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Tillage Effects on Soil Erosion Potential and Soil Quality of a Former Conservation Reserve Program Site

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RESEARCH

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ABSTRACT: This study was conducted to determine the effects of tillage on soil erosion potential and soil quality characteristics of a former Conservation Research Program (CRP) site. Following tillage, the study area in Northern Mississippi was maintained in a fallow condition for nine months. Soil loss from simulated rainfall events was minimal on recently tilled plots and an adjoining, undisturbed CRP area. In contrast, soil loss from the former CRP site which had been tilled nine months previously was similar to values obtained before the CRP program when the area had been cropped for several years. Tillage and over-winter fallowing caused a degradation in soil quality resulting from the decomposition of biological nutrient reserves. The conservation and soil quality benefits derived from the CRP may rapidly decline once an area is tilled and then left fallow during the non-cropped period.

The CRP was initiated to remove environmentally fragile areas from crop production. Approximately 14.8 million hectares (36.5 million acres) of cropland were enrolled in this program (Taylor et al. 1994). To participate in the CRP, producers were required to convert cropland to vegetative cover for a 10-year period. The principal objectives of the CRP were to reduce erosion on highly erodible cropland, decrease sedimentation, improve water quality, foster wildlife habitat, curb the production of surplus commodities, and provide income support for farmers (Young and Osborn 1990).

Soil structure has been found to improve when continuously cultivated land is put into grass (Lindstrom et al. 1994). The perennial grass cover established under the CRP at selected locations within the Great Plains has also resulted in significant increases in soil organic carbon (Gebhart et al. 1994). Because the CRP was established to help stabilize highly erodible soils, returning these areas to crop production could have detrimental effects on long-term soil productivity (Young and Osborn 1990). As CRP lands become eligible for release, many land managers who return their land to crop production will be concerned about adopting procedures that will help to maintain conservation benefits derived during the CRP.

Management systems that include sod have many environmental and production advantages. Detailed information on the effects of grass sod on soil properties and crop productivity at Big Spring, Texas was provided by Zobeck et al. (1995). In the southeastern United States, sod crops planted in sequence with row crops have been found to increase crop yields, provide more efficient use of water and fertilizer, and reduce runoff and erosion (Bennet et al. 1976; Carreker et al. 1977; Harper et al. 1980; Belesky et al. 1981; Wilkinson et al. 1987). No-till corn planted in sod produces excellent yields when nutrient and water requirements are met (Moody et al. 1963; Jones et al. 1969; Carreker et al. 1973; Box et al. 1976, 1980).

Corn yields are greatest the first year after sod, and then decline with each succeeding year of corn production (Parks et al. 1969; and Giddens et al. 1971). Elkins et al. (1979, 1983) concluded that acceptable corn yields could be obtained while maintaining a living grass mulch. Herbicide application rates, vigor of the grass stand, and climatic factors all contribute to the success of intercropping management systems.

A field recently plowed out of meadow is initially much less erodible than one which has been continuously tilled. The fine root network and improved soil structure from meadows serve to maintain high infiltration rates and protect the soil against erosive forces (Foster 1982). In general, the erosion-reducing effectiveness of sod is directly proportional to vegetative dry matter production (Wischmeier and Smith 1978). The objective of this

Interpretive summary

This study was conducted to determine the effects of tillage on soil erosion potential and soil quality characteristics of a former Conservation Research Program (CRP) site. Following tillage, the study area in Northern Mississippi was maintained in an over-winter fallow condition for nine months. Soil loss from simulated rainfall events was minimal on recently tilled plots and an adjoining, undisturbed CRP area. In contrast, soil loss from the former CRP site which had been tilled nine months previously was similar to values obtained before the CRP program when the area had been cropped with clean tillage management for several years. Tillage and fallowing caused a degradation in soil quality resulting from the decomposition of biological nutrient reserves. The conservation and soil quality benefits derived from the CRP may rapidly decline once an area is tilled and then left in a fallow condition.

Key words: conservation, erosion, land management, runoff, soil conservation, soil quality, tillage.

