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# RUSLE Estimates of Soil Erosion in Cotton Production Systems in North Alabama

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## ABSTRACT

**Soil erosion presents environmental and economic problems in conventional tillage (CT) cotton (*Gossypium hirsutum* L.) production systems in the U.S. Tillage and cropping systems which increase yields while reducing soil erosion and leaching of nutrients into ground water are needed to sustain the current cotton production systems. The objective of this study was to estimate soil erosion in cotton under No-till (NT) and mulch-till (MT) systems with winter rye (*Secale cereale* L.) cover cropping and poultry litter (PL) application using the Revised Universal Soil Loss Equation (RUSLE) on a Decatur silt loam soil in north Alabama from 1996 to 1998. Soil erosion estimates in CT plots with or without a winter rye cover crop and ammonium nitrate (AN) fertilizer were double the 11 t ha$^{-1}$ yr$^{-1}$ tolerance level for the Decatur series soils. However, using PL as the N source at 100 kg N ha$^{-1}$ under CT gave soil erosion estimates which were 50% below the tolerance level, while doubling the N rate through PL to 200 kg N ha$^{-1}$ under NT system gave soil erosion estimates below 2 t ha$^{-1}$ yr$^{-1}$. No-till and MT gave erosion estimates, which were about 50% of the tolerance level with or without cover cropping or N fertilizer application. Results from our study show that NT and MT systems with cover cropping and PL application can reduce soil erosion and thus improve the sustainability of cotton soils in the southeastern USA.**

## INTRODUCTION

Soil erosion is a major environmental problem in the US and worldwide. Eroded soils carry nutrients, pesticides, and other farm chemicals into rivers, streams, and ground water resources (Gallaher and Hawf, 1997). Soil erosion has been pointed out as the primary cause of un-productivity of soils in the Southern Piedmont ranging from southern Virginia through central Alabama, which were once some of the most productive cotton producing areas in the U.S. According to Brown et al. (1985), cotton yields can decline by as much as 4% for each centimeter of topsoil loss. Erosion has been suggested as one of the major causes of static or declining cotton yields in some areas in the southeast USA. Unlike gully erosion, which is easily recognized, sheet erosion often goes unnoticed by the producer while having a significant impact on crop yields. In Alabama, soil erosion on crop lands potentially causes a decrease of 440 to 670 kg ha$^{-1}$ of cotton lint yield if no remedial actions are taken (Anon., 1991).

To comply with the requirements of the 1985 Food Security Act and the 1990 U.S. Federal Farm Bill, conservation tillage must be used for cotton production on sloping up-land sites by farmers participating in federal commodity programs. The inclusion of winter cover crops in conservation tillage systems protects the soil from the impact of raindrops after cotton harvest thereby further reducing soil erosion.

The Revised Universal Soil Loss Equation (RUSLE) is an empirical soil erosion model founded on the Universal Soil Erosion Loss Equation (USLE) (Wischmeier and Smith, 1965). It computes the average annual soil erosion estimates caused by rainfall and its associated overland flow from the equation A = R.K.LS.C.P, where A=predicted long-term average of annual sheet and rill soil loss from a defined slope (tons ac$^{-1}$ yr$^{-1}$), R=rainfall-runoff erosivity factor {hundreds of (ft-tons ac$^{-1}$ yr$^{-1}$ in hr$^{-1}$)}, K=soil erodibility factor as measured under unit plot conditions {tons ac$^{-1}$ (hundreds of ft tons ac$^{-1}$ in hr$^{-1}$)$^{-1}$}, LS=the erosion impact of the slope length (L) and steepness (S) on erosion in comparison to unit plot conditions (dimensionless), C = the erosion impact of cover and management schemes on erosion in comparison to unit plot conditions (dimensionless), and P = the erosion impact of conservation support practices (e.g. contour tillage, strip cropping, terraces, and drainage) on erosion in comparison to unit plot conditions (dimensionless). This paper describes soil loss by erosion, estimated by RUSLE, under CT, NT, and MT cotton production systems with winter rye cover cropping and PL application from cotton plots on a Decatur silt loam soil in north Alabama.

