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Cooperative Soil Conservation Studies at Holly Springs 1956-1996

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This publication summarizes 40 years of collaborative soil conservation research at Holly Springs by scientists of the USDA-ARS National Sedimentation Laboratory, Oxford, Mississippi, and the Mississippi Agricultural and Forestry Experiment Station North Mississippi Branch Experiment Station at Holly Springs.

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Many MAFES and USDA workers have been involved in research at Holly Springs since the cooperative erosion studies began 40 years ago. It is appropriate to acknowledge their contributions to the success of this long-term collaborative effort.

S.P. (Bill) Crockett was superintendent of the MAFES North Mississippi Branch Experiment Station when the Agricultural Research Service (ARS) initiated research projects at the Experiment Station in 1956. Billy L. Arnold worked for the station as an agronomist at that time and later became superintendent. He was followed by Joseph R. Johnson as station agronomist, and later, as superintendent. Currently, Donald E. Pogue is serving as the station superintendent. In recent years, C. Pat Bagley, Head of the North Mississippi Research and Extension Center, has provided valuable support and leadership for research at the station. Research efforts at the station could not have been successful without the excellent support and extraordinary efforts of many technicians from MAFES and the National Sedimentation Laboratory (NSL) through the years. The help of career employees, temporary employees, and student help during summertime is gratefully acknowledged.

Calvin K. Mutchler, National Sedimentation Laboratory collaborator and former Laboratory Director of the NSL, provided much of the early historical information for this report. Mutchler was responsible for the first erosion plot installations before being transferred to another ARS location at St. Paul, Minnesota in 1958. He returned to the NSL in 1972 as Research Leader of the Sediment Yield Unit (SYU) of the NSL. The SYU research

responsibilities included the conservation tillage research at Holly Springs. Over the years, the USDA-ARS has undergone organizational changes, and several administrative and organizational changes have occurred at the NSL. The Upland Erosion Processes Unit (UEPU) of the NSL now conducts soil erosion research on conservation tillage, while the Water Quality/Ecology Processes Research Unit (WQEPRU) conducts cooperative water quality research.

Dwight D. Smith had national erosion research responsibilities when the Holly Springs erosion research was initiated. John R. Carreker served as Research Investigations Leader (RIL) for about a decade beginning in the early 1960's, and actively participated in planning soil erosion-related research at Holly Springs and other locations in the southeastern United States.

Several ARS agricultural engineers have worked on erosion-related research at Holly Springs, and several have had duty stations located there. Coy W. Doty, agricultural engineer, arrived in 1958, and left in 1964 for graduate studies in Brookings, South Dakota. Cade E. Carter, agricultural engineer, arrived in 1962 and left in 1967 for graduate studies at Louisiana State University. Keith C. McGregor, agricultural engineer, arrived in 1967.

Under Carreker's leadership, McGregor completed erosion-related plot and watershed studies begun by Doty and Carter, and initiated new conservation tillage studies, including no-till soybeans, a no-till soybean-corn rotation, and no-till soybeans doublecropped with wheat. McGregor completed these studies under Mutchler's leadership, and also began other conservation studies on no-till and reduced-till corn.

Mutchler planned and conducted several conservation tillage studies (including no-till cotton and sorghum) at Holly Springs during the late 1970's and through most of the 1980's; he continues to collaborate on analyzing and reporting results from the conservation tillage research.

McGregor currently conducts conservation tillage research studies (including the return of conservation reserve program land to crop production) at Holly Springs under the leadership of M. J. M. Römkens, the Research Leader of the UEPU unit of the NSL. This research is conducted jointly with MAFES personnel at Holly Springs. George Foster, the NSL Director, also has been involved recently in planning and conducting a tillage study on the effects of grass strips on erosion control.

McDowell, a former Research Leader for the Sediment Properties Unit that preceded the present WQEPRU at the NSL, worked closely with the Sediment Yield Unit in the early years of the conservation tillage studies. He studied the effects of various tillage practices on losses of herbicides and plant nutrients from the runoff plots of these early conservation tillage studies. Several other scientists in the WQEPRU of the NSL have continued water quality research at Holly Springs; this report does not summarize that research.

Invaluable cooperation, support, and encouragement were received from personnel of the Soil Conservation Service (now called National Resource Conservation Service) and the Mississippi Cooperative Extension Service over the full term of this research. As major users of our soil conservation research results, they provided advice on use and conduct of our research and on further research needs.

Contents

Introduction

This report reviews almost 40 years of cooperative research in soil erosion and conservation tillage between the National Sedimentation Laboratory (NSL) and the North Mississippi Branch of the Mississippi Agricultural and Forestry Experiment Station (MAFES) at Holly Springs, Mississippi. Some historical information also is included. The NSL, located at Oxford, and the North Branch Experiment Station, located 30 miles north of Oxford at Holly Springs, are in the north central region of Mississippi. The Brown Loam soils at the station are representative of the severely eroded loess soils of the southeastern United States. These soils are moderately to relatively high in fertility, with high silt and low sand content, and are easily eroded by rainstorms typical of the region.

Soil conservation research at the North Mississippi Branch Experiment Station has produced 58 publications based directly or indirectly on data collected there. The data sets from the erosion plots and small watersheds have been, and currently are, used extensively to validate the Universal Soil Loss Equation (USLE), the Revised Universal Soil Loss Equation (RUSLE), and the Water Erosion Prediction Project Model (WEPP).

Research on runoff and soil loss from conservation tillage is described generally in chronological order. This is followed by a review of other ARS research at Holly Springs over the past 40 years on sediment characteristics, rainfall erosivity, agricultural chemical runoff, equipment design, and other miscellaneous topics.

Plot and Watershed Establishment

In 1956, the runoff/erosion project at the MAFES Branch Station at Holly Springs was authorized in the Soil and Water Conservation Research Branch (SWCRB) of the Agricultural Research Service (ARS). Cooperative research was authorized between the Eastern Soil and Water Management Section (ESWMS) and the Watershed Hydrology Section, which contained the National Sedimentation Laboratory (NSL). The idea for the erosion project is credited to Russell Woodburn, Director of NSL, who had been involved in erosion plot studies at Mississippi State in the 1940's. C. K. Mutchler, Agricultural Engineer in ESWMS at State College; D. D. Smith, Work ProjectLeader in SWCRB-ARS at Beltsville; and S. P. Crockett, Superintendent of the North Mississippi Branch Experiment Station, also were involved in initiation of erosion studies. An ARS reorganization in 1961 placed all of the Holly Springs research conducted by ARS under the NSL.

Smith, Woodburn, Mutchler, and Crockett located erosion plot sites at the Experiment Station in the fall of 1956. Mutchler and F. E. Dendy (NSL) located three small cultivated watersheds and one pasture watershed adjacent to the study site. Dendy and Woodburn installed instrumentation for the watersheds to determine total storm runoff and storm average sediment concentration. The cultivated watersheds were 1.45, 1.61, and 3.88 acres in size with an average slope of 7.0, 6.5, and 7.8%, respectively. The Loring, Lexington, and Providence soils on these watersheds had similar surface texture. The pasture watershed was 3 acres in size with an average slope of 9.2%. The pasture watershed contained Grenada, Providence, and Ruston soils.

Mutchler located and installed eight 0.25-acre contoured plots and eight 0.05-acre pasture erosion plots. The contoured plots were 150 feet across the slope, the pasture plots were 30 feet wide, and the slope length for both sets was 72.6 feet. Four contoured plots were on 5% slope, two were on 2.5% slope, and two on 10% slope. The pasture plots were in four fields, with one plot on 5% slope and one on 10% slope in each field. Soils on the plots were similar to the watershed soils. More complete soil descriptions are given in McGregor et al. (1969).

Coy W. Doty established 12 small erosion plots in 1961. These were "standard" plots with 72.6-foot slope length designed to be farmed up-and-down-hill. The 72.6-foot length was derived from a contour interval at some earlier time, probably in the 1940's. Early plots that were cultivated by hand were 6 feet wide so that area was exactly 0.01 acre. The standard plots at Holly Springs were farmed with two-row tractor-drawn equipment using four 40-inch rows to provide a plot area of 0.022 acre. All of these plots were placed on a 5% slope, or nearly so, to allow easier comparison of treatments on the different plots.

Data collection from erosion studies at Holly Springs began in November 1957 from eight runoff plots on good and poor pasture, eight contoured runoff plots on three slopes using good or poor cultural practices for corn, one small pasture watershed, and three small watersheds with cultivated corn. These studies, designed and started by Mutchler, were used to document significant savings of soil loss and runoff using high fertilization and plant population and good residue management for pasture and corn.

All data collected from the plots, watersheds, and rain gauges since the start of the project were reported annually on standard forms to Walter H. Wischmeier, who headed the ARS erosion data processing group at Purdue University, West Lafayette, Indiana. Smith and Wischmeier are generally credited for the USLE, although numerous people contributed to the development and to the database. Holly Springs data were included in the analysis that formed the basis of the USLE in Agriculture Handbooks 282 and 537 (AH 282 and AH 537) (Wischmeier and Smith, 1965; Wischmeier and Smith, 1978). AH 537 was a revision of AH 282.

In addition to being a good erosion prediction equation, the USLE was of tremendous benefit to researchers around the country. The USLE was a good guide for planning experiments but, more importantly, research results from such experiments could be compared directly. The standard USLE plot was a major contributor to obtaining comparable data from other researchers and different locations.