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study was to measure the effects of tillage on soil erosion potential and soil quality characteristics of a former CRP site in Northern Mississippi.

Procedures

Study area. The study site was located approximately 6 km (4 miles) east of Como, Mississippi. A Grenada (fine-silty, mixed, thermic Glossic Fragiudalf) silt loam soil with a sand, silt, and clay content of 9, 65, and 26%, respectively, was located at the study site. The Grenada series consists of moderately well drained soils that have a fragipan. These soils formed in loessal material on uplands and terraces.

Annual precipitation at the study area averages 1450 mm (57.1 in). The frequency of a 64 mm (2.5 in) rainfall of one-hour duration is once every 10 years (Hershfield, 1961), while a 50 mm (2.0 in) rainfall of one-hour duration occurs every 3 to 4 years. A 25 mm (1.0 in) rainfall of one-half hour duration has a one year recurrence interval. Mean annual temperature is 16°C (60°F) which ranges from 10°C (49°F) in January to 33°C (91°F) in July. The average frost-free growing season is 205 days, extending from April to October.

Soil erosion potential. Prior to initial evaluations, the area had been cropped for several years. Corn had been grown at the site during 1987. In April 1988, corn residue was first removed and the area was then moldboard plowed. The study site was disked immediately before initial testing in June 1988. Two plots, 3.7 m (12 ft) across the slope by 10.7 m (35.1 ft) long, were established using sheet metal borders. The plots were raked by hand prior to testing to provide a uniform surface. This experimental treatment was designed as CR (tillage following long term cropland).

A portable rainfall simulator based on a design by Swanson (1965) was used to apply rainfall at an intensity of approximately 52 mm/h (2.0 in/h). The first rainfall application (initial run) of 1 h duration occurred at existing soil-water conditions. A second rainfall simulation run (wet run) was then conducted approximately 24 h later, again for a duration of 1 h. A trough extending across the bottom of each plot gathered runoff, which was measured using an HS flume with a stage recorder. Additional details concerning experimental procedures are given by Gilley et al. (1990).

The study area was seeded to tall fescue (*Festuca arundinacea*) after being placed in the CRP in the fall of 1988. Following six years in the CRP, one area on the study sight was disked on September 15, 1994, and an adjoining area was disked on June 15, 1995. Each time the areas were disked several times to simulate conditions needed in preparing CRP for crop production. The area disked in 1994 was maintained free of vegetation by application of herbicide and then disked again immediately before the rainfall simulation tests. Beginning on June 16, 1995, rainfall simulation tests were again performed at study locations, including an adjacent undisturbed CRP site which was designated as UN. The experimental treatments on which simulation tests were conducted four days and nine months following tillage were designated as FD and NM, respectively.

Tilling a former CRP area and then keeping it free of vegetation for nine months created a condition that was optimum for soil erosion. After CRP contracts expire, many producers are expected to till their land in the fall and then keep it in a fallow condition until a crop is planted the following spring. The rainfall simulation tests conducted in 1988 were performed on a site that had been maintained in a bare, fallow condition. Therefore, similar site preparation procedures were used in 1995 in order to allow comparisons in soil loss with the earlier tests.

Surface cover was measured at the time of the rainfall simulation tests using the point quadrant method (Mannering and Meyer 1963). Photographic color slides were taken at three locations on each plot. The slides were later projected onto a screen containing a grid and the number of residue and crop elements intersecting the grid points were determined. The ratio of the number of intersection points over the total grid points is the fraction of the soil surface covered by residue. This ratio times 100 is the percent cover.

A circular frame covering a 0.589 m^2 (6.34 ft^2) area was used to obtain samples for vegetative dry matter measurements from two areas on each experimental treatment. Standing vegetative materials and residue lying on the soil surface within the frame were removed at the time the CRP areas were disked. The plant and residue material was later oven dried, and the weight of dry matter per unit area was calculated. Vegetative dry mass was 432 and 289 kg/ha (385 and 258 lb/acre) on the 1994 and 1995 tillage dates, respectively.

