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ABSTRACT

TILLAGE treatments leaving 20% or more of the soil surface covered with residue reduced soil erosion by at least 50% of that which occurred from a moldboard plow system. No-till had the least erosion and tended to have the lowest cumulative runoff. These results were based on rainfall simulation tests on six tillage treatments used on both 5 and 10% slopes in continuous corn production.

INTRODUCTION

Soil erosion and subsequent sedimentation have been identified as major water quality problems in Nebraska (NNRC, 1979). Annual Nebraska erosion losses are estimated at more than 127 million metric tons with about 75% of these losses coming from row crop production areas. The Soil Conservation Service estimated that soil erosion from unusually heavy rains in the spring and early summer of 1982 caused more than 260 million dollars damage in eastern Nebraska.

Water induced soil erosion on cropped fields is largely a function of soil particle detachment by raindrop impact and subsequent downstream transport of the detached soil by flowing water. One of the most effective and least expensive methods of controlling this erosion is conservation tillage (Nicol et al., 1974 and Seay, 1970). The term "conservation tillage," as used in this paper, includes all tillage methods that leave at least 20% of the soil surface covered with residues after planting. Residues protect the soil from raindrop impact, thus limiting the amount of soil particle detachment. The series of intricate dams and debris basins formed by the residue also slows the rate at which runoff occurs which, in turn, reduces the sediment transport capability of the flowing water and further limits soil erosion.

Objectives of this research were to measure and compare soil and water losses for selected tillage systems in continuous corn production used on soils and slopes representative of eastern Nebraska row crop production areas.

METHODOLOGY

Research was conducted at two different locations in order to obtain erosion information for soils from different soil series and slopes. One location was at the University of Nebraska Rogers Memorial Farm in Lancaster County, 18 km east of Lincoln, Nebraska. The soil evaluated was within the Wymore Series (Aquic Argiurdolls, fine montmorillonitic, mesic) with a 5% slope (SCS, 1980). The other site was at the University of Nebraska Northeast Station in Dixon County near Concord, Nebraska. The soil at this site was in the Nora Series (Udic Haplustolls, fine silty, mixed, mesic) with a 10% slope (SCS, 1978). The Soil Conservation Service describes the soils at both locations as friable with soil erosion from water being the main hazard.

The experimental design at both locations was a randomized complete block with three replications for each tillage treatment. Individual tillage plots were 9.1 m wide and 22.9 m long. Plots were tilled and planted up-and-down hill and positioned to obtain nearly equivalent slopes.

Basic tillage methods evaluated were the moldboard plow, chisel plow, disk, till-plant and no-till systems. Additionally, rotary-till and strip rotary-till systems were evaluated at the Northeast Station. Tillage treatments were initiated in the spring of 1980 at the Rogers Farm and in the fall of 1980 at the Northeast Station. Specific field operations in order within each tillage system were:

MOLDBOARD PLOW—fall moldboard plow, fertilize, disk twice, plant, apply herbicide, cultivate.

CHISEL PLOW—fall chisel plow, fertilize, disk, plant, apply herbicide, cultivate.

DISK—fertilize, disk twice, plant, apply herbicide, cultivate.

TILL-PLANT—fertilize, till-plant, apply herbicide, cultivate.

NO-TILL—fertilize, plant, apply herbicide.

ROTARY-TILL—fertilize, rotary-till, plant, apply herbicide, cultivate.

STRIP ROTARY-TILL—fertilize, strip rotary-till, plant, apply herbicide, cultivate.

In addition, the stalks were shredded for the till-plant, no-till, rotary-till and strip rotary-till treatments at the Northeast Station.

Standard production implements were used for all field operations. Depths for the tillage operations were 20 cm for the moldboard plow, 25 cm for the chisel plow, 17 cm for the anhydrous ammonia applicator knives, and 15 cm for the initial disking. For final seedbed preparation, disking depth was 10 cm. The rotary tillers were operated 13 cm deep, with the strip rotary tiller adjusted to till a strip 38 cm wide, centered on the row. Planting depth was 5 cm and row spacing was 76 cm in all plots.