Soil Loss Equations

Universal Soil Loss Equation

A note is needed here to explain the use of the USLE for collection of research data and for use in erosion estimation. The soil loss equation is:

$$\mathbf{A = R\ K\ L\ S\ C\ P} \qquad \mathbf{(1)}$$

where A is the computed soil loss per unit area, R is the rainfall factor, K is the soil erodibility factor, L is the slope length factor, S is the slope-gradient factor, C is the cropping-management factor, and P is the erosion-control practice factor. The R-factor for a particular location is defined as the average annual erosion index (EI) of rainfall at that location. The EI of any one storm is the product of the storm's rainfall kinetic energy and the storm's maximum 30-minute rainfall intensity. Wischmeier and Smith defined the factors in AH 282 (Wischmeier and Smith, 1965) and essentially repeated the definitions in AH 537 (Wischmeier and Smith, 1978). All of the data reviewed in this paper were collected in the format of the USLE so it is important to know how the equation is used.

The estimated soil loss (A) is used to decide if the crop and tillage are suitable for conservation purposes; the "soil loss tolerance" (usually 3 to 5 tons/acre) is used as a guide. Soil erodibility (K) is assumed constant throughout the year in the USLE (but not in RUSLE); L, S, and P also are constant values. However, soil loss varies greatly during the year because of cover and canopy of the crop and the erosivity of rainstorms.

Therefore, the year is divided into crop stages so that the two varying factors of the USLE, R and C, could be assumed constant for the crop stage. Thus, for each research crop stage:

$$\mathbf{SLR = At\ /\ (EIt\ K\ L\ S\ P)} \qquad \mathbf{(2)}$$

Note that C is used for an average annual value and SLR is used for some other time period, e.g., crop stage. Also, since R is an average annual value, EI is used for rainfall erosivity during the crop stage. Crop stage soil losses, At, are added to get the annual soil loss, A. The other factors become a constant for a particular site, or a research plot. The values of SLR are used with local values of rain energy, EI, and the constant values in equation 2 to compute locational values of soil loss for various crops and tillage systems. In use, an EI distribution curve and a locational R-factor are used to compute EI for each crop stage.

Data from research erosion plots are collected and tabulated to be compatible with crop stages used in the USLE. Soil loss and EI are measured for each storm during the year and are then accumulated for the crop stages. The crop stages were defined in AH 282 (Wischmeier and Smith, 1965) and repeated in AH 537 (Wischmeier and Smith, 1978) with some small revision. They are summarized from AH 537 as follows:

- **Period F (rough fallow)** -- Inversion plowing to secondary tillage.
- **Period SB (seedbed)** -- Secondary tillage until 10% canopy cover.
- **Period 1 (establishment)** -- End of SB until 50% canopy cover.
- **Period 2 (development)** -- End of period 1 until 75% canopy cover.
- **Period 3 (maturing crop)** -- End of period 2 until crop harvest.
- **Period 4 (residue or stubble)** -- Harvest to plowing or new seeding.

These crop stages were modified for some tillage systems used at Holly Springs, and period 4 was usually subdivided to better describe winter erosion in the warm climate of the South.

Revised Universal Soil Loss Equation

Research conducted by the NSL in cooperation with MAFES (much of which is discussed in this bulletin) contributed to several changes incorporated into the Revised Universal Soil Loss Equation (RUSLE) that are particularly applicable to Mississippi. These improvements include a reduction in the R-factor, which compensated for ponded water on flat slopes; an improved slope steepness relationship for low slopes; a subfactor method to compute the effect of cover and management for a wide range of conditions; the consideration of the effect of winter weeds; much improved accuracy for no-till; a method to compute the effect of contouring as a function of storm erosivity, row grade, and ridge height; and a method to compute the effect of a wide variety of cropping systems that involve grass strips.

Initial Research Results

Poor vs Improved Management for Corn

Doty (1961) reported first-year soil and water losses from poor and improved management for corn on 5% and 10% contoured plots. Doty and Dendy (1962) reported losses from a 2-year period (Nov. 1, 1958 through Oct. 31, 1960) from four 5% contoured plots and four small watersheds. Poor practices included light fertilization and planting rates; cornstalks were left standing following harvest. Improved management practices included using MAFES recommended fertilization and planting rates; cornstalks were shredded in the fall and left on the soil surface to protect the soil from erosion.

Soil losses, even with improved practices, were higher than generally acceptable; however, the well-fertilized stand of corn provided some erosion benefits. High erosion in May and June of 1959 was reduced one-third with the improved practices. Twelve inches of rain in October, November, and December of 1959 resulted in 3 inches of runoff and 0.2 ton/acre (t/a) soil loss from the improved practice for corn compared to 4 inches of runoff and 0.5 t/a soil loss from the poorly managed corn.

Doty and Dendy (1962) reported the reduction of soil and water losses by improved management using 2 years of data (Nov. 1, 1958 through Oct. 31, 1960) from four 5% sloping contoured plots and four small watersheds

(Table 1). Several important findings for Mississippi farming were documented. Runoff and soil loss from the prevailing management practice for corn on the 5% contoured plots resulted in 18 in/yr of runoff and 18 t/(a-yr) of soil loss. Liming, fertilization, plant population, and residue management according to best farming practices reduced runoff to 14 in/yr and soil loss to 9 t/(a-yr). The same relative results were obtained from the small watersheds. Thus, the importance of good management for erosion control was evaluated and documented.

Poor vs Improved Management for Pasture

Carter et al. (1966a) reported the results of research on improved management of pasture using eight 0.05-acre plots and one 3-acre watershed. The plots and watershed were discontinued at the end of 1963 after about 6½ years of operation.

Improved management for the pasture research included the control of grazing, appropriate fertilization, reseeding, and clipping for weed control. Poor management areas were not fertilized or reseeded and were overgrazed.

The data in Table 2 show that soil loss from properly managed pasture was very small. Soil loss from poorly managed watersheds, although small, increased with slope on the plots. Larger soil losses on the watershed were attributed to rills and small gullies that formed as the vegetative cover deteriorated under poor management toward the end of the experiment. This increase in erosion from poor pasture management is very significant, and has probable similar effects in other land uses where fertilization is inadequate.

Research During the 1960'S

Doty and Dendy (1962) reported that 28 fractional-acre plots and four small watersheds had been selected for measurements of runoff and soil loss. The fractional acre studies included 12 small 0.022-acre erosion plots that Doty established in 1960. These were the "standard" 72.6-foot slope-length plots with 40-inch wide rows in up-and-down-hill directions used to collect data for the USLE. For experiments involving the effects of contouring, row direction was made perpendicular to the slope. Doty established three experiments on these plots with the first usable data collected on Oct. 1, 1962.

Four plots were used to compare the effect of contouring; one pair was contoured, one pair was farmed with the slope, and continuous corn was grown on all four plots. Six plots were used to evaluate a 3-year rotation of 2 years of bermudagrass followed by a year of corn. Two plots, one on Loring and the other on Lexington soils, were used to determine base rates of erosion; these plots were kept fallow and free of cover. These fallow plots were cultivated in the spring in the same manner as conventional-till corn plots, smoothed to a level surface by harrowing, and then only lightly cultivated as necessary to control weeds or to destroy the formation of a crust on the soil surface. Data from the fallow plots also allowed direct computation of soil loss ratios and C-factors. A C-factor is defined in the USLE as the ratio of soil loss from some particular management to the soil loss from fallow.

Six contoured 0.25-acre plots, two each on 2.5%, 5%, and 10% slopes, were planted to continuous corn using the same management as on the standard plots. Runoff and soil loss data were collected from Oct. 1, 1961 through Sept. 30, 1968. Data from the larger contoured plots on three slopes was used to evaluate the effect of slope on erosion.

Results of these studies were reported by Carter et al. (1968) and McGregor et al. (1969b) and are summarized below.

Effects of Contouring

The effect of contouring in the USLE is defined as the ratio of erosion from up-and-down-hill tillage to that from contouring. Data from the two up-and-down-hill plots, the two contoured standard plots, and the two 5%

contoured plots were used to evaluate the effect of contouring on soil and water losses (Table 3).

Contours on the standard plots were only 13.3 feet long, and thus reflected nonrealistic field situations because field rows usually are not perfectly contoured. On the small plots, soil loss was reduced 90% by these miniature terraces formed by tillage for bedding. However, the 0.25-acre contoured plots had 150-foot graded rows (0.2 to 0.4 ft/100 ft) that were more representative of field conditions. The ratio of soil loss from contoured and standard plots of 0.41 was a legitimate addition to the database used for determining the contour factor in AH 282 (Wischmeier and Smith, 1965).

Bermudagrass-Corn Rotation

Sod-based rotations have had a history of good land use because the grass provides good protection from erosion. The crop rotation in this study (Table 4) used bermudagrass, which is a warm-season perennial that thrives on sunshine and hot weather.

These data show the value of a grass-based rotation in controlling erosion in Mississippi; however, the reputation of bermudagrass as a weed in cornfields was borne out. Corn often had to be replanted, and grass competed for moisture. Interestingly, some 10 years or so later when chemicals were more available, trials of corn in chemically-killed sod were tried with little success, especially in dry years. However, no-till cotton and no-till corn were successfully grown in 1994 in chemically-killed sod on watersheds simulating the return of conservation reserve program land to crop production (McGregor et al., 1995).

Effect of Slope Steepness on Erosion

Because data from the 0.25-acre contoured plots were from the same cropping and management practices, they also could be used to examine the effect of slope on erosion (Table 5).

Runoff and soil loss both increased as slope increased in the 0.25-acre contoured plots. Runoff increased linearly with slope, and soil loss nearly did so. The slope factor in the USLE is described as curvilinear in AH 282 (Wischmeier and Smith, 1965) and AH 537 (Wischmeier and Smith, 1978). However, the latest slope equation is linear with a break at 9% to a steeper slope (Renard et al., 1995); this agrees with the data in Table 5.