Duncan's multiple range test was used to determine if differences in rainfall intensity, slope, surface cover, runoff, sediment concentration, and soil loss existed between the experimental treatments. Tests were run at the 5% confidence level (p = 0.05).

Soil quality characteristics. The basic indicators of soil quality as described by Doran and Parkin (1994) were used in 1995 to evaluate the three management treatments. Soil samples from the 0-30.5 cm (0-12.0 in) soil layer were obtained for soil characterization and laboratory assessments of soil quality by compositing five randomly sampled 1.9 cm (0.75 in) diameter cores for three replicate areas of each experimental treatment. Soil sampling sites which were replicated by upper, middle, and lower slope positions were immediately adjacent to or within (1995 tillage treatment only) the areas where rainfall simulations were conducted. Samples were stored under ice in an insulated chest for transport to the laboratory for processing within 48 hours after collection. Moist soil samples were passed through a 4.75 mm (0.187 in) sieve for analyses of microbial biomass C and N by the chloroform fumigation/incubation procedure or for mineralizable N by the anaerobic incubation method. Samples were passed through a 2 mm (0.08 in) sieve for analysis of 2N KCL extractable mineral N (NO_3 and NH_4), total C and N by dry combustion, Bray^{-1} extractable P, and particle size analysis by the hydrometer method. The methods used for laboratory analyses were all standard procedures employed by the USDA-ARS Soil and Water Conservation Research Unit and the University of Nebraska Soil and Plant Testing Laboratory.

Soil quality assessments for the 0-7.6 cm (0-3.0 in) depth were conducted in the field for 3 replicated sites within each treatment on June 15, 1995, before rainfall simulation tests were initiated. On-site soil quality measurements as described by Sarrantonio et al. (1996) included soil water content, bulk density, field water holding capacity, electrical conductivity, nitrate (NO_3)-N, infiltration, temperature, and respiration rate before and after irrigation with two 2.54 cm (1.00 in) increments of water. Fifteen cm diameter aluminum rings, installed to a 7.6 cm (3.0 in) depth in the soil, were used for infiltration and respiration measurements. The soil infiltration rate measured after the addition of the second 2.54 cm (1.00 in) of water represented a 'ponded' infiltration rate. The soil-water content 16 hours after irrigation was used as an estimate of field water holding capacity. Further details on the utility and reliability of these approaches for measuring soil water

Table 1. Rainfall intensity, slope, surface cover, and soil organic carbon for selected experimental treatments

Treatment*	Rainfall Intensity[†] (mm/hr)	Slope (%)	Surface Cover (%)	Soil Organic Carbon[‡] (Mg/ha)
UN	64a[#]	5.4 b	100 a	30.7 (7.7) a
FD	67a	6.4 a	77 b	31.8 (1.9) a
NM	65 a	7.1 a	18 c	22.2 (4.0) b
CR	52 b	6.7 a	0 d	———-

* UN (Undisturbed CRP), FD (Four days following tillage), NM (Nine months following tillage), CR (Tillage following long term cropland).
[†] Average rainfall intensity for the paired plots during the initial and wet simulation runs.
[‡] Soil organic carbon content for the 0 - 30.5 cm (0 - 12.0 in) depth. Values in parentheses represent standard deviation of the mean.
[#] Values followed by the same letter do not differ significantly at $p = 0.05$.

Table 2. Runoff, sediment concentration and soil loss for selected experimental treatments*

Treatment[†]	Run	Runoff (mm)[‡]	Sediment Conc. (ppm × 10^3)	Soil Loss (t/ha)
UN	Initial	48a	0.8 c	0.4 c
FD	Initial	33b	2.4 c	0.7 c
NM	Initial	31b	19.6 b	7.6 b
CR	Initial	35b	40.5 a	12.0 a
UN	Wet	51a	0.4 b	0.2 b
FD	Wet	50a	1.1 b	0.5 b
NM	Wet	46a	27.8 a	13.0 a
CR	Wet	41a	30.6 a	12.7 a

* Plots were 3.7 by 10.7 m (12 by 35.1 ft). Values given are the average of two replications. Runs lasted for a 60-min duration.
[†] UN (Undisturbed CRP), FD (Four days following tillage), NM (Nine months following tillage), CR (Tillage following long term cropland).
[‡] Within each type of run and for each column, values followed by the same letter do not differ significantly at $p = 0.05$.

status are given by Lowery et al. (1996).