## MATERIALS AND METHODS

### Study Location and Baseline Soil Analysis

The study was conducted at the Alabama Agricultural Experiment Station, Belle Mina Alabama (34° 41' N 86° 52' W) on a Decatur silt loam soil (clayey, kaolinitic thermic, Typic Paleudults) from 1996 to 1998. Before starting the experiment, soil cores for the determination of baseline soil hydrological, physical, and chemical properties were taken (Table 1).

### Treatments and Experimental Design

The treatments consisted of three tillage systems:

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**Table 1. Baseline soil physical and chemical properties for cotton plots prior to imposing tillage, cropping system, and N fertilizer treatments, Belle Mina, AL, November 1996.**

**Physical and Hydrological Properties**

| Physical Properties | | Hydrological Properties | | | |
|---|---|---|---|---|---|
| Bulk Density ($g\ cm^{-3}$) | Infiltration Rate ($mm\ hr^{-1}$) | Field Capacity ($cm^3\ cm^{-3}$) | Permanent Wilting Point ($cm^3\ cm^{-3}$) | Available Water Capacity ($cm^3\ cm^{-3}$) | Saturated Hydraulic Conductivity ($cm\ hr^{-1}$) |
| 1.56 | 28 | 0.33 | 0.25 | 0.08 | 1.28 |

**Chemical Properties (standard errors in parenthesis)**

| Soil Depth (cm) | pH (1:1soil:water) | Organic matter ($g\ kg^{-1}$) | $NH_4$-N | $NO_3$-N | P |
|---|---|---|---|---|---|
| | | | ---------------------- $mg\ kg^{-1}$ ---------------------- | | |
| 0-15 | 6.17 (0.14) | 14.7 (3.9) | 80 (10) | 35 (10) | 44 (7) |
| 15-30 | 6.15 (0.04) | 13.6 (5.6) | 110 (0.7) | 22 (5) | 38 (9) |
| 30-60 | 5.65 (0.15) | 4.3 (3.2) | 55 (1.3) | 37 (15) | 8 (8) |
| 60-90 | 5.26 (0.18) | 2.2 (2.4) | 59 (1.4) | 42 (14) | 3 (6) |

conventional tillage (CT), mulch-till (MT) and no-till (NT); two cropping systems; cotton-fallow system, that is cotton in summer and fallow in winter (CF) and cotton-winter rye sequential cropping, that is cotton in summer and rye in winter (CR); three nitrogen levels (0, 100 and 200 kg N $ha^{-1}$) and two nitrogen sources; ammonium nitrate (AN) and fresh poultry litter (PL). Ammonium nitrate was used at one N rate (100 kg N $ha^{-1}$) only. An additional weed-free (bare) fallow treatment (BF) was included. The bare fallow plots were not tilled and cropped. They were kept weed-free by use of Roundup (glyphosate) herbicide. The purpose of these control plots was to get an estimate of soil loss from plots without any vegetation canopy and surface residue protection. Conventional tillage included moldboard plowing in November and disking in April in both years. A field cultivator was used to prepare a smooth seedbed after disking. Mulch-till included tillage with a cultivator before planting.

During the season, a field cultivator was used for controlling weeds in the conventional tillage system while spot applications of herbicides were used to control weeds in the no-till and mulch-till systems. The PL used in the study contained 30 g $kg^{-1}$ N, 13 g $kg^{-1}$ P and 20 g $kg^{-1}$ K on dry weight basis. A 60% (Keeling et al., 1995) factor was used to adjust for N availability from the PL during the first year. The PL was broadcast by hand and incorporated to a depth of 5 cm by pre-plant cultivation in the conventional and mulch-till systems. In no-till system, the PL was not incorporated. The experimental design was a randomized complete block design with 4 replications. Plot size was 8 m wide and 9 m long, which resulted in 8 rows of cotton, 1 m apart.

