGregor et al. 1990a,1990b). Moldenhauer and Langdale (1995) concluded from a summary of research on residue management that erosion rates approach zero as surface cover approaches 100%, 83% reduction with 50% cover, and 30% reduction with only 10% residue cover. Cogo et al. (1984) reasoned that surface residue reduced erosion by (i) providing protection from raindrop impact, (ii) slowing runoff rates and increasing the flow depth, (iii) decreasing particle detachment and sediment transport, and (iv) creating small reservoirs that serve to increase on-site sediment deposition.

While numerous studies have shown the effectiveness of crop residues in controlling erosion, much debate has existed as to the benefits of incorporating residue. Wischmeier (1973) found that incorporating corn residue reduced runoff 40% compared to removal of residue at harvest. Wischmeier and Smith (1978) concluded from a compilation of runoff and soil loss data from numerous studies that incorporated residue was less effective than surface residue for erosion control. McGregor et al. (1988a, 1988b) conducted laboratory studies on the effects of surface and incorporated residue on runoff and erosion using a rainfall simulator with a rate of 64 mm/h applied for 60 minutes to dry soil followed 24 h later with two 30 minutes applications spaced 30 minutes apart. They found that fully incorporated fresh residue had no effect on runoff and erosion, but surface residue reduced erosion. McGregor et al. (1990b) conducted a companion field study using two diskings to partially incorporate previous crop residue and freshly applied residue. Using the same simulated rain patterns, they found that runoff and soil loss decreased as surface coverage increased. They concluded that incorporation of residue did not affect soil loss. However, these studies evaluated the effect of residue immediately after incorporation of freshly applied residue.

Improvement in soil tilth, soil structure and many other beneficial physical and chemical properties of the plow layer have been attributed to decomposition of previously incorporated residue. Thus there should be a temporal affect of incorporated residue with tillage. No-till systems have been shown to result in improvement in soil physical soil properties as a result of accumulation of organic matter (Tyler et al. 1983, Stearman et al. 1989). It is not clear, however, if the benefits of no-till in reducing runoff and erosion are from the changes in the physical properties as a result of residue management or the existence of the surface coverage of residue. It is also uncertain as to the longevity of the benefits if residue was removed and/or no longer applied to the surface.

Until recently, CT has been the most common tillage system on loessial soils in the southeast. Conversion of these long-term CT lands into NT has resulted in NT being the most popular practice in many region of the southeast. It is widely recognized that the improvement in soil properties under NT takes 3-5 years to be realized. Due to lack of incorporation of fertilizers and the fact that the heaviest of machinery (harvesters) is still needed with NT, the soil surface under NT can potentially develop high pHs and bulk densities at the surface. Some have advocated periodic, maybe once a decade, tillage of long-term NT lands to remove these deleterious properties. Very little is known about the impact on runoff and erosion of tillage on land with a long-term history of NT or the impact of converting long-term NT land into CT. McGregor et al. (1999) performed rainfall siumlations on freshly tilled soil that had a long-term history of NT. They found the no-till history (NTh) plots had 11 to 35% less runoff than the plots with a long-term history of CT (CTh) and soil losses were 23 to 77% lower.

OBJECTIVES

The objective of this study was to use long-term CT and NT plots on loessial uplands in north Mississippi to elucidate residue management and tillage effects on runoff and erosion. The carry-over benefits of residue management will be determined along with the impact of converting NT systems back to conventional-till (CT) systems and long-term CT systems into NT on runoff and erosion.

MATERIALS AND METHODS

Field plots at the Nelson farm in the loessial uplands of north Mississippi (89.957 W, 34.565 N) were used for this study. Research at the Nelson farm has included 16 runoff and erosion plots, 32 corn plots, 140 production plots, and three watersheds (Fig. 1). Soils were predominately Grenada silt loam (fine silty, mixed, thermic, Glossic Fragiudalf) with some areas consisting of Memphis and Loring silt loams soils. Plots with long-term history of CT and NT were selected for study and the management changed when necessary to obtain the following treatments: (1) CT history maintained in CT with residue left on the surface prior to tillage in year one and removed in year two (CTh-CT, RL-RR), (2) CT history maintained in CT with residue removed from the surface in year one and removed again in year two (CTh-CT, RR-RR), (3) CT history converted to NT with residue removed from the surface in year one and removed again in year two (CTh-NT, RR-RR), (4) NT history maintained in NT with residue left on the surface in year one and removed in year two (NTh-NT, RL-RR), (5) NT history maintained in NT with residue removed from the surface in year one and removed again in year two (NTh-NT, RR-RR), and (6) NT history converted to CT with residue removed from the surface in year one and removed again in year two (NTh-CT, RR-RR). Tillage and other management practices were up and down the slope.