Soil Erodibility from Fallow Plots

Data from the two standard plots that received the fallow treatment (Table 6) were used to compute the erodibility of the Loring and Lexington soils and served as a base for computing a standard value for the other treatments on the standard and contoured plots. These two plots were installed in September 1960. Runoff and soil loss measurements were not made for the first 2 years, which allowed time for prior crop residues to decompose.

Total soil loss and EI from 1963-1967 were used to compute K-factors for the two soils (McGregor et al., 1969a). A K-factor of 0.51 was determined for Loring soil and a K-factor of 0.45 was determined for Lexington soil. These values were useful to conservationists who assembled tables of K values for Mississippi soils. For example, these measured values were included along with other values computed with the nomograph method (Wischmeier and Smith, 1978). Also, these values allowed researchers collecting data at Holly Springs for determination of C values for various tillage systems to cease measurements of fallow plots.

Note that a soil loss ratio, or C-factor, is defined as a ratio of soil loss from a specified cropping practice divided by loss from fallow under the same soil and topographical conditions. The USLE is A = RKLSCP. On experimental plots, A (soil loss), R (rainfall erosivity), and LS (length and slope) are measured. On small plots, P (support practice factor) equals 1 for the usual up-and-down-hill tillage. Therefore, prior knowledge of K (soil erodibility) allows computation of C from rainfall and soil loss measurements (see equation 2).

Storm data from the fallow plots also were used to show the variability of erodibility throughout the year. This research, published in 1983, is described later.

Effect of Terracing

A 1.45-acre watershed was used to evaluate terracing (Carter et al., 1966b). The watershed had an average slope of 7% and was in corn continuously from 1960 to 1966. During 1960-1962, the watershed rows were on the approximate contour. Then, in the spring 1963, broadbase parallel terraces were constructed along with a waterway sodded with common bermudagrass. Data from before and after terracing are shown in Table 7.

Soil loss after terracing was about 50% less than before terracing. This reduction was attributed to the graded rows in the terrace plan and the grassed waterway. The grass sod not only protected the channel from erosion, but also filtered out some of the sediment in the runoff. These data supported the P value of 50% for contouring on 3% to 8% slopes given in AH 537 (Wischmeier and Smith, 1978).

Conservation Tillage Research

The modern era of conservation tillage research at Holly Springs began in the fall of 1969. During the 1969 transition year, preceding increased emphasis on conservation tillage, research areas were planted to conventional-till soybeans to help provide uniformity between plots. These were the standard 0.22- acre plots, a 3.88-acre watershed, and a 1.61-acre watershed.

For many years, the experiments at Holly Springs were the only field research conducted to evaluate the effects of conservation tillage on soil erosion in the Deep South. Originality in crop management was necessary because there were very few sources to draw upon in applying no-till and reduced-till practices in this area of the country. Several things had to be done in those early years to "simulate" no-till conditions. For example, soybeans had to be replanted on research plots because rabbits ate the tender soybean plants. One person would hand-spray herbicides while two others would walk along holding wooden "troughs turned upside down" over the plants to protect them from the chemicals. Much has been learned, and better resources are now available to conduct conservation tillage research.

Conservation Tillage for Soybeans

In the fall of 1969, wheat was drilled with a "Pasture-dream" planter on two watersheds and two erosion plots to begin no-till, doublecropped, soybean-wheat systems to be grown on these areas (McGregor et al., 1975). Planting of wheat in this fashion was successful after using a side-delivery rake to remove the residue in front of the planter. The side-delivery rake was then used to replace the residue. The next spring, soybeans were planted in standing wheat stubble to reduce "planter-clogging" problems with a no-till planter, then the stubble was shredded and left on the surface to provide maximum soil loss protection.

During a 3-year period (1970-1972), soil losses were measured from duplicate 5% sloping, 0.022-acre erosion plots. No-till cropping treatments included continuous soybeans, soybean-corn rotation, and doublecropped soybeans and wheat. Soil losses also were measured from duplicate plots of conventional-till continuous soybeans. The doublecropping system was also used on up-and-down-slope rows on the 3.88-acre watershed and on contoured rows on the 1.61-acre watershed. Results are given in Table 8 for the doublecrop soybean-wheat treatment on standard plots and two small watersheds. Research using the same treatments on plots was continued for a fourth year and is reported in Table 9.

During this no-till soybean study, the no-till plots were not cultivated after midsummer of 1969. The normal sequence of tillage operations in the conventional-till plots during the study period was disk-harrow, turn-plow, disk- harrow, bed, and section-harrow at planting, which was followed by cultivation for weed control as needed during the growing season. The only tillage in the no-till system was that done as a fluted coulter cut through surface residues and into the soil at planting. The no-till planter was first used on most of the plots in the spring of 1970. The 3-year (1970-1972) water-year (Oct. 1 through Sept. 30) averages showed the erosion-control benefits of conservation tillage versus conventional-till, even though these data included the 1969 residue crop stage from conventional-till plots as part of the no-till averages. Erosion on conventional-till plots on moderately sloping land usually can be controlled during the residue crop stage provided residues are left uniformly over the soil surface.

Soil loss results from watersheds were larger than from the small plots (Table 8). However, the data showed that doublecrop soybeans-wheat could be grown in field situations with erosion-control benefits. Also, the benefits of contouring with no-till were documented. As explained earlier, the use of C in the USLE is reserved for an average annual cropping-management factor value and SLR is used to mean some soil loss ratio for some time period other than a year. Likewise, EI is used here for any time period other than a year since the R-factor is defined as the average annual erosion index. Occasionally, the literature refers to the erosion index during a year as being an annual R value, or as being an annual EI value.

Data in Table 9 illustrated that lower soil loss ratios (SLR) could be obtained in the humid southern United States. Values of SLR's given in AH 282 (Wischmeier and Smith, 1965) and essentially repeated in AH 537 (Wischmeier and Smith, 1978) were equal to or greater than 24% for the crop stages in conventional-till soybeans. The SLR = 0.114 in Table 9 is 11% for the entire crop year. This large reduction in soil loss estimates was of great value for conservationists in the South dealing with high rainfall rates and amounts that resulted in R-factors of 350 and greater. Use of no-till in the 1970's was recognized in AH 537 and given an estimated SLR of equal or greater than 11% for the crop stages. The SLR values for no-till (Table 9) are much less. These data and later Holly Springs research findings were influential in lowering C-factors for no-till to current levels used in RUSLE. Soybeans and wheat grown in a doublecrop system was made easier because of no-till. The system is effective in controlling erosion.

As a result of the previously described research, cropping and management factors (C) for use in soil loss prediction were established for no-till soybeans, no-till corn and soybeans in a rotation system, and doublecropped no-till soybeans and wheat. These values were significant because their use in the USLE reflects the large conservation benefits of no-till compared to conventional-till, and because of severe erosion problems resulting from increasing acreage (at that time) of soybeans planted on marginal land. These results were directly useful in farming practices as well as in Soil Conservation Service (now the Natural Resource Conservation Service, NRCS) operations in the humid United States.

Effects of Weeds in Soybeans

Mutchler and Greer (1984) reported soil loss for no-till continuous soybeans, reduced-till continuous soybeans, and reduced-till soybeans-wheat doublecropped during a 3-year period from 1978 to 1980. In the reduced-till system, a no-till planter was used to plant soybeans in a slot made by a small chisel following a fluted coulter that cut through surface residues. But the reduced-till plots were cultivated twice for weed control during the growing season using three sweeps in each middle.

The no-till and conventional-till treatments were repeated from the 1970-72 experiment reported by McGregor (1978). However, the primary objective was to evaluate the effect of weeds on erosion control. Since weeds vary in different parts of the country, SLR's for soybeans without weeds were needed for nationwide use. The estimated effect of weeds for the particular locality could easily be added to the no-weed SLR. Results of these tests are given in Table 10.

Soil loss ratios are independent of other factors of the USLE so they can be used to compare the erosion-control effectiveness of the various tillage systems and crops. Measured soil losses usually are greater in years of greater rain and rainfall energy. In Table 10, all the soil loss values are from the same years. However, they were adjusted to an annual value of KE=360 to allow direct comparison with like adjusted SL values from other crops and conservation tillage systems.

Weeds made a relatively small contribution to cover and, consequently, to a reduction in soil loss with soybeans. This result is in contrast to the larger influence of weeds in conservation tillage for corn (discussed later).

The average annual soil loss and C-factors (Table 11) for various conservation tillage systems for soybeans during the 1970-1973 study period were compared to those from the 1978-1981 period (Mutchler and Greer, 1984). The later 3-year study provided average annual C-factors for conventional-till and no-till soybeans that were almost identical to those McGregor obtained earlier. These computed C-factors also showed that C values given in AH 537 (Wischmeier and Smith, 1978) would over-predict soil loss about five times as compared to measured values for either conventional-till or reduced-till soybeans.

Conservation Tillage for Corn

McGregor and Greer (1982) reported 3 years of data from a conservation tillage for corn experiment using standard erosion plots and three small watersheds. The five treatments were:

Duplicated plots:

1. Conventional-till corn for silage (C-SIL).
2. Conventional-till corn for grain (C-GR).
3. No-till corn for silage (N-SIL).
4. No-till corn for grain (N-GR).
5. Reduced-till corn for grain (planted no-till but followed by two or more cultivations during the growing season (R-GR).

Non-duplicated watersheds:

1. No-till corn for silage on the 3.88-acre watershed.
2. No-till corn for grain on the 1.45-acre watershed.
3. Reduced-till corn for grain on the 1.61-acre watershed.