## Cover Crop Establishment and Cotton Planting

In the first year, the winter rye cover crop was planted on December 4, 1996 and killed by Roundup herbicide (glyphosate) on April 8, 1997. In the second year, the winter rye cover crop was planted on November 24, 1997 and killed by Roundup herbicide on February 28, 1998. A no-till planter was used to plant the rye cover crop in both years. Cotton variety Deltapine NuCotn 33B was planted in all plots using a no-till planter. A herbicide mixture of Prowl (pendimethalin) at 2.3L $ha^{-1}$, Cotoran (fluometuron) at 3.5L $ha^{-1}$, and Gramoxone extra (paraquat) at 1.7 L $ha^{-1}$ was applied to all plots before planting on May 8, 1997 and May 5, 1998 for weed control. In addition, all plots received 5.6 kg $ha^{-1}$ of Temik (aldicarb) for the control of early season thrips.

## Data Collection

Immediately after planting, surface residue cover was measured in all plots using the camline transect method (Reddy et al., 1994). Cotton data collected were days to squaring, days to flowering, days to maturity, plant height, leaf area index (LAI) using the AccuPAR linear ceptometer (Decagon Devices, Pullman, WA), % canopy cover surface root biomass, number of squares per plant at surface root biomass, number of squares per plant at boll formation, number of bolls per plant at harvest, leaf N concentration, shoot biomass and seed cotton yield. Weather data were taken from an automatic weather station at the Experimental Station. Mean monthly temperature, total monthly rainfall distribution at Belle Mina, and irrigation water applied during the cotton-growing period in 1997 and 1998 are presented in Fig. 1.

## Data for RUSLE Factors - R, K, LS, P and C

Values for R, K, LS, and P factors used by RUSLE in the estimation of soil erosion were respectively, 275 hundreds of (ft tons $ac^{-1}$ $yr^{-1}$ in $hr^{-1}$), 0.33 tons $ac^{-1}$ (hundreds of ft tons $ac^{-1}$ in $hr^{-1})^{-1}$, 0.16 (dimensionless), and 1 (dimensionless). The cover management (C) factor varies with season and crop production system and need to be measured in the field, unlike the other information such as rainfall and soil data, which can be obtained from published records. In this study, crop data which was collected for the RUSLE C-factor calculation included winter rye biomass, surface residue cover (SRC) after cotton planting, cotton canopy cover, effective fall height from the cotton canopy, and cotton surface (top 10cm of soil) root mass. Surface residue cover was measured in all plots using the camline transect method (Renard et al., 1993; Reddy et al., 1994) immediately after cotton planting. Canopy cover was determined by measuring the width of the crop canopy of each row from the four central rows on each plot using a ruler and expressing the figure as a percentage of the row width. Effective fall height (FH) is the distance a raindrop falls after striking the crop canopy. This was calculated from the equation:

$$FH = (TH - BH)/2 + BH \quad [1]$$

where TH and BH are the top and bottom heights of the cotton canopy, respectively. Root biomass was determined by sampling plants with their roots intact from $0.5m^2$ quadrants from each plot. Roots were extracted out of the soil by removing soil from both sides of the row and lifting the intact plants from the base with a garden fork. The roots were cut from the shoots, washed in water to remove soil and placed in separate bags. The shoot and root samples were oven dried to constant weight at 65ºC for 72 hours before weighing. The cotton crop growth data were taken in each plot at 15-day intervals.