Rainfalls with a simulator designed by Meyer (1960) were conducted on 13 plots in year one and 11 plots in year two. The simulator consisted of a series of oscillating Veejet nozzles (80150) located approximately 3 m above the soil surface. Nozzles traversed the area horizontally in two-dimensions in order to apply a uniform rainfall application with an impact energy of 275 kJ/ha-mm. Rainfall was applied to a 3.7 m by 10.7 m area within plots at a rate of 64 mm/h for one hour under antecedent soil-water conditions (dry run), followed by a 0.5 h simulation four hours later (wet run), and another 0.5 h application 0.5 h later (very wet run). According to McGregor and Mutchler (1977), rainfalls at this intensity with 0.5 h and 1 h durations are expected in this region about once every year and ten years, respectively.

The time of runoff initiation was recorded and runoff rates measured by collecting the runoff for 15 second intervals every 3 minutes until rainfall was terminated at which point runoff was collected for 15 seconds every minute until runoff ceased. Runoff volume was recorded and sediment content analyzed to determine soil loss. The rainfall application amount was measured (MAR, mm) for each simulation. The measured runoff volume (RO_m) was converted to a depth of runoff, R_m (mm) knowing the application area. Measured runoff and soil losses (SL_m, t/ha) were adjusted for variations in rainfall to the prescribed application rate of 65 mm (expressed on hour basis) by :

$$RO_{65} = RO_m + (65 - MAR)$$
$$SL_{65} = SL_m\,(65/MAR)^2$$

Due to differences in duration of rainfall simulations between the dry run and the subsequent two runs, runoff depth was scaled to the rainfall applied, P (mm) as R/P (%) for comparison purposes.

Plots had an average slope of 5.7% with a standard deviation of 1.1%. Runoff is affected less by variations in slope than soil loss, McGregor et al. (1990a). Therefore, only soil loss was adjusted (SL_{as}) by each plots measured slope ($?_{ms}$) to the average slope ($?_{as}$) according to (McCool et al. 1987):

$$SL_{as} = SL_{65}\,(C_{as}/C_{ms})$$
$$\text{where } C_{as} = 10.8 \sin ?_{as} + 0.03,$$
$$\text{and } C_{ms} = 10.8 \sin ?_{ms} + 0.03$$

RESULTS

Treatment Effects

Soil water contents were measured immediately prior to rainfall application of each run. These data were used to account for variations between runs using a covariant analysis which adjusted the least square means to a consistent moisture content of 30%. The SAS Proc Mixed procedure was used with and without moisture as a covariant to determine differences in least square means between treatments and years. Only differences between average percent runoff and total soil loss for the three runs combined will be discussed. Moisture was not significant but treatment effect and year effect F values decreased with moisture included as a covariant, thereby indicating that it explained some of the variance. Moisture was included in the analysis of variance reported in Table 1 for differences between treatments and years.

Overall differences in percent runoff between treatments were significant at the 95% probablity level for the combined average of the runs (Table 1). The combined average runoff did not exhibit an overall significant difference among treatments. However, differences were significant between some individual treatments in all cases as indicated by letters in Figure 2. The year effect for both percent runoff and soil loss is a result of the carry-over effect of residue removal.

Long-Term Tillage Impacts

Establishment of NT will generally result in increased infiltration due to improvement in surface soil properties. However, this generality does not necessarily hold true when comparing runoff from the first storm event after tillage. The infiltration capacity of freshly tilled (CT) soil is temporarily high and typically exceeds that of NT. Since rainfall simulations were conducted immediately after tillage, CT plots tended to have lower runoff than NT plots. This is seen in the plots with a long-term history of CT that remained in CT as compared to NT history that remained in NT, Figure 2. If residue was left on the surface, runoff was significantly higher from these NTh-NT plots, at the 90% probablity level, than the CTh-CT. If residue was removed, the NTh-NT plots had significantly higher runoff than the CTh-CT plots at the 90% level in 1997 and at the 95% level in 1998. This suggests that there is a compounding effect of residue removal from the initial removal to the subsequent year.