Soil erosion was measured, after planting and prior to the establishment of appreciable canopy cover or crop cultivation, from sub-plots, 3.0 m wide and 10.7 m long, located within each of the larger tillage plots. In order to

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maintain nearly equivalent soil conditions, the erosion sub-plots were in different locations within the main tillage plots from year to year. A rotating boom rainfall simulator (Swanson, 1965) was used to apply water at a rate of approximately 63.5 mm/h until runoff rates reached equilibrium, usually after 45 minutes. Actual water application rates for all treatments averaged 64.0 mm/h with a standard deviation of 5.33 mm/h. The rainfall simulator, applying water at a rate of 63.5 mm/h has a rainfall erosion index (EI) similar to a single storm event expected to occur once every two years in eastern Nebraska (Wischmeier and Smith, 1978). Every three minutes, the runoff rate was measured gravimetrically and a 0.5 L runoff sample was collected to determine sediment concentration. Rainfall simulations took place May 20 and 21, 1981 and May 20, 1982 at the Rogers Farm and May 26 through 28, 1981 and June 3 and 4, 1982 at the Northeast Station.

Canopy and residue covers on the soil surface were measured at the time of rainfall simulation using the photographic grid method described by Laflen et al. (1978). Residue and vegetation were collected from a one square meter area and oven dried to determine weight. Although not an integral part of this project, the average corn grain yield across all plots for both years was 5.19 t/ha at the Rogers Farm and 7.57 t/ha at the Northeast Station.

RESULTS AND DISCUSSION

Soil Surface Cover

The percentage of soil surface covered with crop residues following tillage and planting operations ranged from 1.1 to 75.7% (Table 1). The percent surface cover reported includes a small amount of crop canopy since the corn was in the three to four leaf growth stage at the time of measurement except for the 1982 data at the Northeast Station where the corn had not emerged prior to simulation.

At the Rogers Farm, surface cover remaining after tillage and planting was similar within tillage treatments for both years. The no-till cover, averaging 44.3%, was significantly greater at the 10% level each year than the till-plant cover which averaged 21.7%. The till-plant system had a residue cover significantly greater than the moldboard plow treatment which averaged 4.8% for the two years. The disk and chisel plow treatments had similar residue covers averaging 13.3%.

Unlike the Rogers Farm data, the percent cover within tillage treatments was quite different between years at the Northeast Station. The difference could be because of unusually heavy spring rains which delayed field operations in 1982. The residue underwent further weathering and was very fragile by the time tillage and planting occurred. Generally, there tended to be a greater percentage of residue cover at the Northeast

TABLE 1.
MEASURED SURFACE COVER, SOIL LOSS AND EROSION RATE FOR VARIOUS TILLAGE SYSTEMS USED FOR CONTINUOUS CORN PRODUCTION

Location and Tillage System	Residue cover* %	Soil loss† t/ha	Erosion rate‡ t/(ha·h)
Rogers Farm - 1981			
Moldboard Plow	5.8 a	17.01 a	32.73 a
Chisel Plow	11.0 b	13.63 ab	25.06 b
Disk	14.9 b	10.18 b	18.31 b
Till-plant	21.9 c	10.67 b	18.18 b
No-till	49.5 d	3.00 c	4.75 c
Rogers Farm - 1982			
Moldboard Plow	3.8 a	22.64 a	35.64 a
Chisel Plow	12.6 ab	18.72 ab	24.08 b
Disk	14.8 ab	14.80 b	22.98 b
Till-plant	21.4 b	14.53 b	22.66 b
No-till	39.1 c	7.22 c	12.15 c
Northeast Station - 1981			
Moldboard Plow	6.3 a	17.62 a	42.23 a
Chisel Plow	34.6 bc	4.60 b	10.96 b
Disk	20.6 b	4.93 b	15.11 b
Till-plant	33.6 bc	2.40 b	8.92 b
No-till	38.9 c	1.57 b	5.00 b
Rotary-till	26.4 bc	4.28 b	12.73 b
Northeast Station - 1982			
Moldboard Plow	1.1 a	38.76 a	74.78 a
Chisel Plow	7.6 abc	12.08 b	25.33 bc
Disk	14.4 cd	8.50 b	19.12 bc
Till-plant	7.2 ab	13.23 b	30.04 b
No-till	75.7 e	1.88 b	3.07 c
Rotary-till	11.0 bc	13.81 b	22.82 bc
Strip Rotary-till	20.3 d	7.49 b	18.31 bc

*Cover measurements taken after tillage and planting but prior to rainfall simulation.
†Soil loss after 51 mm water applied.
‡Erosion rate after reaching equilibrium conditions between runoff and water application.
aNumbers with the same superscript are not significantly different (Duncan's multiple range test, 10% level) at each site for each year for each column.