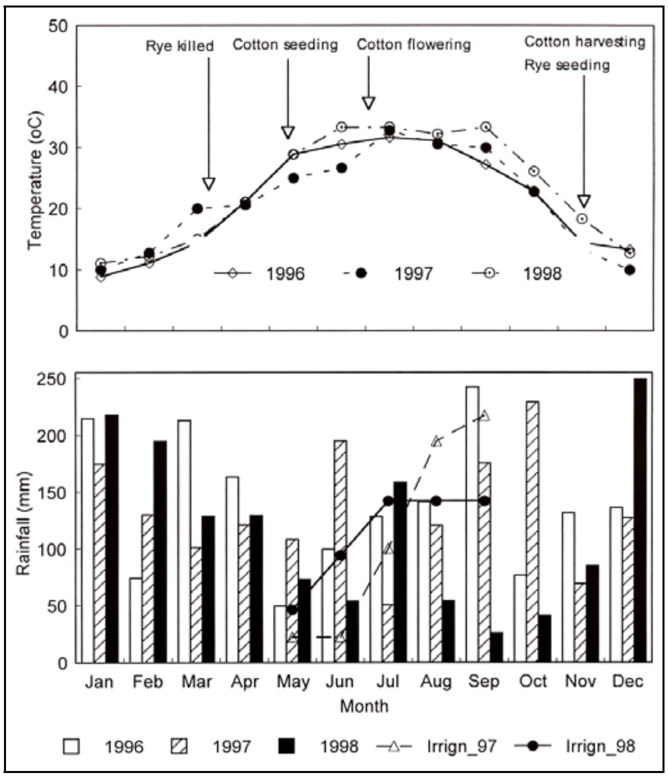

**Figure 1. Mean monthly maximum temperature, rainfall, and irrigation water applied to cotton plots, Belle Mina, AL., 1996 to 1998.**

The overall C-factor value used by RUSLE was calculated by the model from subfactor values of: prior land use (PLU), which has a strong impact on soil aggregation and aggregate stability, as well as physically inhibiting the formation of rills; vegetative canopy cover (CC), which intercepts raindrops and reduces their impact energies; surface cover (SC), which slows runoff and reduces raindrop impact and flow; surface roughness (SR), which slows runoff and causes local deposition of transport sediment; and soil moisture (SM) which affects the rainfall infiltration rate. The subfactor values are multiplied together to yield a soil-loss ratio (SLR), thus SLR = PLU.CC.SC.SR.SM. The SLR values for each plot were then weighted by the fraction of rainfall and runoff erosivity (EI) associated with the corresponding time period of the cover and management, and these weighted values were combined into an overall C-factor value (Renard et al., 1993).

## Data Analysis

The data were statistically analyzed using the GLM procedures of the Statistical Analysis System. Contrast analysis procedures were used to compare the main effect treatment means for tillage systems, cropping systems, and N treatments. The analyses were performed separately for each year. There were significant tillage x cropping system and tillage x nitrogen source interactions for C-factor and soil erosion estimates.

# RESULTS AND DISCUSSION

## Surface Residue Cover

Any tillage and planting system that leaves at least 30% of the soil surface covered with crop residues can be called conservation tillage (Gallaher and Hawf, 1997). Percent surface residue cover (SRC) after cotton seeding for CT, NT and MT tillage systems under continuous cotton and cotton-rye sequential cropping at Belle Mina Alabama in 1997 and 1998 are given in Table 2. Based on the above definition for conservation tillage, NT or MT with cotton-winter rye cropping systems left at least 30% of the soil surface covered with residues hence they qualify to be described as

**Table 2. Surface residue cover in cotton plots immediately after seeding as affected by tillagesystems under continuous cotton (CC) and cotton-winter rye sequential (CR) cropping systems, Belle Mina, AL, 1997 and 1998**

| | Tillage Systems | | | | | |
|---|---|---|---|---|---|---|
| | Conventional till (CT) | | Mulch-till (MT) | | No-till (NT) | |
| | 1997 | 1998 | 1997 | 1998 | 1997 | 1998 |
| Cropping Systems | ---------------------%--------------------- | | | | | |
| CC | 1.3a[†] | 1.2a | 6.1a | 5.7a | 16.8a | 12.6a |
| CR | 20.4b | 19.8b | 64.8b | 51.3b | 99.8b | 100.0b |
| S.E. | 9.5 | 9.3 | 25.3 | 21.9 | 41.5 | 43.7 |
| CV (%) | 4.8 | 4.3 | 4.8 | 4.3 | 4.8 | 4.3 |

[†]Means within a column followed by different letters are significantly different at P < 0.001 level