While runoff was higher from the NTh-NT plots than the CTh-CT plots, soil losses were higher from the CT plots, Figure 3. The combined soil losses for the CTh-CT plot with residue left (Trt 1) was over 27.0 t/ha as compared to only 3.1 t/ha soil loss from the NTh-NT with residue left. This difference is a result of exposure of soil due to incorporation by tillage of what residue was left. Rainfall simulations on NTh-NT plots immediately following removal of residue resulted in increased soil losses to 18.0 and 6.2 t/ha for Trt 4 in 1998 and trt 5 in 1997, respectively. Soil losses from the NTh-NT in the second year of residue removal (trt 5 in 1998) increased to over 64.9 t/ha. These findings suggest that the benefits of NT, from an erosion standpoint, are transient and largely lost by the second year if residue cover is not maintained.

Conversion of Tillage

The impact of converting long-term CT plots into NT and long-term NT plots into CT were only investigated under conditions of residue removal. Conversion of long term CT plots into NT resulted in significantly higher runoff in 1997 than if it had be maintained in CT but differences, while higher, were not significant in 1998. While residue removal from long-term NT plots increased the soil loss, soil losses from long-term CT plots that were converted to NT were 38.5 and 52.6 t/ha in 1997 and 1998, respectively, as compared to 49.6 and 70.0 if the land continued in CT. Even though these differences were not significant, due to the lack of power in the statistics, leaving the soil undisturbed for just a year (time from previous year's tillage) resulted in less erosion even with residues removed.

Conversion of long-term NT into CT with residue removed significantly reduced runoff at the 95% probability level. The average runoff of the three runs from the plots maintained in NT was significantly higher than from those converted to CT. The CT plots exhibited greater erosion, with total soil losses of 19.2 and 82.7 t/ha in 1997 and 1998, respectively as compared to the 6.2 and 64.9 t/ha reported earlier under NT. These differences in total soil losses were not significant but with additional replications these large numeric differences would likely be significant.

Residue Removal Impact with Tillage Conversion

These results suggest that the combination of two years of CT following NT and a second year of residue removal resulted in significantly higher soil losses than if the land had been maintained in NT. Comparing year one of residue removal to year two of removal for both types of system conversion revealed negligible differences in overall average percent runoff. Thus, when long-term CT was converted to NT or long-term NT was converted to CT, residue removal did not have a carry-over affect on runoff. It did have a big affect on erosion when NT land was converted to CT. This was clearly seen in comparing the NTh-CT plots in 1997 to 1998, Figure 3. Soil losses were higher the second year when long-term CT land was converted into NT but the differences were not significant. Thus, residue management appears to be more important when NT land is converted to CT. Please note, however, that these comparisons of removal of residue did not account for the impact that tillage would have due to incorporation of residue left from years of NT.

Residue Removal Impacts

To account for the impact of residue incorporation under CT as compared to residue removal under CT, treatment 1 in 1997 was compared to treatment 1 in 1998 and treatment 1 in 1997 was compared to treatment 2 in 1997. Both treatment

1 in 1998 and treatment 2 in 1997 were CTh-CT plots immediately following residue removal and, therefore, runoff and erosion were not significantly different from each other for any of these runs. Runoff was significantly higher when residue was removed as compared to incomplete incorporation by tillage of residue left. Measurements of surface coverage indicated that residue removal left plots essentially bare (0% coverage) while tillage left some surface coverage of residue. This resulted in lower runoff likely due to factors discussed earlier such as small reservoirs for infiltration and slower runoff rates with some residue on the surface. One would expect an even greater response of residue removal on erosion. While soil losses were greater immediately following residue removal (Figure 3), the differences were only significant at the 90% level for the treatment 1 in 1997 compared to treatment 2 in 1997. If the power of statistics had been greater, e.g. more replications, then these differences would likely be significant.