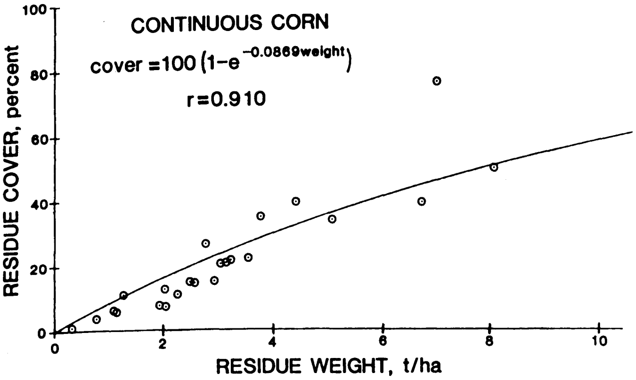

Fig. 1—Relationship between corn residue weight and percent residue cover.

Station than at the Rogers Farm. The higher levels at the Northeast Station can be attributed to a greater yield and a more uniform residue coverage resulting from the stalk shredding operation.

The chisel plow, disk, till-plant, rotary-till and no-till systems used in 1981 at the Northeast Station had residue levels exceeding the 20% minimum cover required for conservation tillage and were significantly greater than the 6.3% cover of the moldboard plow treatment. However, in 1982, only no-till and strip rotary-till would be classified as conservation tillage based on the minimum 20% cover criterion.

Fig. 1 illustrates that surface cover increases as the residue weight increases. Data from both sites for both years were used to develop the equation:

soil surface cover, percent =

$$100\,(1 - e^{-0.0869\,(\text{weight, t/ha})}) \quad \ldots\ldots\ldots\ldots [1]$$

which has a correlation coefficient (r) of 0.910. Percent surface cover, highly correlated with residue weight, was used to develop erosion-residue relationships because of its relative ease of measurement.

Soil Erosion

Cumulative soil losses for the rainfall simulations are shown in Figs. 2 and 3. The curves, which represent the average of three replications, illustrate cumulative soil loss versus water applied with the rainfall simulator. Without exception, the moldboard plow treatment had the highest soil loss while the no-till treatment had the least. Generally, decreasing the amount of tillage resulted in a decrease in soil loss, with the chisel plow system tending to have more erosion than the disk system.

Cumulative soil loss at the Rogers Farm following 51 mm of water application was 17.0 t/ha in 1981 and 22.6 t/ha in 1982 for the moldboard plow treatment (Table 1). The chisel plow system reduced the loss by an average of 18.6% of that which occurred from moldboard plowing. Similarly, the disk, till-plant and no-till systems reduced the soil loss by 37.5, 36.6 and 75.2% respectively. In 1981 and 1982, there were no significant differences in soil loss among the chisel plow, disk and till-plant treatments. Soil loss from the no-till system, which averaged 5.1 t/ha for the two years, was significantly lower than the loss from all other tillage treatments.

No-till had the lowest cumulative soil loss following 51 mm of water application at the Northeast Station. However, because of some large plot variabilities, only the moldboard plow treatment had significantly more total soil loss than no-till and averaged over 28 t/ha for the two simulations. Using any of the other tillage

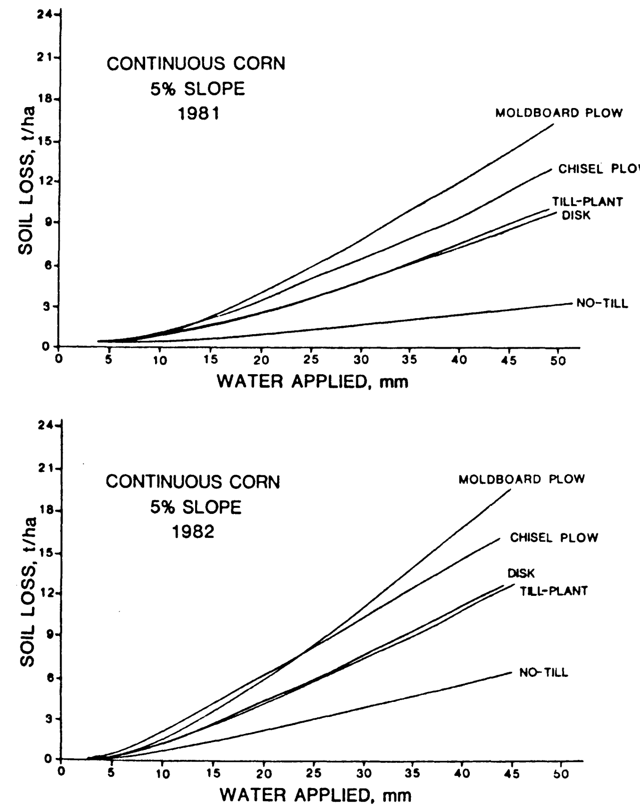

Fig. 2—Cumulative soil loss vs. water application for different tillage treatments evaluated at the Rogers Farm.