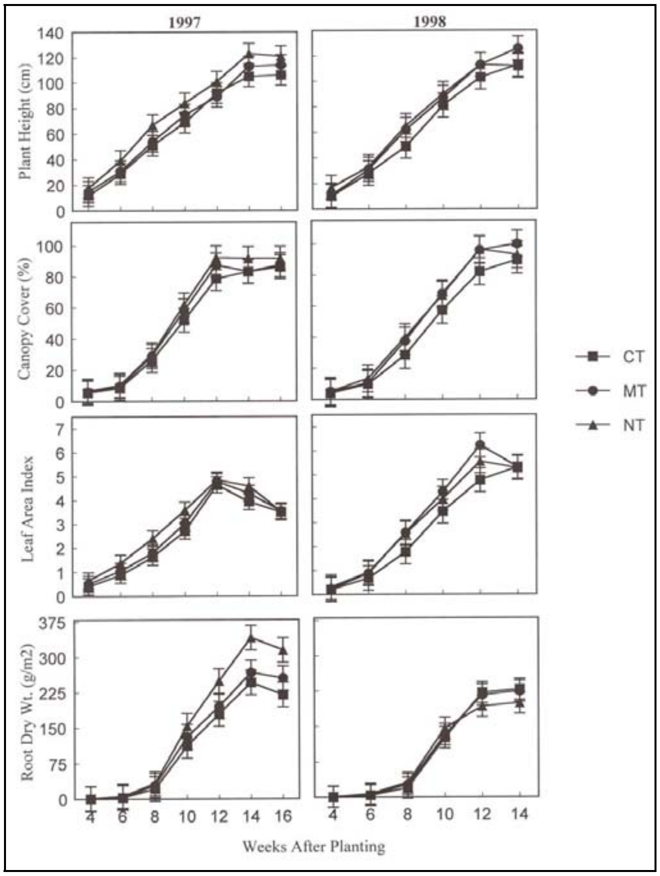


**Figure 2. Cotton growth parameters as influenced by conventional till (CT), mulch-till (MT), and no-till (NT) systems, Belle Mina, AL., 1997 to 1998 (Error bars = standard errors).**

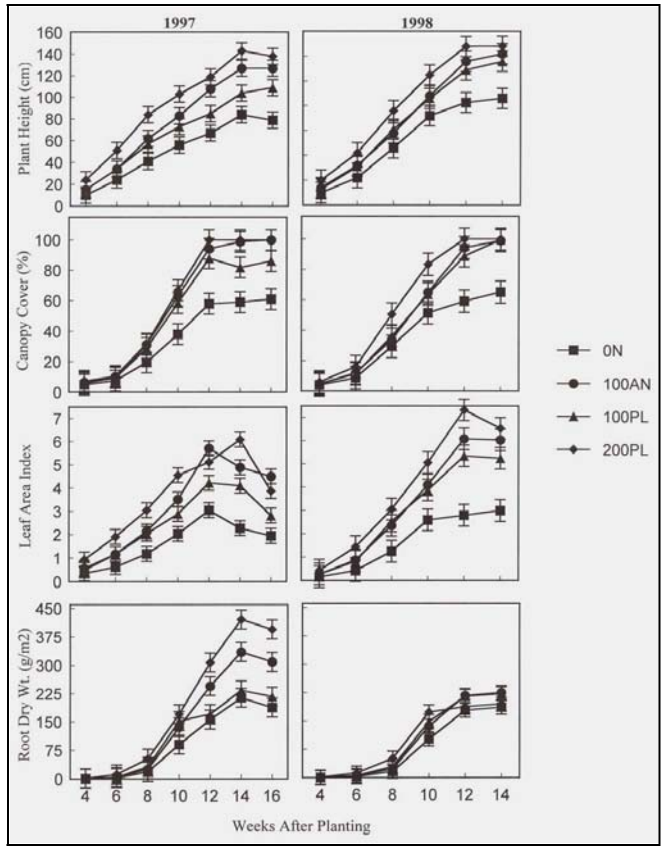


**Figure 3. Cotton growth parameters as influenced by nitrogen from ammonium nitrate (AN) and poultry litter (PL), Belle Mina, AL., 1997 to 1998 (Error bars = standard errors).**

conservation tillage (Table 2). As SRC approaches 100%, soil erosion approaches zero (Moldenhauer and Langdale, 1991). With 50% residue cover, soil erosion reduction is about 83% compared to no residue cover, whereas with 10% residue cover, soil erosion reduction is only about 30%. Based on the above figures, soil erosion in plots with NT or MT under cotton-rye sequential cropping was expected to be very low.