The impact of not maintaining residue cover (residue removed) did appear to be carried over as the subsequent year exhibited an enhanced response to residue removal. Runoff did appear to increase slightly from the first to second year of residue removal but these differences were not significant. The soil losses were dramatically higher in the year following residue removal (1998) as compared to immediately following residue removal (1997). However, these differences were only significant at the 90% level for CTh-CT (treatment 2). A carry over effect was clearly seen in comparing the residue left year (1997) to the second year of residue removed. Differences for CTh-CT in both runoff and soil loss between residue left and the second year of residue removal were significant.

A good deal of research exists on the impact of surface residue verses residue incorporated by tillage, however it is less clear what the significance is of residue cover for NT. The NTh-NT plots with residue left were compared to the response immediately following residue removal. This was accomplished by comparing treatment-4 in 1997 to 1998 and to treatment-5 in 1997. There should not be any differences in the treatment-4 1998 and treatment-5 1997 systems. However, runoff was significantly higher in the 1997 treatment 5 plots while soil loss was higher, but not significant, than for treatment-4 in 1997. Despite these unexplained differences, runoff was not significantly different between NT with residue left on the surface and NT immediately following residue removal. Soil losses were higher with residue removed for all runs but differences were not significant.

The impact of not maintaining residue cover was most evident for the long term NT that remained in NT. The percent runoff for NTh-NT (Trt 4, 1997) was significantly lower, at the 90% level, when residue was left as compared to the second year (Trt 5, 1998) of residue removal. This was true at the 95% level for treatment-4 in 1998 (immediately following removal) as compared to treatment-5 in 1998 (year following residue removal). Continuity in good residue management from year to year clearly is important to controlling runoff.

The effect of residue management under NT was greater on the control of erosion and the carry over effect more evident. While the total soil losses when residue was left on NT were not significantly different than immediately following residue removal, soil losses were significantly higher than the year following residue removal. The beneficial effects of NT on soil properties that protect the surface from erosion are lost one year after failure to maintain residue cover. The loss in carry-over of beneficial properties was evident by significantly greater, at the 95% level, total soil losses a year later (1998) than immediately following residue removal. Therefore, residue management is particularly important for NT systems. A long-term NT system will behave as a long-term CT system with regards to erosion the subsequent year following failure to keep residue on the surface, even though the surface of the NT is not being exposed by tillage.

CONCLUSIONS

Runoff was higher under NT than the CT systems due to the CT systems being freshly tilled with high infiltration rates and storage capacities. This trend would likely reverse during subsequent events as the CT systems develop a surface seal. Regardless of the runoff rates, soil losses were significantly higher under CT systems immediately following the removal of residue. The reason is that there is no immediate reduction in erosion control due to poor residue management, such as failing to maintain residue cover, under NT. However, during the subsequent year, the beneficial soil properties that had developed under NT had deteriorated without the residue cover and the long-term NT system behaved as poorly as the CT system by exhibiting high soil loss rates. This result demonatrates that, for these silt loam soils, the carry-over benefits of long-term NT management does not last as long as one year if resiude cover is removed.

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Table 1. Analysis of variance by Proc Mix procedure for all runs combined for ratio of runoff to precipitation (R/P) and soil loss.

Source of Variation		Average R/P (%)		Total Soil Loss (t/ha)	
	df	F	Pr>F	F	Pr>F
Treatments	5	8.5	0.0023	2.85	0.1028
Year	1	1.28	0.2837	15.95	0.0027
Treatment*Year	5	1.05	0.4431	5.97	0.0645
Moisture	1	0.46	0.5111	0.83	0.3851