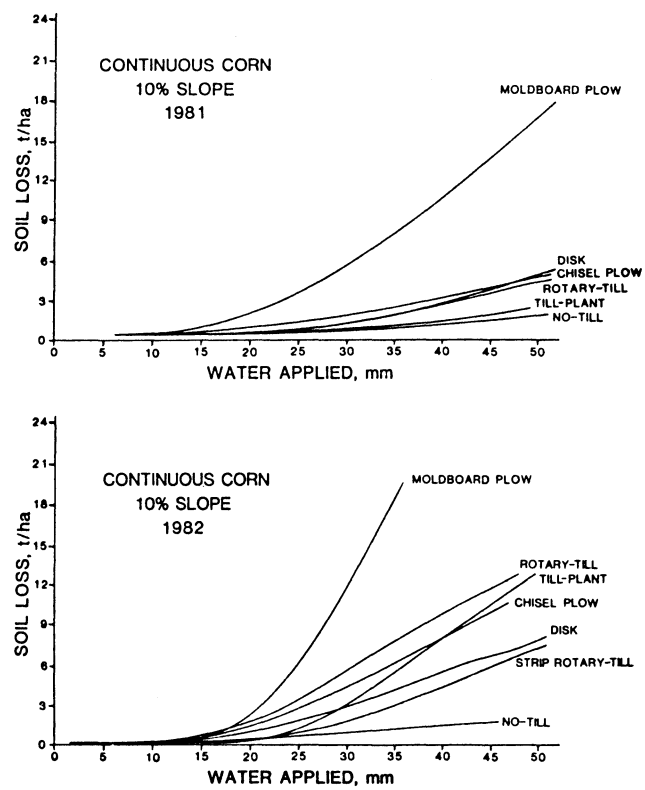

Fig. 3—Cumulative soil loss vs. water application for different tillage treatments evaluated at the Northeast Station.

systems reduced the cumulative soil loss by 65% or more of that which occurred from the moldboard plow treatment. In 1982, no-till reduced the soil loss by 95%.

For a more complete evaluation of the soil loss from the different tillage systems, the erosion rate following equilibrium runoff conditions should also be compared. This condition generally occurred after 25 mm of water had been applied. The average erosion rate (Table 1) for the moldboard plow system at the Rogers Farm was 34.2 t/(ha·h) and 58.5 t/(ha·h) at the Northeast Station. The erosion rates from the chisel plow, disk and till-plant systems were not significantly different at the 10% level at the Rogers Farm and, on the average, were 36% lower than that of the moldboard plow. No-till had an erosion rate which was 75% less than the moldboard plow system.

In 1981 at the Northeast Station, the erosion rates for all treatments except moldboard plow were not significantly different and averaged 75% lower than that of the moldboard plow. Results were similar in 1982 except that till planting had a significantly greater erosion rate than no-till planting. This difference between the till-plant and no-till treatments also occurred at the Rogers Farm in both years and reflects a potential problem when using the till-plant system up-and-down the hill rather than on the contour. Even though till planting may leave a large amount of surface residue cover, a strip of bare soil, vulnerable to erosion, is left in the row area.

Runoff

Differences in the cumulative runoff curves (Fig. 4) are primarily the result of differences in infiltration and surface storage among the tillage treatments. At the Rogers Farm in 1981, no-till tended to have the lowest cumulative runoff. However, there were no significant differences after 51 mm of water application among the tillage treatments (Table 2). In 1982, the no-till system had 32 mm of runoff which was significantly less than all other tillage treatments.

At the Northeast Station, the only significant difference in runoff after 51 mm of water was applied was between the no-till and moldboard plow treatments, with no-till being 53% less. Moldboard plowing tended to have a larger amount of runoff, but not significantly greater than chisel plow, disk, till-plant and rotary-till treatments. In 1982, the disk treatment had 13.5 mm of runoff which was significantly less than that from the no-till, rotary-till and moldboard plow treatments.