## Cotton Growth Parameters

Drier weather and higher temperature in the summer of 1998 (Fig. 1) resulted in a faster rate of cotton growth and development in 1998 compared to 1997. The effect of tillage systems and N levels on cotton growth parameters used as input data into the RUSLE C-factor is shown in Figures 2 and 3. Height of cotton plants under NT system was 17 to 30% higher than that under CT system at 8 weeks after planting in 1997 (Fig. 2). In 1998, height of cotton plants under NT and MT systems were 11 to 30% higher than that under CT system (Fig. 2).

The cotton crop attained maximum canopy cover and leaf area index (LAI) between 12 and 14 weeks after planting in both years. A good cotton canopy cover is a desirable attribute in several ways. Since cotton is planted in wide rows, most of the inter-row spacing is exposed to the direct impact of raindrops resulting in high soil erosion rates. Therefore, treatments that enable cotton to rapidly develop high LAI hence a good canopy cover will most likely result in reduced soil erosion. Plant height was significantly correlated to canopy cover, r = 0.88 and 0.83 in 1997 and 1998 respectively. Maximum canopy cover for cotton plants under NT and MT systems was, respectively, 7 and 11% significantly higher than that for plants under CT in both years (Fig. 2).

Cotton root mass in the top 10 cm of the soil at 10 to 14 weeks after planting under NT was 20 and 38% higher than that under MT and CT systems respectively in 1997 (Fig. 2). In 1998, however, cotton root mass in the top 10 cm of the soil at 10 to 14 weeks after planting for plants under NT was 15% lower than that for plants under CT or MT systems, but the differences were not significant (Fig. 2). The lower root mass in the top 10cm of the soil for cotton plants under NT system in 1998 can largely be attributed to the drought in the months of August and September (Fig. 1). However, the lower root biomass in the top 10cm of the soil in NT system at 10 to 14 weeks after planting did not nullify the benefits of soil moisture conservation under NT system prior to the drought period. Roots and crop residues control soil erosion directly by physically holding soil particles together and providing a mechanical barrier to soil and water movement. In addition, roots exude binding agents and serve as a food source for microorganisms, which increase soil aggregation and thereby reducing its susceptibility to erosion.

In both years, cotton growth parameters for plants which

Table 3. Cover management (C) factors of cotton as influenced by conventional-till and no-till systems under cotton-winter fallow and cotton-winter rye cropping systems and ammonium nitrate (AN) and poultry litter (PL) sources of N, Belle Mina, AL, 1997 and 1998

| | Conventional-till | | No-till | |
|---|---|---|---|---|
| | 1997 | 1998 | 1997 | 1998 |
| Cropping Systems | | | | |
| Cotton-winter fallow | 0.487a†A†† | 0.525aA | 0.130bB | 0.136bB |
| Cotton-winter rye | 0.423bA | 0.410bA | 0.056aB | 0.050aB |
| LSD(0.05) | 0.019 | 0.031 | 0.019 | 0.031 |
| CV(%) | 4.0 | 6.4 | 4.0 | 6.4 |
| N-Sources | | | | |
| 0 | 0.440aA | 0.430aA | 0.131bB | 0.136bB |
| 100AN | 0.423aA | 0.410aA | 0.129baB | 0.056aB |
| 100PL | 0.189bA | 0.220bA | 0.068aB | 0.052aB |
| LSD(0.05) | 0.079 | 0.040 | 0.079 | 0.040 |
| CV(%) | 9.5 | 12.4 | 9.5 | 12.4 |

†Means for cropping systems or N sources for the same year, followed by different lower case letters are significantly different at 0.05% level.

††Means for conventional and mulch-till systems within a cropping system or N source for the same year, followed by different upper case letters are significantly different at 0.05% level.