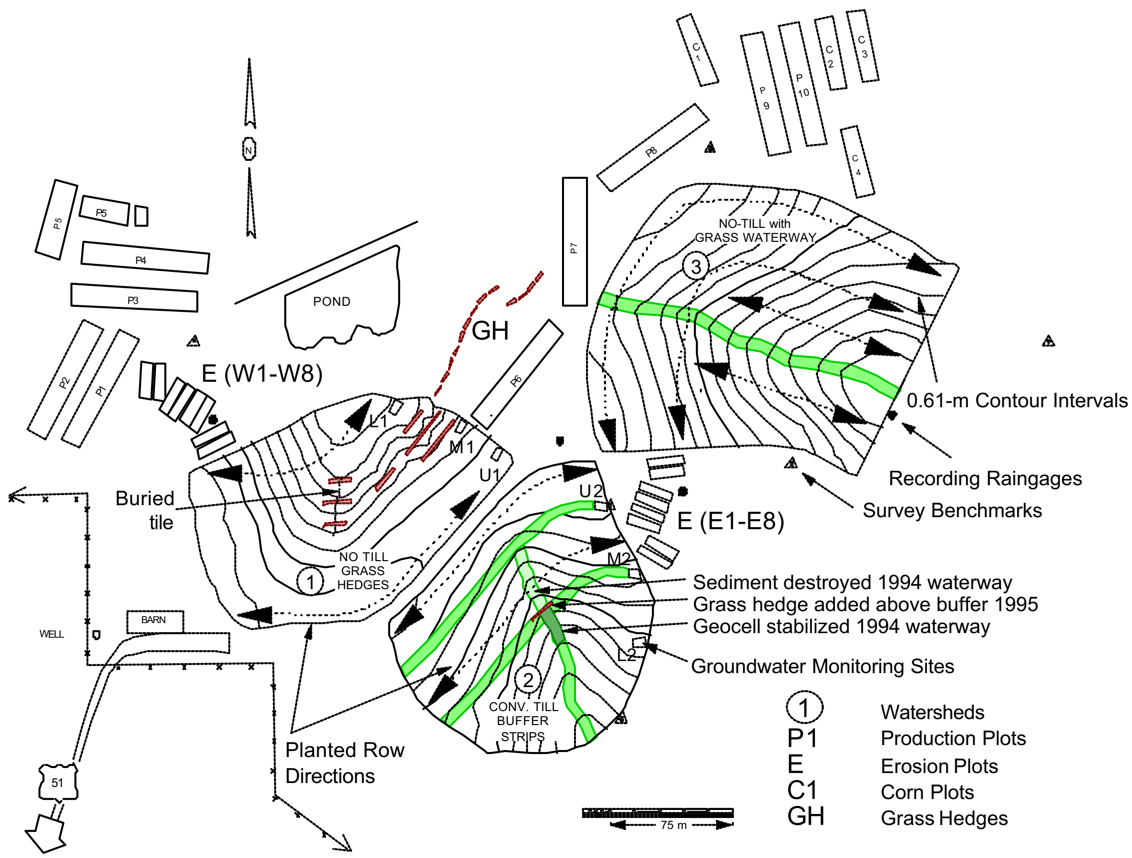

Figure 1. Diagram of Nelson Farm plots and watersheds. Plots used in this study were in the corn (C) and production (P) blocks shown at the upper right corner.