Data from the plots for the 3 years were combined with a fourth year and reported by McGregor and Mutchler (1983), who computed C values for no-till and conventional-till corn for grain and for silage and for reduced-till corn for grain. Tillage methodology was the same as described in the earlier soybean study except for some changes made in no-till planting. As in the earlier no-till corn-soybean rotation study, only a fluted coulter cut through the crop residues at planting. However, in this study, a small chisel was located behind the coulter and modified to allow the placement of both seed and fertilizer in the same slot, but with the seeds separated from the fertilizer by a 2- to 3-inch layer of soil. This modification ensured the incorporation of fertilizer beneath the ground surface, thus reducing plant nutrient losses and the subsequent contamination of surface runoff.

Table 12a shows the average annual soil loss and the average annual C values, computed with and without the influence of weeds, for the various tillage treatments on plots. Rainfall during this corn study was 64, 51, 45, and 43 inches with annual EI values of 467, 361, 348, and 266, respectively. These annual amounts of rainfall and EI provided ranges below and above the average values that McGregor and Mutchler (1983) reported for the previous 12 years of 52 inches and 418, respectively. The average annual EI distribution for the study period followed closely that expected for Holly Springs, according to AH 537 (Wischmeier and Smith, 1978). The average annual soil loss measured from conventional-till corn for grain was more than 16 times that measured from no-till grain; soil loss from conventional-till corn for silage was more than 25 times that from no-till silage.

Runoff and soil loss data from the small watersheds are shown in Table 12b. Soil losses from cropping treatments on the watersheds were slightly less than from the same treatments on plots. However, the different years may have accounted for some of these differences. The important result was the large reduction in erosion from corn grown with the conservation tillage systems.

The literature usually shows expected C values for crop stages expressed as soil loss ratios. The soil loss ratio definition for a crop stage is the same as a measured C value, but expressed as a percentage rather than a decimal value. McGregor and Mutchler (1983) adjusted soil loss ratios to remove the cover effect of weeds because the number and effect of weeds vary from one location to another. These adjustments help in comparing C values from one location to another, although values based on measurements will be dependent on EI distributions for different locations.

Weeds made a significant reduction in erosion from corn in contrast to their effect on soybeans as presented earlier. This reduction was especially large for silage that is harvested early in the fall leaving time for extensive growth of summer weeds before the first frost.

Table 13 shows a comparison of these adjusted values for this corn study with those reported in AH 537 (Wischmeier and Smith, 1978) for similar treatments. Crop stages used in this table are from AH 537, as described earlier under the Soil Loss Equation Section.

Handbook values were higher than the Holly Springs data by a factor of about 3, 3, 6, 6, and 5 for conventional-till for grain, conventional-till for silage, no-till for grain, no-till for silage, and reduced-till for grain, respectively. Differences between adjusted and Handbook values for conventional-till treatments were more uniform throughout all crop stages than were differences for no-till and reduced-till treatments. Differences between adjusted and Handbook values for the no-till and reduced-till treatments were significantly higher in the earlier crop stages, showing higher than expected effectiveness of crop cover during these periods. These results help to illustrate the high potential of no-till and reduced-till systems in reducing erosion in the deep South. In this region, highest rates of rainfall often occur during the early growing season when fields are most vulnerable to erosion (Greer, 1971).

Conservation Tillage for Cotton

Mutchler et al. (1985) evaluated no-till, reduced-till, and conventional-till cotton systems for erosion-control effectiveness using the same tillage procedures described by McGregor and Mutchler (1983) for tillage evaluation of corn and by Mutchler and Greer (1984) for tillage evaluation of soybeans. Treatments were:

1. No-till cotton after reduced-till soybeans.
2. No-till cotton after no-till soybeans-wheat.
3. Reduced-till cotton after no-till fallow, 1-year fallow in which chemicals were used to eradicate bermudagrass.
4. Reduced-till cotton after no-till soybeans-wheat.
5. Conventional-till cotton after 11 years of conventional-till corn and soybeans.
6. Conventional-till cotton after 11 years of no-till corn and soybeans.

Table 14 gives annual soil loss values and soil loss ratios for use in soil loss prediction, with and without weeds, for these tillage treatments adjusted to an annual EI of 360 (customary English Units). Soil loss values were adjusted to a common EI base because data collection periods during 1979 through 1983 for the various treatments were not the same. Before the EI adjustments were made, values of soil loss without weeds were subtracted using a weed cover subfactor approach (McGregor and Mutchler, 1983). Table 14 also shows runoff as percent of rainfall for information.

These data show that growing conventional-till cotton in northern Mississippi on moderate slopes without conservation measures can be very erosive. Average annual soil losses from conventional-till cotton on plots with 11 years of conventional-till history were more than three times that reported earlier by McGregor and Mutchler (1983) from conventional-till soybeans and more than four times that reported for corn, even though grown under similar climatic conditions (Mutchler et al., 1985). Prior tillage affects the amount of erosion even for conventional-till practices; conventional-till cotton following 11 years of conventional-till produced more than 1.5 times the erosion measured from conventional-till cotton following 11 years of no-till practices.

Cotton with Winter Cover Crops

Mutchler and McDowell (1990) reported on the soil conservation effectiveness of winter cover crops with no-till and conventional-till cotton. Treatments studied in this 1981-1983 period included:

1. No-till cotton with vetch or wheat winter cover after 1 year of no-till cotton following soybean-wheat doublecrop.
2. Reduced-till cotton with vetch or wheat winter cover after 2 years of reduced-till cotton following no-till soybeans.
3. No-till cotton with vetch or wheat winter cover after 3 years of no-till cotton following reduced-till soybeans.
4. Conventional-till cotton with vetch or wheat winter cover after three years of conventional-till cotton following 11 years of no-till soybeans or corn.
5. Conventional-till cotton with vetch or wheat winter cover after 14 years of conventional-till for cotton, soybeans, and corn.

Table 14 gives the average annual soil loss, soil loss ratios, and runoff as percent of rainfall for these cotton treatments (Mutchler et al., 1985). Soil loss from conventional-till cotton without winter cover was more than three times that from conventional-till cotton with a winter cover in this study (Mutchler and McDowell, 1990). Mutchler and McDowell (1990) reported that the addition of vetch or winter wheat cover reduced erosion from cotton plots to acceptable levels. Wheat was as effective as vetch in reducing erosion and was easier to chemically burn down in the spring. The major contribution of these cotton studies was the evaluation of soil loss ratios for cotton using conventional and conservation tillage since values being used for soil loss prediction had been based primarily on research grown in a flatland watershed.

Soil Loss from Conservation Tillage for Sorghum

In this study, a ridge-till system was evaluated for use in the Midsouth. McGregor and Mutchler (1992) reported that sorghum was selected as the crop because of its similarity to corn and because it had not been evaluated before on the erosion plots. Treatments on the standard erosion plots were:

1. Ridge-till sorghum after one year of conventional-till sorghum used to prepare ridges with three cultivations and preceded by no-till cotton with wheat cover crop.
2. Conventional-till sorghum after 3 years of reduced-till cotton with vetch or wheat cover crop.
3. No-till sorghum after 3 years of conventional-till cotton with vetch or wheat cover crop.
4. Reduced-till sorghum (no-till plant and cultivate for weed control) after 3 years of conventional-till cotton with vetch or wheat cover crop.
5. No-till sorghum after 4 years of no-till cotton with vetch or wheat cover crop.

Ridge-till was defined as no-till planting on ridges left by cultivation of the previous sorghum crop. The crop had been cultivated two times, leaving a ridge about 6 inches higher than the middle. In 1988, the old sorghum stalks were removed from the ridges with a ridge sweep before planting. This procedure was not used again because planting on the ridge was not made any easier.

Reduced-till differed from ridge-till only in that use of conventional cultivators left a ridge about 2 to 3 inches higher than the middle. Conventional-till, in this study, consisted of one or two diskings and harrow at planting followed by two cultivations during the growing season that left a ridge about 2 to 3 inches high, the same as for the reduced-till treatment. Residues for all treatments were shredded immediately after harvest. Regrowth of sorghum furnished canopy cover that shaded out weed growth in the fall.

Table 15 gives the average annual soil loss, soil loss ratios, rainfall, and runoff for the various sorghum treatments. Adjusted soil loss of 3.49 t/a from conventional-till slightly exceeded the accepted limits for the thin fragipan soils at Holly Springs (3 t/a). The high amounts of residue left after harvest and the high canopy cover in the fall because of regrowth after harvest helped minimize soil erosion from sorghum. High ridges made the ridge-till practice slightly better than conventional-till for erosion control. The reduced-till practice was a more effective erosion-control practice than ridge-till, thus is recommended over conventional-till where cultivation for weed control is desired. No-till was easily the most effective erosion-control system. Cropping history effects were discernible even with the no-till studies. No-till following no-till produced less erosion, only 0.11 t/a of soil loss, compared to 0.89 t/a for no-till sorghum following conventional-till cotton. McGregor and Mutchler (1992) also noted that the high residue cover during the fall, winter, and spring was an important factor in reducing erosion. Although the study was not designed as a yield test, crop yields for no-till apparently were not reduced.

Sediment Characteristics

The transport of eroded soil material depends greatly on the size of the eroded particles. Sediment sizes and characteristics depend on the characteristics of the soil generally described as soil type. Consequently, the USDA agricultural engineers at Holly Springs were concerned with soil physics as it contributed to the primary objective of evaluating conservation tillage systems for erosion prediction and control. Four papers were published over the years primarily discussing soil physics.

Erosion from Unit Source Areas

Doty and Carter (1965) reported the results of a study on Holly Springs plots to measure sediment concentrations and particle sizes during a rain. They collected data from two 0.25-acre corn plots and one 0.022-acre fallow plot. Equipment and procedures were developed to obtain runoff samples during a storm.

Sediment concentrations were determined from each runoff sample. The eroded sediment was separated into sand, silt, and clay.