Statistical analysis for soil quality comparisons were made using the General Linear Models Procedure and orthogonal contrasts (SAS 1990). Tests were run at the 5% or 1% confidence levels ($p = 0.05$ or $p = 0.01$).

Results and discussion

Soil erosion potential. The rainfall simulator was designed to provide an intensity of 64 mm/hr (2.5 in/h). However, due primarily to differences in operating pressure and wind drift, variations from this design intensity sometimes occurred. It can be seen from Table 1 that rainfall intensity values for the tests conducted in 1995 were similar. However, significant differences in rainfall intensity were found between the 1988 and 1995 testing dates.

Slope gradients in this study ranged from 5.4% to 7.1%. The experimental plots on the undisturbed CRP site had slopes which were significantly less than the tilled areas. This was probably not a serious problem in this experiment since the soil infiltration rate on the undisturbed CRP site, as discussed later, was much lower than on the tilled soils. For the tilled treatments, there was no significant difference in slope gradients.

It can be seen from Table 1 that surface cover varied substantially on each of the experimental treatments. The ground surface on the undisturbed CRP treatment was completely covered with vegetative material. A substantial amount of vegetation remained on the soil surface immediately after the disking operation. However, most of the surface cover had disappeared nine months following tillage. Surface cover was absent on the site that had been plowed in 1988 following long term cropland production.

No significant difference in soil organic carbon was found between the undisturbed CRP treatment and the site which had been recently tilled. However, a substantial reduction in the amount of soil organic carbon in the top 30.5 cm (12.0 in) of soil occurred nine months following tillage. Since the soil organic carbon generated during the CRP period is rapidly depleted, it must be replaced periodically to maintain soil quality levels.

Cumulative runoff from both the initial and wet rainfall simulation runs are shown in Table 2. It can be seen from Table 2 that for the initial rainfall event, runoff was significantly larger on the undisturbed plots than the tilled treatments. Initially, tillage appeared to have caused increased infiltration rates, when compared with the undisturbed CRP. For the wet run, however, no significant difference in runoff was found between any of the experimental treatments. Runoff rates on the undisturbed treatment were similar for the initial and wet runs.

For both the initial and wet simulation runs, sediment concentration and soil loss (Table 2) were minimal on the undisturbed CRP site and the plots which had been recently tilled. In contrast, soil loss measured during the wet run on the plots which had been tilled nine months previously were similar to values obtained when the area had been used as cropland. Once tillage occurred and the residual residue accumulated during the CRP period had been depleted with no additional input of organic material, the reduced soil erosion potential derived during the CRP period was eliminated.

This study was conducted to determine soil loss potential. Erosion values measured after the CRP site had been tilled and then left in a fallow condition for several months should be considered as soil loss extremes. The biomass produced from cropping and volunteer winter vegetation could serve to reduce erosion. A no-till management system that helped to preserve existing surface cover and soil organic matter proved to be an effective management practice for reducing the potential for erosion at a former CRP site in southwestern Iowa which was returned to crop production (Gilley et al. 1997).

Soil quality characteristics. Soil quality characterizations, made before the rainfall simulation tests had begun, indicated important differences in soil physical condition between experimental treatments (Table 3). For the NM treatment, dry bulk density was the lowest for any of experimental treatments at the 0-7.6 cm (0-3.0 in) depth and greatest among experimental treatments at the 0-30.5 cm (12.0 in) depth. For silt loam soils, a bulk density of 1.55 g/cm^3 is considered the threshold above which plant rooting is limited by soil strength. These results suggest a change in soil compaction and structural stability associated with the earlier tillage and lack of vegetation on this treatment.