CV = coefficient of variation

received N in the form of AN or PL were consistently higher than those which did not (Fig. 3). Growth parameters for cotton plants which received 100 kg N $ha^{-1}$ in the form of AN were higher than those for plants which received 100 kg N $ha^{-1}$ in the form of PL. This can be attributed to the less availability of N from PL. However, doubling the N rate to 200 kg N $ha^{-1}$ in the form of PL gave significantly higher cotton growth parameters than all the other N levels (Fig. 3). Negatu et al. (1995) found that PL resulted in better cotton growth compared to urea on the Decatur silt soil. Improved soil moisture conservation in NT system was largely responsible for better plant growth and higher yield parameters in cotton. Soil moisture measurements in the top 7 cm of the soil taken during the first four days of cotton seedling emergence showed significantly higher volumetric soil moisture content in NT plots compared to CT plots in both years (Nyakatawa et al., 1998; Nyakatawa and Reddy, 2000).

## Cover Management (C-Factors) and Soil Erosion Estimates

Higher C-factor values indicate higher soil erosion loss since the C-factor is a ratio of soil loss in a cover-management sequence to soil loss from the unit plot. C-factors for cotton-winter rye cover cropping under conventional till were significantly reduced by 15% (0.487 vs. 0.423) and 28% (0.525 vs. 0.410) compared to cotton-winter fallow cropping in 1997 and 1998, respectively (Table 3). C-factors under conventional till were about four times greater than those under no-till, under cotton-winter fallow cropping in 1997 and 1998, respectively (Table 3). However, under cotton-winter rye cropping, C-factors under conventional till were up to seven times greater than those under no-till both years.

The main factor, which caused differences in the C-factor, is SRC since most of the other parameters such as rainfall and soil factors are constant for all the treatments. The SRC plays an important role of slowing surface runoff and protecting soil from the direct impact of raindrops whose energy breaks the soil particles apart which can then be carried away by moving water. Data for soil erosion loss from cotton plots under different tillage systems and N levels in 1997 and 1998 estimated by RUSLE are presented in Figure 4. The reduced C-factors explain the 15% lower

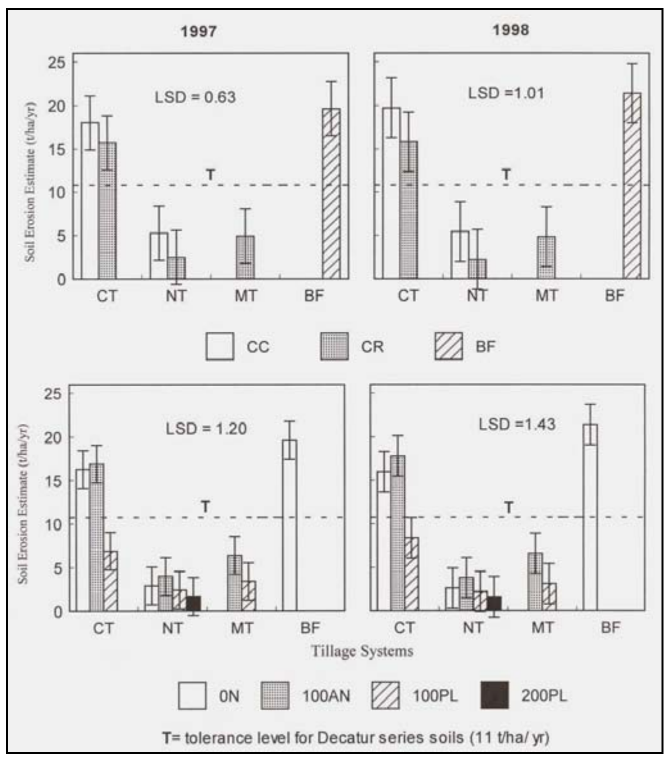


**Figure 4. Soil erosion estimates in cotton plots as influenced by conventional till (CT), mulch-till (MT), and no-till (NT) systems and nitrogen from ammonium nitrate (AN) and poultry litter (PL), Belle Mina, AL., 1997 to 1998 (Error bars = standard errors).**

(15.7 vs. 18.0 t $ha^{-1}$ $yr^{-1}$) and the 25% lower (15.8 vs. 19.7 t $ha^{-1}$ $yr^{-1}$) soil erosion estimates in CT with winter rye cover cropping compared to CT without cover cropping in 1997 and 1998, respectively (Fig. 4).