The highest erosion rate measured from the 0.25-acre unit source area was 11.5 t/(a-hr). Rates of soil movement varied in the same manner as the runoff. The peak sediment concentration occurred at about the same time or slightly before runoff peaked.

The proportion of silt increased and the proportion of clay decreased as the sediment concentrations increased up to approximately 20,000 ppm. Above 20,000 ppm, the particle size distribution in the runoff samples was about the same as that in the unit source area soil (Grenada silt loam, in this case).

Large differences were observed in erosion rates from fallow soil, corn under poor management, and corn under improved management practices.

Sediment Sizes from Low Slopes

Mutchler and McDowell (1986) reported measurements of sediment sizes from 0.2% slopes. This project was not performed at Holly Springs but is included because it was done in cooperation with the MAFES Northeast Mississippi Branch Station at Verona.

Sediment particle sizes were measured from runoff samples taken during simulated rainfall tests in an experiment designed to determine the effect of slope length on soil loss from Leeper silty clay loam. A statistical analysis could not detect any difference in the sediment size distributions because of time during the storm, plot length, or dry or wet runs. Differences were found only between nondispersed and dispersed sediment and between sediment and dispersed surface soil from the plots.

More than 70% of the sediment clay was transported in aggregates. Enrichment ratios of the particle sizes ranged from 1.4 for the clay and fine silt to 0.1 for the sands. The sediment particle size distribution appeared to be bimodal when plotted on semilogarithmic paper. Log equations representing the data showed that median particle sizes (D_{50}) of the nondispersed clay and silt sizes were more than twice as large as the dispersed particles while the D_{50} of the nondispersed sand size particles was four times as large as the dispersed D_{50} for that size.

Tillage Effects on Erosion and Sediment Sizes

The C-factor of the USLE had been evaluated for most of the different crops and management systems as a systems effect. However, for greater advances in erosion knowledge, more understanding was needed about the effect of each subfactor of the C-factor. These subfactors include tillage, cover, canopy, and their residual effects (Mutchler et al., 1982).

This research was concerned with the effect of tillage on erosion independent of the other subfactors of crop and residue (Mutchler and Murphree, 1988). The major objective was to formulate a relationship of erosion and tillage with respect to time and intensity of tillage that would allow the prediction of erosion from rainfall at any time after tillage. This type of knowledge was essential both for understanding the mechanics of erosion and for predicting or modeling erosion continuously throughout the year.

Limitations of resources required that the experiment be narrowed to a study of just the effect of time from last tillage on erosion. Because soil conditions are presumed to be a function of erodibility, tillage effects on sediment sizes were also studied.

Tillage was performed 0, 30, and 60 days before time of testing. Immediately before the rainulator use, the plots were given a final smoothing operation to make the plot surfaces the same. No soil loss differences could be attributed to the time of tillage. However, rainfall applied 30 days after the first test without further tillage resulted in 17% greater runoff, 39% greater soil loss, and twice as much aggregated silt and clay in the sediment as measured during the first test. These results demonstrated that differences in effects of tillage are relatively small but differences in runoff, soil loss, and sediment sizes are large because of wetting and drying with time after tillage.

Effects of Tillage with Different Crop Residues

The objective of this study was to determine the effect of newly incorporated residue on runoff and soil loss as part of a larger study on the placement and mixing of residue in the plow layer to control soil erosion (McGregor et al., 1990). Treatments included tillage of 2 diskings on plots with corn residue, wheat residue, or no crop residue. Soil losses were measured from 10-foot x 35-foot plots using simulated rainfall. Total soil loss from 2 hours of rainfall averaged 4.69, 7.43, 0.23 t/a for corn, fallow, and wheat, respectively. Extremely low soil losses from the wheat plots compared to corn and fallow plots occurred because two diskings were sufficient to incorporate corn residues but left substantial amounts of wheat residues on the surface.

Effects of surface cover were analytically removed by using mulch factor adjustments from AH 537 (Wischmeier and Smith, 1978) for average surface cover of 15%, 79%, and 0% for corn, wheat, and fallow plots, respectively. This resulted in very similar values for adjusted soil losses for all treatments. Results indicated that soil erosion benefits credited to incorporation of crop residues are not merited for recently incorporated residues. The soil erosion benefits of incorporation of crop residues over time were not evaluated.

Rainfall Erosiveness

The effect of rainfall on soil erosion is represented by the R-factor in the USLE. The R-factor is the accumulated storm values of rainfall energy times the 30-minute intensity (EI). Rainfall as represented by the R-factor is the initial driving force in the erosion process. Consequently, considerable attention was given to researching rainfall characteristics. This research resulted in a major improvement in the raindrop size and energy relationships with rainfall intensity that are the basis of R. Also, the extensive rain gauge records in the nearby Pigeon Roost Watershed gave an opportunity to compute a highly replicated R for northern Mississippi.

Raindrop Measurements

Studies during the 1960's included raindrop size-intensity relationships (these were based on samples of raindrops collected in pans of flour during selected storms) that were needed for use or verification of relationships used in soil loss prediction. Collecting and processing all of these "raindrop" flour pellets required many hours of work over many years. The subsequent analysis of rainfall energy and rainfall intensity relationships resulted in a significant reduction in the energy value used for higher rainfall intensities.

Rainfall energy is based on raindrop size-intensity relationships used in the USLE that were based on data taken at Washington, DC in the early 1940's. Rainfall intensities are much higher in the southern United States. This prompted Carter to initiate studies at Holly Springs to verify or change the energy computation from rainfall intensity. This was a highly significant piece of research because of its difficulty.

The R-factor in the USLE (Wischmeier and Smith, 1965) represents the erosivity of rainfall and is determined by energy of falling raindrops and intensity of rainfall. Energy of the falling drops is a function of mass times velocity. Conveniently, impact or terminal velocity is related to drop sizes and drop size is related to intensity. Thus, a measurement of raindrop sizes and storm intensity gives data to determine the needed specific relationship required to further compute the function of kinetic energy and rainfall intensity needed for the R-factor.

After Carter transferred to Baton Rouge in 1967, measurement of raindrops at Holly Springs continued under the supervision of McGregor. Carter also collected drop size data at Baton Rouge as part of a Masters thesis (Carter, 1972). The combined data sets from Holly Springs and Baton Rouge were used in the thesis and a publication (Carter et al., 1974). The major result of this research was an equation relating rainfall drop size and intensity.

$$\mathbf{D_{50} = 1.63 + 1.33\,I - 0.33\,I^2 + 0.02\,I^3} \qquad \mathbf{(3)}$$

where D_{50} is the median drop diameter (mm) and I is the rainfall intensity in inches per hour (in/hr). Mutchler, Research Leader for Holly Springs research at that time, disagreed with the prediction equation for values beyond 3 in/hr. Consequently, he directed McGregor to use the data collected at Holly Springs to derive another equation to use in an R-factor study that is described later. The equation developed by McGregor and Mutchler (1976) is:

$$\mathbf{D_{50} = 2.76 + 11.40\,e^{-1.04I} - 13.16\,e^{-1.17I}} \qquad \mathbf{(4)}$$

This equation was fitted to the data with a model parameter optimization program. It gave the desired result of showing that drop size increases with intensity (and fall velocity) up to some intensity between 2 and 3 in/hr and then decreases at higher intensities to some finite size. Only 8 samples out of the 315 collected had intensities greater than 6.5 in/hr, which leaves little basis to predict that large changes in median drop size occur in that range. Also, so little rain falls at those intensities that storm rainfall energy is little affected.

Rainfall Energy

As mentioned previously, rainfall energy values for the USLE were based on a drop size and intensity measured at Washington, DC. Measured rainfall data were used to compare energy-intensity equations developed by Wischmeier-Smith (equation 5) and McGregor et al. (equation 6), respectively, and also to determine a reliable data-based R value for northern Mississippi.

The Wischmeier-Smith (1965) equation is:

$$\mathbf{KE = 916 + 331\,\log_{10} I} \qquad \mathbf{(5)}$$

and the McGregor et al. (1980) equation is:

$$\mathbf{KE = 1{,}035 + 822\,e^{-1.22I} - 1{,}564\,e^{-1.83I}} \qquad \mathbf{(6)}$$

Equation 5 gave increasingly large values of energy for intensities more than about 3 in/hr. Thus, Wischmeier and Smith (1978) recommended in AH 537 the continued use of equation 5, but with the limitation that KE for intensities beyond 3 in/hr be limited to the value of KE for an intensity of 3 in/hr. This change was credited to the publication by Carter et al. (1974), but the change made the equation in AH 537 very similar to equation 6. A major impact of the raindrop studies was the finding that raindrop sizes did not continue to increase as rainfall intensity increased for intensities greater than 3 in/hr, which was the point Wischmeier and Smith made in AH 537.

North Mississippi R Values

Rainfall erosivity (R) values were computed from rainfall records in two North Mississippi watersheds using equations 5 and 6 (McGregor et al., 1980). Rain gauges in Pigeon Roost watershed (117 sq. mi.) varied from 15 in the first year of record (1958) to 34 during the 1958-1976 study. There were five rain gauges in the Laboratory Creek Watershed (1.57 sq. mi.) in 12 years of the 1961-1976 study for that watershed.

There was little difference in computed R values using the Wischmeier-Smith equation and using the McGregor-Mutchler equation for either watershed. This gave confidence in the computation of rainfall energy values from rain gauge records given in AH 282 (Wischmeier and Smith, 1965). However, the average R value computed using both equations was greater than shown in the isoerodent map given in AH 282, 14% greater for the Pigeon Roost data and 22% greater for the Laboratory Creek data. In AH 537 (Wischmeier and Smith, 1978), a revision of AH 282, the difference was made even greater, preesumably because of truncating equation 5.