Soil volumetric water contents at time

Table 3. Tillage effects on selected soil quality indicators for the 0-7.6 and 0-30.5 cm depth of the Grenada silt loam soil

Soil quality indicator	Depth (cm)	Treatment* UN	Treatment* FD	Treatment* NM
Dry bulk density	0-7.6	1.34(0.07)	1.33(0.07)	1.23(0.07)
(g/cm^3)	0-30.5	1.40(0.18)	1.44(0.01)	1.55(0.11)
Water content	0-7.6	34(2)	33(1)	27(2)
(%, cm^3/cm^3)	0-30.5	34(3)	30(1)	36(2)
Very fine silt	0-7.6	34(14)	29(2)	24(2)
& clay (%)	0-30.5	33(6)	27(4)	28(4)
Sand	0-7.6	14(1)	22(12)	16(1)
(%)	0-30.5	9(2)	9(4)	8(4)
Total C	0-7.6	14.2(2.3)a	14.1(0.07)a	10.0(0.8)b
(Mg/ha)	0-30.5	30.7(7.7)a	31.8(1.9)a	22.2(4.0)b
Microbial C	0-7.6	351(186)a	265(64)ab	152(15)b
(kg/ha)	0-30.5	413(136)ab	604(144)a	360(58)b
Microbial N	0-7.6	34(5)a	33(10)a	10(5)b
(kg/ha)	0-30.5	41(14)a	46(9)a	24(1)b
Mineralizable	0-7.6	63(20)a	61(9)a	14(3)b
N (kg/ha)	0-30.5	40(19)a	43(6)a	23(6)b
Nitrate-N	0-7.6	0.1(0.1)b	0.1(0.06)b	25(5)a
(kg/ha)	0-30.5	0.3(0.1)b	0.3(0.2)b	38(9)a
Elec. Cond.	0-7.6	0.02(0.01)	0.03(0.01)	0.22(0.05)
(1:1 soil/water)	0-30.5	0.01(0)	0.01(0)	0.07(0.01)
Soil pH	0-7.6	5.4(0.1)	5.5(0.1)	4.8(0.2)
(1:1 soil/water)	0-30.5	4.8(0.1)	4.9(0.1)	4.8(0.1)
Extractable P	0-7.6	17(7)ab	22(3)a	13(1.4)b
(kg/ha)	0-30.5	30(9)ab	33(3)a	21(5)b

* UN (Undisturbed CRP), FD (Four days following tillage), NM (Nine months following tillage).
† Values in parenthesis represent the standard deviation of the mean (n = 3). Values within rows followed by the same letter do not differ significantly at $p = 0.05$ or 0.1.

Table 4. Tillage effects on water holding capacity, infiltration, runoff and soil loss for the Grenada silt loam soil

Treatment*	Water holding capacity† 0-7.6 cm [% (cm water)]	Infiltration‡ 1st (minutes)	Infiltration‡ 2nd (minutes)	Rainfall simulation# Runoff (mm)	Rainfall simulation# Soil loss (t/ha)
UN	37 (2.8)	45	—	15 (21)	0.2 (0.1)
FD	57 (4.4)	0.5	66	7 (24)	0.2 (0.3)
NM	41 (3.1)	3.9	28	3 (22)	0.3 (5.5)

* UN (Undisturbed CRP), FD (Four days following tillage), NM (Nine months following tillage).
† In field soil volumetric water content 16 hours after irrigation with 5 cm (2 in) of water, values in parenthesis represent cm of water.
‡ Time for 1st- and 2nd- 2.54 cm (1.00 in) of water to infiltrate the soil.
\# Runoff and soil loss after 1/2 hour at a rainfall intensity of 65 mm/hr (2.5 in/hr) for the initial simulation run, values in parenthesis are for the wet run.

of sampling ranged from 27 to 34% which represented 50 to 87% of the total soil porosity being filled with water. Thus, the capacity of the top 7.6 cm (3.0 in) of these soils to accept additional water ranged from 2.1 cm (0.85 in) for the NM treatment to 1.2 and 1.3 cm (0.47 and 0.52 in) for the UN and FD treatments, respectively. The capacity of the top 30.5 cm (12.0 in) of soil to accept additional water ranged from 1.8 cm (0.71 in) for the NM treatment to 4.0 cm (1.6 in) for the UN and FD treatments. Tillage also influenced the soil water holding capacities of the upper soil profile as indicated in Table 4.