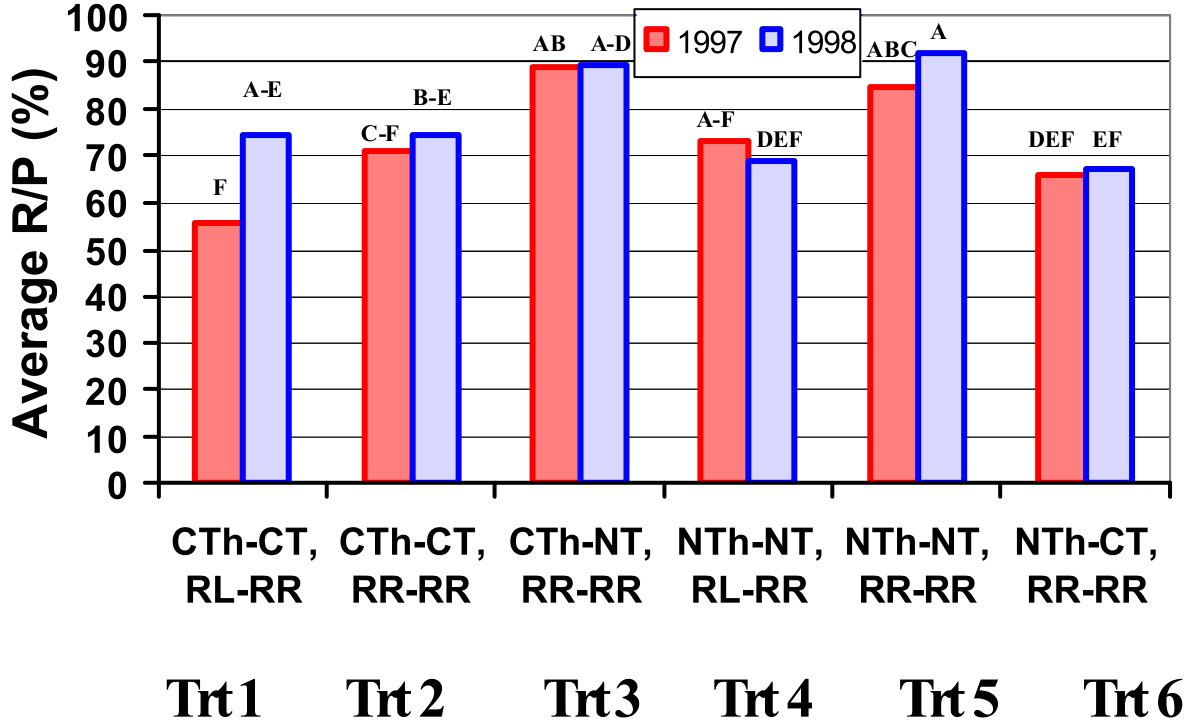

Figure 2. Least square means in the average runoff to rainfall ratio (R/P) of the three runs. Letters indicate significant differences in means at the 95% level.

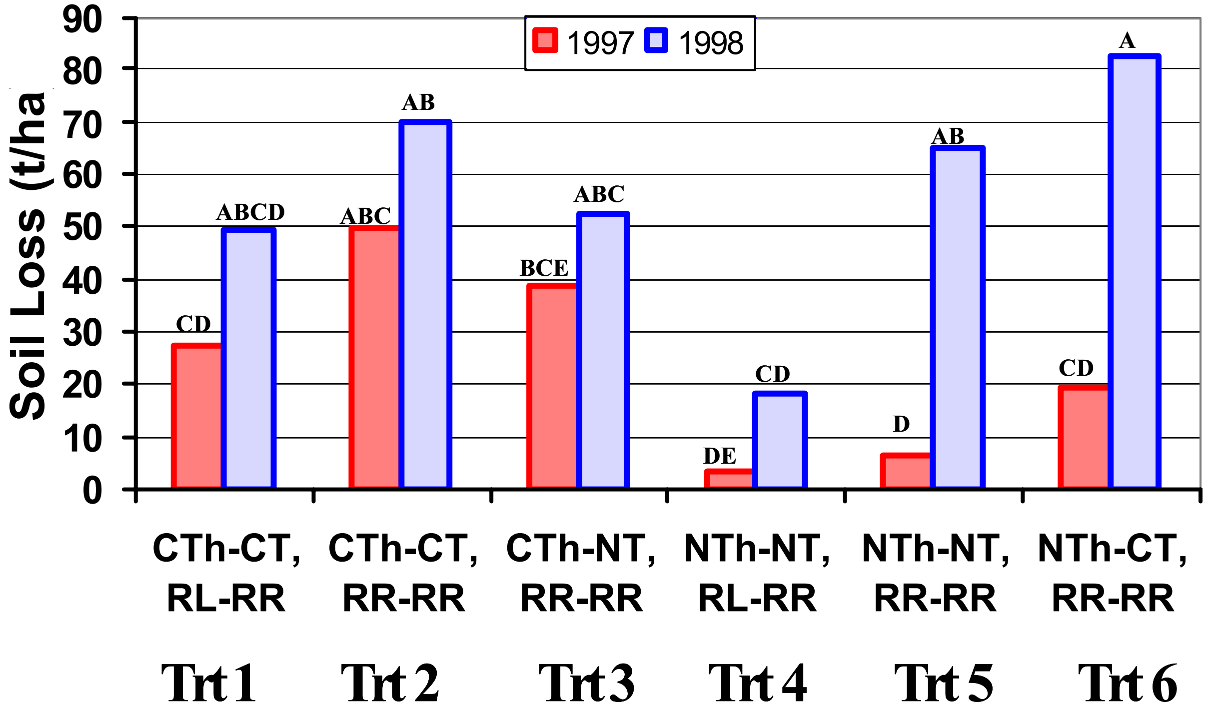

Figure 3. Least square means in the total soil losses of the three runs combined. Letters indicate significant differences in means at the 95% level.

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