The importance of the early R-factor research at Holly Springs is supported by later findings for erosivity values in Goodwin Creek Watershed (8.3 sq. mi.) near Batesville, Mississippi. Erosivity (R) values from recent rainfall data (over an 11-year period) near Batesville were about 30% higher than those used in RUSLE (McGregor et al., 1995). Analyses using Brown and Foster's as well as Wischmeier and Smith's kinetic energy-rainfall intensity relationships supported and strengthened the earlier conclusions regarding the need for increasing erosivity values in RUSLE for this area. Based on these analyses and results from several other locations, R values should be recomputed for all of the eastern United States as well, but especially so for the southern United States, as was done for the western United States. RUSLE is used by the NRCS to assist farmers in the selection of conservation practices to comply with policy in the 1985 and 1990 farm bills.

Geographical Differences in Rainfall

Annual rainfall and the intensity of rainfall vary greatly with location. These two rainfall characteristics are most commonly measured with a recording rain gauge. Unfortunately, most of the early Weather Bureau measurements were made with standard gauges that only yielded daily rain amounts. Recording gauges needed for intensity measurements were less common. Fortunately, most erosion research locations maintained chart records that had the data required to determine storm amounts and intensities throughout the storm.

EI and the R-factor could be computed for all locations having recording gauge records. But the large areas without such records needed some estimate from the daily gauge records. Three equations relating rainfall erosivity and 2-year, 6-hour rainfall were reviewed. The intensity-duration-frequency curves that include 2-year, 6-hour rainfall are well documented in Weather Bureau publications. Wischmeier and Smith (1978) reported the following relationship between R and this rainfall frequency parameter:

$$\mathbf{R = 27.38\ P^{2.17}} \qquad \mathbf{(7)}$$

where R is the annual erosion index and P is the 2-year, 6-hour rainfall amount.

Ateshian (1975) presented the following relationship:

$$R = 16.55\,(P_6)^{2.2} \tag{8}$$

where R refers to the annual erosion index and P_6 is the 2-year, 6-hour rainfall amount. This equation was designed for use in the western part of the United States, as delineated by the NRCS Type I rainfall. Ateshian also developed the following equation, which was used for the remainder of the United States (NRCS Type II rainfall area):

$$R = 27.00\,(P_6)^{2.2} \tag{9}$$

Although the R-factor geographical distribution was not originally calculated for the eastern United States in this manner, the above equations allowed R or EI to be calculated for all the United States. However, the question by Mutchler and McGregor (1979) was how to simulate rainfall with a rainfall simulator for erosion determinations. They suggested the following alternatives:

1. Simulate drop-size distribution and intensity-duration characteristics of specific rain types.
2. Simulate rainfall characteristics as represented by periodic sampling for a year or greater as exemplified by data of Laws and Parsons, Carter, and McGregor-Mutchler.
3. Calibrate the simulator with either a simulator of known performance or against natural rain using an erosion plot.

They concluded that any of the alternatives could be used successfully with consideration of differences in rainfall characteristics. However, they concluded that alternative 1 was too difficult in light of the variability of the other elements of the soil erosion system. The second alternative seems best, and the third alternative useful when the second cannot be used.

Excessive Rate Storms

An early study examined erosion from excessive rate storms (Greer, 1971). Before the R-factor based on EI became accepted, other equations were proposed, including simply using only the most intense or largest storms to predict erosion. The USLE includes this notion to some degree since all storms less than 0.5-inch (unless the maximum 15-minute intensity exceeded 0.95 in/hr) are omitted in research calculations of the USLE factors.

The project at Holly Springs was based on 6 years of rainfall, runoff, and erosion from corn on the 0.25-acre contoured plots on 2.5%, 5.0%, and 10.0% slopes. Excessive rate storms are those with intensities equal to or greater than 3.00, 1.40, 1.00, and 0.80 in/hr for 5, 15, 30, and 60 minutes, respectively.

Total rainfall in storms that had excessive intensities was 37% of all rainfall. These storms accounted for 59%, 55%, and 54% of total runoff and 80%, 78%, and 73% of total soil loss from the 2.5%, 5%, and 10% sloping plots, respectively. Significantly, excessive-rate storms produced about 50% of total soil loss, with 6% of rainfall during the seedbed period when the soil was relatively unprotected. However, during the time when cover exceeded 70% during other parts of the crop year, excessive-rate storms were about 31% of total rainfall but produced only 25% of total soil loss. The R-factor in the USLE accounts for these findings by neglecting storms less than 0.5 inch. Also, bare soil culture is becoming less common in tillage systems, which decreases the effect of excessive storms.

Agri-Chemical Runoff

The erosion project benefitted greatly from research cooperation with the NSL Water Quality Unit led by L. L. McDowell. He and others in the unit assumed responsibility for the chemical applications in the tillage systems being evaluated on the erosion plots. This group measured agricultural chemicals in the runoff, including quantifying the amount of chemicals attached to the sediment the runoff. Four publications are reviewed here, three on plant nutrient losses from corn and soybeans and one on organic carbon from crop residues.

Nitrogen and Phosphorus from No-till Soybeans

No-till studies in north Mississippi on loessial fragipan soils indicated that soybeans, corn, and wheat could be grown on these highly erodible soils with reduced soil loss and total (solution plus sediment) nitrogen and phosphorus losses (McDowell and McGregor, 1980). During a 2-year study, soil losses from no-till soybeans on standard erosion plots were about 1% of that from conventionally tilled soybeans. In 1973, total losses of N and P (sum of solution and sediment) from no-till soybeans were about one-tenth and one-sixth, respectively, of that from conventional tillage. In both cases, fertilizer was inserted in the soil; fertilizer was not broadcast.

No-till reduced total plant nutrient losses, even though soluble N and P concentrations in runoff were greater and sediments were enriched three to four times in N and P. Total N and P losses in 1973 from no-till soybeans were only 4.2 and 2.5 lb/a, respectively, as compared with 41.4 and 15.7 lb/a from conventional tillage. Total loss of plant nutrients was reduced because of the significant reduction in sediment concentration on runoff and resulting reduction in soil loss.

These documented reductions of total plant nutrient losses attributed to no-till provide additional potential benefits to the soil saving promise established earlier for no-till conservation systems for soybeans.

Plant Nutrient Losses from Conservation Tillage Corn

The reduction in plant nutrient losses from corn because of conservation tillage was similar to the reduction from soybeans using no-till. Five crop-tillage treatments were duplicated on the standard 13.3-foot x 72.6-foot erosion plots as follows:

1. Conventional-till corn for silage (C-SIL).
2. Conventional-till corn for grain (C-GR).
3. Reduced-till corn for grain (R-GR).
4. No-till corn for silage (N-SIL).
5. No-till corn for grain (N-GR).

Recommended fertilizer rates for silage and grain corn were applied. Ammonium nitrate, superphosphate, and muriate of potash were inserted into the soil at planting, and urea was surface applied as sidedress in late May or early June.

Storm runoff was measured for the 1975-1977 water years (Oct. 1 through Sept. 30). Sediment concentrations were determined from aliquot runoff samples. Nutrient concentrations were determined from runoff and sediment samples for each storm or small group of storms. Average annual data are given in Tables 16 and 17.

Solution and sediment concentrations of nutrients were greater from conservation tillage than from conventional tillage. There was little difference in concentrations between the two conventional-till treatments or between the three conservation-till treatments.

Runoff was determined for each storm and soil loss was calculated by multiplying storm runoff by storm sediment concentration. Nutrient losses were calculated by multiplying storm runoff and soil loss amounts by the respective nutrient concentration. Annual losses for the tillage treatments are given in Table 17.

Total losses of N and P (sum of solution and sediment) were greater from conventional tillage than from conservation tillage. Sediment N and P losses were significantly greater from conventional tillage than from conservation tillage even though concentrations of TKN and STP on a mass basis (mg/kg) were significantly greater from conservation tillage.

Reductions in soil loss from conservation tillage were large enough to reduce total (solution + sediment) N and P losses. More than 91% of the total N and P losses from conventional-till were transported by the sediments compared with about 60% from N-GR. The results of this study illustrate the potential conservation benefits of reduced-till and no-till practices to reduce total plant nutrient losses.

Nutrients in Runoff from Broadcasting

Mutchler et al. (1994) reported a comparison of plant nutrients in runoff from broadcast fertilizer. The objectives of the study were to determine the concentration, amount, and time of nutrient loss in runoff and soil loss after fertilizer was applied on the surface compared to that lost from fertilizer inserted under the surface for no-till corn production.

Corn was planted on two of the 2.5% sloping contoured plots using a no-till planter, which also applied fertilizer (560 lb/a 13-13-13) under the seed for the insert-fertilizer treatment. Sidedress fertilizer (400 lb/a 34-0-0 first 2 years and 200 lb/a urea 48%) was inserted 10 inches on each side of the corn rows and about 3 inches deep with a chisel-type sod seeder. All fertilizer on the other plot (same amount) was applied by broadcasting. The same tools were run without fertilizer on the broadcast-fertilizer plot to provide the same soil disturbance on both plots. Thus, the only difference between the plots was fertilizer either broadcast or inserted. The data are summarized in Table 18.

Concentrations for single storms varied around the tabulated crop stage values. Only one storm concentration (from broadcast-fertilizer) exceeded 10 mg/l. Broadcasting significantly increased the concentration of all three nutrients carried in the runoff in solution. Most of this increase was because of the large increases during the pl-fert crop stage when the surface applied fertilizer was most available to runoff. Increases in this crop stage were 3, 3, 6 times for nitrate, phosphate, and ammonia, respectively. Concentrations of sediment nitrogen and phosphate were not significantly affected by broadcasting.