Soil chemical and biological properties were greatly influenced by tillage and fallowing of the former CRP site. Total C levels, in the surface 0-7.6 cm (0-3.0 in) and 0-30.5 cm (0-12.0 in) of the NM treatment were substantially lower than those in the FD treatment. Similar results were observed for microbial C and N, mineralizable N, and extractable P with values being highest for the UN and FD treatments and lowest for the NM treatment. Higher soil nitrate and electrical conductivity values and lower soil pH for the NM treatment is reflective of a soil condition where organic residues have been mineralized and nitrified but the resultant nitrates produced are not taken up by plants. These results are consistent with a degradation of soil quality resulting from decomposition of biological nutrient reserves due to soil tillage where the nutrients released are neither efficiently utilized nor recycled to soil organic matter by plants. Plant growth not only maintains the soil biological reserves of C and N but also removes excess nutrients from soil resulting in reduced soil nitrate levels, lower potential for N leaching, and neutralization of the acidity produced during nitrification of N mineralized from organic residues.

The higher levels of soil organic matter and biological reserves in undisturbed soils on which plant growth had been maintained were associated with greater soil structural stability and resistance to erosion compared with CRP land which was tilled and left fallow. Varying soil physical condition and infiltration capacity of the different CRP treatments resulted in differences in the time for soil to accept 2.54 cm (1.00 in) of water, especially when the soil was at or below field capacity when water was first added (Table 4). Infiltration times for 2.54 cm (1.00 in) of water were much lower for tilled treatments than the undisturbed CRP which represented a potential runoff problem. These characteristics were confirmed by the rainfall simulation test where 46% of the 3.2 cm (1.3 in) of water applied in the first one-half hour was lost as runoff in the undisturbed CRP treatment whereas only 9-22% was lost as runoff in tilled treatments. While the runoff characteristics of the NM treatment compared favorably with the UN and FD treatments, the erosivity of the NM treatment after the addition of 3.2 cm (1.3 in) of simulated rainfall was considerably higher, especially where the soil was at water-holding capacity when rainfall occurred.

Summary and conclusions

This study was conducted to determine the effects of tillage on soil erosion potential and soil quality characteristics of a former CRP site in Northern Mississippi. Rainfall simulation tests were conducted before the site was placed in the CRP when the area had been cropped for several years, on undisturbed CRP plots, and on former CRP areas which had been tilled four days and nine months previously. Selected soil physical, chemical, and biological properties were measured on the undisturbed CRP plots and the tilled treatments.

Vegetation covered the entire plot surface on the undisturbed CRP site but residue cover was reduced to 18% nine months following tillage. A substantial reduction in the amount of soil organic carbon in the top 30.5 cm (12.0 in) of soil occurred nine months following tillage. For saturated surface conditions, no significant difference in runoff was found between the undisturbed CRP and tilled treatments. Soil loss values were minimal on the undisturbed CRP site and the plots which had been recently tilled. In contrast, soil loss on the plots which had been tilled nine months previously were similar to values obtained when the area had been used as cropland.

Soil physical, chemical, and biological properties were also greatly influenced by tillage and fallowing of the former CRP site. A degradation of soil quality resulted from the decomposition of biological nutrient reserves during the fallow period. Once an area is tilled and then left in a fallow condition, the conservation and soil quality benefits derived from the CRP may rapidly decline. Maintaining residual grass residue and soil organic matter produced during the CRP period on and near the soil surface will be important during the initial cropping season. As the residual grass residue and soil organic matter are lost through erosion and decomposition, additional crop residue must be provided.

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