In both years, soil erosion estimates under MT system were about a quarter of those under CT. The highest soil erosion of about 20 t $ha^{-1}$ $yr^{-1}$ was estimated in the BF plots (Fig. 4). These results demonstrate the importance of cover cropping for soil erosion control in cotton production systems since cotton does not leave enough residues after planting, to meet conservation tillage requirements. Mean soil erosion estimates in CT plots under CR system were 3 to 5 times higher than those under NT and MT. This result shows that reduced tillage is necessary for achieving the benefits of reduced soil erosion with cover cropping in cotton production. Without cover cropping, soil erosion estimates in NT plots were about one third of that in CT in both years. Similar results were found by Stevens et al. (1992), who reported that no-till cotton cropping without cover cropping may reduce soil erosion by 70% compared to CT system.

Surface application of PL at 100 kg N $ha^{-1}$ gave significantly lower C-factors compared to control plots and 100 kg N $ha^{-1}$ in the form of AN under CT in both years (Table 3). Similar results were obtained in NT system. The lower C-factor values with use of PL indicate that soil erosion rates were lower than those in plots which received an equal amount of N but in the form of AN, or those which did not receive any N. The better erosion control with PL can be attributed to the fact that when surface applied, the litter material acts as a residue cover, which protects soil from the direct impact of raindrops, slows runoff water movement, and also increases infiltration. The RUSLE model takes into account of the residue effect of PL in the calculation of the C-factor.

At each level of N, soil erosion estimates in NT was below 5 t $ha^{-1}$ $yr^{-1}$ compared to over 15 t $ha^{-1}$ $yr^{-1}$ under CT at 0 or 100 kg N $ha^{-1}$ AN levels in both years (Fig. 4). Plots which received 100 kg N $ha^{-1}$ in the form of PL had 10, 3, and 3 t $ha^{-1}$ $yr^{-1}$ less soil erosion rates under CT, NT, and MT systems respectively, compared to plots which received the same amount of N in the form of AN in 1997. Similar figures for 1998 were 9, 2, and 3 t $ha^{-1}$ $yr^{-1}$. Doubling the N rate through PL to 200 kg N $ha^{-1}$ under NT system gave the lowest soil erosion estimate levels of less than 2 t $ha^{-1}$ $yr^{-1}$ in both years (Fig. 4). Application of N in the form of AN or PL reduced soil erosion rates due to higher cotton canopy cover, root biomass, and more cotton residues compared to control plots (Fig. 3).

The tolerance level of soil erosion loss for these Decatur series soils is 11 t $ha^{-1}$ $yr^{-1}$ (Reddy et al., 1994). Results from this study clearly show that growing cotton under CT with or without a winter rye cover crop using AN fertilizer at 100 kg N $ha^{-1}$ on the Decatur silt loam soils results in soil erosion estimates up to 10 t $ha^{-1}$ $yr^{-1}$ in excess of the tolerance level (Fig. 4). However, using PL as the N source under CT gave soil erosion estimates 4 to 5 t $ha^{-1}$ $yr^{-1}$ below the tolerance level (Fig. 4). Soil erosion estimates under NT and MT systems were about 50% of the tolerance level. The reduction in soil erosion will result in a reduction of the amount of nutrients and pesticide residues, which end up in surface and groundwater resources.

## CONCLUSIONS

Soil erosion estimates under CT and CF cropping system with the use of AN fertilizer were similar to that in BF plots, which are about twice the tolerance levels for north Alabama. Adoption of NT or MT systems with winter rye cover cropping and PL in the current cotton production systems can significantly reduce soil erosion and thus improve the sustainability of cotton soils in the southeastern USA, where erosion and safe disposal of PL are major problems.

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