As with concentrations, broadcasting fertilizer did not have a significant effect on the losses of nutrients carried on sediment. Large variations of nutrient losses between years were because of different amounts of runoff resulting from variable rainfall and rain intensities.

The most important difference found in losses in runoff was that resulting from broadcasting fertilizer and the application method-crop stage interaction. This indicated that broadcasting caused greater nutrient losses in runoff during the planting (pl) and sidedress (sd) crop stages. The loss of NO_3-N, PO_4-P, and NH_4-N on runoff was about three, three, and five times greater, respectively, from broadcasting in the pl/fert crop stage. Losses were about two times greater during the sd period. The nitrogen sidedress did not increase nitrate or ammonia losses as much during the sd period because of higher temperatures and less runoff because of more cover after sidedressing. Losses of nutrients in runoff from harvest in the fall to planting in the spring were only slightly affected by broadcasting.

Nitrogen lost each year in runoff and soil loss from the insert-fertilizer plot totalled 8.4 lb/a; broadcasting increased this loss to 13.7 lb/a. Phosphorus loss was 2.1 lb/a from the insert-fertilizer plot and 3.5 lb/a from broadcasting. These amounts are small compared to the amount of fertilizer applied. Because of the ease of broadcasting and the cost of inserting fertilizer, savings from inserting fertilizer is questionable for no-till farming. However, when the possible environmental benefits are considered, inserting fertilizer is better than broadcasting.

Organic Carbon in Runoff

Research had indicated that some soluble chemical concentrations, including organic carbon, were higher in runoff from no-till practices, especially when crop residues were left on the surface. In runoff from agricultural land, organic carbon moves in association with sediment, as well as in the aqueous phase, and may be important in accelerated eutrophication. The biodegradation of organic compounds in streams and lakes creates a biochemical oxygen demand, which can harm aquatic life.

Samples were taken from runoff and soil loss from conventionally tilled corn for silage and no-tilled corn for grain. These cropping systems were selected because no-till represented a maximum amount of residue on the ground and conventional-till represented a minimum. Items measured were (1) total organic carbon (TOC), (2) chemical oxygen demand (COD), and (3) 5-day biochemical oxygen demand (BOD_5).

Higher concentrations and losses of aqueous TOC and COD from grain plots resulted from organic carbon released from crop residues. Although sediment TOC and COD concentrations from the no-till corn and silage practices were considerably larger than those from comparable conventional practices, sediment TOC and COD losses from conventional practices were 6 to 13 times greater because of larger runoff and soil losses. While the annual average BOD_5 values were similar for the conventional silage and no-till for grain practices, 19.6 and 19.2 mg/l, respectively, these values differed seasonally. It was concluded that no-till was a likely candidate for a best management practice to minimize oxygen demand and losses of organic carbon in runoff from corn land.

Erosion Research Techniques

An early and excellent review of erosion research was given by Smith and Wischmeier (1962). They describe the development of rainfall erosion research from its beginnings in Germany to about 1960 in the United States. Erosion research in the United States began in 1917 at the University of Missouri. Federal research was started between 1929 and 1933 by the United States Department of Agriculture (USDA) with the establishment of 10 Federal-State Experiment Stations. Most of these early studies were discontinued by 1943 (probably because of World War II). However, interest in erosion research continued throughout the 1940's.

In 1953, a Runoff and Soil Loss Data Laboratory was established at Lafayette, Indiana, by the Soil and Water Conservation Research Division of ARS, USDA, in cooperation with Purdue University. The need for standardization of erosion research techniques was again emphasized as old data were analyzed in an attempt to develop an equation for estimating annual field soil loss on farmland.

This need for standard erosion plots was reflected in the Holly Springs research, and resulted in publication of runoff plot design and erosion research methods, and development of runoff measuring equipment.

Runoff Plot Design

Mutchler (1963) wrote an ARS-41 series publication, "Runoff Plot Design and Installation for Soil Erosion Studies," in cooperation with the Minnesota Agricultural Experiment Station. Since the publication was based on experience gained at Holly Springs, it is reviewed as part of the ARS research accomplished in cooperation with the Mississippi Agricultural and Forestry Experiment Station. The publication proved to be very popular; it was reprinted in 1976 and now is being photocopied to fill requests.

The purpose of Mutchler's publication, written at the request of D. D. Smith about 1962, was to document and update current procedures for research methods of measuring runoff and soil loss. A major objective was to provide USDA with a publication to fill the many requests for information on erosion plots and to help standardize erosion data collection.

Mutchler described important factors to consider in selecting areas to site plots and discussed criteria for the design of runoff and soil loss measuring equipment. He also gave suggestions for selection and installation of equipment for erosion plots. In the early 1960's, multi-slot divisors were considered most reliable for collecting much of the sediment in a primary tank and taking aliquot samples of the remainder for soil loss determination. Therefore, the designs were based on the use of these divisors, which could sample heavy loads of sediment produced by fallow plots and conventional tillage plots. Although use of flumes was not necessary since the multi-slot divisor collected a known fraction of the runoff and soil loss in (usually) two tanks, a flume was used to determine runoff intensities during a storm. The major drawback of this method was the large labor requirement to measure and remove the sludge.

Cochocton Sampler

This sampler was invented in 1944 by W. H. Pomerene at the USDA-ARS (then SCS) field station near Cochocton, Ohio. It went through development and modification by several people including D. A. Parsons, S. H. Anderson, and T. W. Edminster. Pomerene's design used a flume to measure flow and the wheel sampler to sample the runoff for use in determining sediment concentration. Note that the multi-slot divisor was useful only for small plots because most of the soil loss was collected in a sludge tank.

The need for a runoff sampler that did not use a sludge tank led to developmental research reported by Parsons in 1954. Also, there were hopes that the sampler could give a reliable measure of runoff amount as well as an aliquot sample. Unfortunately, problems in measurement of runoff were not solved. The final design of the Cochocton-type sampler included a flume and wheel as a unit.

Field tests of the Cochocton-type wheel runoff sampler were conducted at Holly Springs and reported by Carter and Parsons (1967). They determined that the smaller N-1 sampler extracted about 1.10% of the flow instead of the design 1%, and the larger N-1 sampler extracted about 0.57% instead of the design 0.5%. Also, they specified closer dimensions of the sampling slot on the wheel. They verified that wheel operation was satisfactory with use of sloping floors in H-flumes as used at Holly Springs. However, confidence in the sampling fraction was insufficient for flow rates greater than 70% for the 0.5-foot H-flume capacity (N-1 sampler) and 80% of the 1.0-foot H-flume capacity (N-2 sampler).

Significantly, Carter and Parsons (1967) ended their discussion with the observation that heavy sediment or sand loads prevented reliable operation of the Cochocton sampler. They recommended a sediment trap ahead of the sampling unit. Fortunately, conservation tillage systems produced much less sediment and, thus, relieved researchers of the need for sediment traps and their laborious sampling.

Erosion Research

The book, *Soil Erosion Research Methods*, was published in 1988. It covered most of the current methods and instrumentation used in soil erosion research. The book was well accepted and the second edition was published in 1994. Mutchler et al. (1988) contributed the chapter in the book that discussed laboratory and field plots for soil erosion studies. Much of the knowledge for this chapter was gained and tested in erosion research at the Holly Springs station.

Miscellaneous

This section is labelled miscellaneous simply to accommodate the variety of research conducted at Holly Springs. It also mentions some of the newspaper reports that were written as part of Annual Reports of Marshall County Soil and Water Conservation District (Greer, 1982; Greer, 1983; Mutchler, 1984; Mutchler and Rhoton, 1985; Mutchler and Greer, 1987; and Mutchler and Greer, 1988). Cooperation with the Mississippi Soil and Water Conservation Districts was documented with these newspaper articles.

Erosion from a Lister-till System

The lister-till system has been used in areas with low rainfall to provide water for seed emergence. In a lister-till system, the crop is planted in the furrow instead of on the ridge. The system was evaluated for erosion control at Holly Springs because it used minimum tillage and offered runoff reduction. Unfortunately, the practice could not be recommended for use in high rainfall areas such as northern Mississippi.

As reported by Greer et al. (1976), 2-year average annual soil losses from lister-till, doublecropped soybeans and wheat were 3, 4, and 7 t/a on 2.5, 5, and 10% sloping contoured plots, respectively. Average annual soil loss from the same system on a 1.45-acre watershed with an average slope of 7% was 6 t/a. In contrast, average annual soil loss from lister-till, singlecropped soybeans on 5% plots was 5 t/a.

The soil loss rates indicated that contoured lister-till, even in a doublecropping system could not be recommended in northern Mississippi for slopes steeper than 5%.

K-Factor Variation

Usage of the K-factor in the USLE assumes that soil has an inherent erodibility that is constant throughout the year, which is satisfactory for estimating average annual soil erosion. However, the variable erodibility of soil because of variations of soil moisture, especially, does not allow soil loss estimates for periods shorter than a year unless this variation is accounted for either directly or indirectly by some other erosion factor.

This variable erodibility was noticed by researchers using rainfall simulation; evaluation of replicate treatments later in the summer yielded lower soil losses. Also, Mutchler (1982) reported the need for a K-factor adjustment when the USLE C-factor was divided into subfactors as shown below:

$$\mathbf{A = R\ K\ K_c\ L\ S\ C_s\ P} \qquad \textbf{(10)}$$

where K_c is a dimensionless number that varies around unity, and C_s is a set of dimensionless subfactors.

Data from Mississippi and Minnesota were used to derive erodibility variability equations. Data from Mississippi were collected at Holly Springs from two replicate fallow plots from 1963 to 1968. Minnesota data were collected at Morris from three replicate plots from 1962 to 1971.

The variability coefficient was calculated from data as K_c=Km/K where Km was average monthly erodibility and K was average annual erodibility. This coefficient was then related to time of year as follows for Holly Springs:

$$\mathbf{K_c = 1 + 0.6903\ cos((t - 2.147)\ 2\ /12)} \qquad \textbf{(11)}$$

where t is time expressed in months. Data from Morris, MN resulted in

$$\mathbf{K_c = 1 + 0.6508\ cos\ ((t - 4.456)\ 2\ /12)} \qquad \textbf{(12)}$$

Because normal monthly temperatures also fit the cosine function, use of locational temperature was proposed as a method to fit the K-factor coefficient for different locations. This has not been done. However, the variable erodibility concept has been accepted and is currently a part of RUSLE.

Subfactors for USLE C-Factors

A system of subfactors for computing the C factor in the universal soil loss equations was proposed for cotton (Mutchler et al., 1982). The subfactors are multipliers that represent the effects of land use residual, incorporated residue, tillage intensity and recency, macroroughness, canopy, and cover. Parts of the proposal have been used in development of the RUSLE. A major result of this study was the subfactor for macroroughness. This factor was included to account for the effect of ridging or bedding tillage. Research using a rainfall simulator showed that erosion from a bedded plot on a 1 percent slope was more than twice as great as from a flat-tilled plot. The ridge height, h, of the bedded plot was 8 inches and that of the flat-tilled plot was about 1/2 inch, and the soil loss ratio of bedded to flat-tilled was 2.5. The following equation was derived by assuming a linear relation of bed height and subfactor C_4.

$$\mathbf{C_4 = 0.9 + 0.20\ h} \qquad (13)$$

This relationship helps explain why tillage systems like ridge-till are not as beneficial for soil conservation as the large residue cover maintenance would seem to promise.

Contoured Ridge-till

This study was done primarily to document the reduction in soil loss from tilling on the contour (Mutchler et al., 1994). Ridge-till was selected because high ridges were thought to make contouring most effective. Evaluation of contouring with year-round measurements is very difficult, and none has been reported since McGregor et al. (1969b).

Two duplicate standard plots, 13.3 feet x 72.6 feet long, were tilled up-and-down-slope. Two duplicate contoured plots, 72.6-foot slope length and 150- foot row length were tilled with rows graded with a slope of 0.2 to 0.4% to a waterway at the plot edge. All plots were on 5% sloping land.

Ridge-till involves planting on ridges with the old crop stalks removed from the ridge with a ridge sweep before planting and cultivation. This is designed to build and maintain the ridges. After the final cultivation, ridges were about 6 inches higher than the row middle. Data were collected for 4 years (1987-1990) and are summarized in Table 20.

Note that P values were computed from 4-year crop stage total soil loss to avoid the high variability of individual annual values that often contained small storms or no storms. The effectiveness of contoured ridges in reducing soil loss was maintained throughout the year, resulting in an average annual P value of 0.31. This value compares to P=0.41 for cultivated corn planted on high beds in earlier research at Holly Springs (McGregor et al., 1969b). The lower P value for the ridge-till beds than for the earlier study was because the ridge-till sorghum beds were maintained higher through the years than in the earlier corn study. In the earlier study, beds initially were formed with "middle-busters" and cultivated as needed during the growing season.

Erosion and Soil Productivity

The loss of soil productivity as erosion progressed was measured and documented (McGregor et al., 1992). Soybeans were grown on 12 pairs of plots with lengths of 150 feet and slopes ranging from 3 to 4% on Loring silt loam soil. In 1983, the plot area was tilled uniformly preceding planting of soybeans. Since then, no-till soybeans have been grown on one plot of each pair to provide a minimal loss of productivity caused by erosion, and conventional-till soybeans have been grown on the adjacent plot to provide a continuous larger loss of productivity because of excessive erosion.

Conventional-till soybean yields exceeded no-till yields during the first 2 years of the study. During the fourth through eighth years, no-till soybean averaged 44% greater yields than conventional-till. The developing trend of lower yields with conventional-till with from no-till indicated an adverse effect of excessive erosion on soil productivity in conventional-till plots.

Simulated rainfall was applied to the lower third (50 feet) of different pairs of plots in 1986, 1987, and 1990 after receiving tillage of two diskings and harrowing. Tillage immediately preceding the rainfall simulation provided a similar soil surface for testing the effects of tillage history (either no-till or conventional-till) on soil erosion. Plots with conventional-till history were more erodible than those with no-till history.

Runoff during the initial 60-minute rainfall simulations from conventional-till plots was 21, 13, and 52% greater than from no-till plots in 1986, 1987, and 1990, respectively. Soil loss during initial runs during these same years was 62, 34, and 350% greater, respectively, from conventional-till plots than that from no-till plots. Significantly, eroded soils with a conventional-till history were more susceptible to further erosion under additional intensive tillage than soils protected through a no-till management system.

Moisture Content Effect on Erosion

This study was done with data from rainulator studies on the long-term erosion-productivity plots discussed above (Auerswald et al. 1994).

Soil moisture, prior to first runs, was 7.5% greater on the previously untilled (no-till) plots. Soil loss from no-till plots was less than 30% of losses from previously tilled (conventional-till) plots. To eliminate the effect of antecedent moisture content (M_a) on soil loss and isolate the effect of other differences induced by soil use history, an equation between M_a and soil loss was used. This equation had been independently derived from another silt loam. Three-fifths of the difference in soil loss were attributed to the greater M_a. Two-fifths (2.5 t/a) of the difference were attributed to other benefits of no-till such as greater aggregate stability and more biopores.

Greater soil loss from the drier conventional-till was a result of the increased breakdown of the soil surface structure before runoff started. The smoother surface resulted in a smaller water depth during runoff. Average depth on the driest conventional-till plot was only one-third of that on the no-till with the greatest M_a. The reduced depth increased further detachment by raindrop impact and increased sediment transport. The initial breakdown of structure influenced soil loss during all three consecutive simulator runs. For both treatments, soil loss of the third run was still influenced by the initial moisture content of the first run.

Present Studies (1996)

Return of CRP Land to Crop Production

Sediment and agrichemical losses are being evaluated from idle upland watersheds being returned to row crop production with implemented conservation measures (McGregor et al., 1995). These studies involve the use of crop production plots, small watersheds, and rainfall simulator plots. Research studies include the sediment trapping efficiency of grass buffer strips; and erosion-control and crop-yield effects of various tillage methods on idle land being returned to row-crop production. The Water Quality and Ecology (WQE) Unit at the NSL is evaluating the agrichemical losses for this CRP study.

Based upon preliminary results from crop production plots, no-till crops can be grown during the first year following sod with crop yields comparable to first year conventional-till crops following sod. Preliminary sediment yield and soil loss data from watersheds and rainfall simulator plots indicate that use of no-till with grassed buffer strips allows CRP land to be returned to production without excessive erosion.

Stiff Grass Hedges

Runoff and soil loss are being measured from no-till and conventional-till cotton plots with and without stiff grass hedges located across the lower ends of the plots to evaluate the sediment-trapping efficiency and soil-reducing effectiveness of the hedges. Hedges were transplanted in March 1991 preceding the planting of cotton, and even though hedges were not fully developed during that first growing season, soil losses decreased immediately. In the first year, soil losses for both conventional and no-till practices were reduced by about 56% (McGregor and Dabney, 1993). Studies with the grass hedges are continuing on larger plots. Seth Dabney, an agronomist with the NSL, also has established grass hedges in several on-farm trials to determine their applicability in typical field situations.

Other Research

The NSL continues to cooperate with the MAFES North Mississippi Branch Experiment Station on studies of the long-term effects on erosion of conventional-till versus no-till and the effects of crop residue placement on runoff and erosion. The WQE Unit of the NSL also conducts studies on the effects of alternative tillage practices on water quality of surface runoff as well as on ground water.

Summary

For many years, the only research in the southern United States to determine the soil erosion effectiveness of no-till conservation tillage practices was conducted at Holly Springs. Early research showed the erosion-control benefits of terraces, contoured graded rows, and good cropping practices versus poor management; however, the highly erosive climate and highly erodible soils of this region required other effective alternative erosion-control practices, especially considering the reluctance of farmers to use standard erosion-control practices on increasing number of soybean acreages and fields with irregular topography and long slopes.

Information was lacking about whether residue management in no-till conservation systems for crops like soybeans and cotton would provide enough residue to control erosion under the highly erosive environment. Conservation tillage studies with soybeans, corn, grain sorghum, and cotton have shown that no-till and reduced-till cropping systems can dramatically reduce erosion in the southern United States.

Careful selection and planning of sequential studies on plots and watersheds have resulted in improved soil erosion conservation practices and the improvement and validation of the USLE, RUSLE, and WEPP erosion models. The previously used USLE C-factor over-estimated erosion three to six times for corn using no-till and reduced-till, respectively. The re-evaluation of the rainfall erosivity factor for the Midsouth has shown the need for a 30% increase in erosivity (R) values for this region of the country and for the need to re-evaluate R values in the eastern United States.

Cooperative conservation tillage research over the past 25 years between the National Sedimentation Laboratory and the MAFES North Mississippi Branch Experiment Station at Holly Springs has improved understanding of erosion-control practices for conservation planning. Data from these studies have been used by the USDA-Natural Resource Conservation Service (NRCS) to set specifications and criteria for conservation tillage systems throughout the United States and by ARS and NRCS to refine erosion prediction technology used by USDA to ensure compliance with provisions to federal legislation in the 1985 and 1990 Farm Bills. These continuing studies enable conservationists to help farmers nationwide to use their land productively and profitably.

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