Runoff rates, after reaching equilibrium between runoff and water application, are shown in Table 2. Because the surface storage volumes of the various tillage systems generally were filled, differences among the runoff rates for the different tillage treatments primarily reflect differences in the surface infiltration rate of the soil. The silt loam soil at the Northeast Station had a lower runoff rate, thus a higher infiltration rate, than the silty clay loam at the Rogers Farm. At the Rogers Farm, the only significant difference measured in the runoff rate was in 1981 when till-plant, having a rate of 54.9 mm/h, was less than the moldboard plow treatment of 68.6 mm/h. Similarly, no-till was lower than moldboard plowing at the Northeast Station in 1981. In 1982 at the Northeast Station, runoff rates for the disk and no-till treatments were significantly lower than the rotary-till treatment.

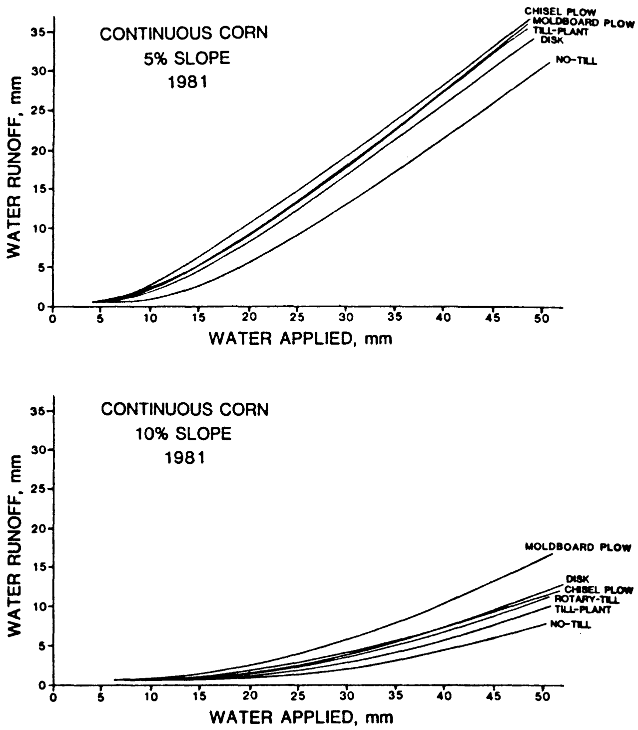

Fig. 4—Cumulative runoff vs. water application for different tillage treatments.

Sediment Concentration

Sediment concentrations in the runoff during rainfall simulation in 1981 are shown in Fig. 5. The 1982 results were similar. Without exception, the sediment concentration was highest for the moldboard plow treatment and lowest for the no-till treatment. At the Rogers Farm, sediment concentration for each tillage treatment tended to be constant over time. At the Northeast Station, sediment concentration for each tillage treatment began at a similar value and with the exception of no-till, tended to increase until an equilibrium runoff rate was obtained, usually after 25 mm of water had been applied.

Except for the chisel plow treatment at the Rogers Farm, the moldboard plow system had a sediment concentration significantly greater than the other tillage treatments (Table 2), averaging 50,100 ppm for the two simulations. The disk and till-plant treatments had average sediment concentrations which were not significantly different and averaged 34% less than the moldboard plow treatment. The average sediment concentration from no-till was 16,100 ppm, 68% lower than the moldboard plow system. Because the runoff rates at the Rogers Farm were very similar for the various tillage treatments, the sediment concentration results closely parallel the cumulative erosion results shown in Table 1.

In 1981 at the Northeast Station, no significant differences were observed in average sediment concentrations among the chisel plow, disk, till-plant, no-till and rotary-till treatments. The average sediment concentration for these treatments was 30,800 ppm which was 71% lower than the average sediment concentration for the moldboard plow treatment. In 1982, the average sediment concentration of 10,000 ppm for no-till was significantly lower than those of the moldboard plow, chisel plow and till-plant treatments.

TABLE 2. MEASURED RUNOFF, RUNOFF RATE AND AVERAGE SEDIMENT CONCENTRATION IN THE RUNOFF FOR VARIOUS TILLAGE SYSTEMS USED FOR CONTINUOUS CORN PRODUCTION.

Location and Tillage System	Runoff* mm	Runoff rate† mm/h	Concentration‡ ppm
Rogers Farm - 1981			
Moldboard Plow	38.1 a	68.6 a	44400 a
Chisel Plow	38.6 a	64.5 ab	35500 ab
Disk	35.6 a	59.9 ab	28500 b
Till-plant	37.6 a	54.9 b	28300 b
No-till	31.0 a	57.9 ab	9900 c
Rogers Farm - 1982			
Moldboard Plow	40.4 a	59.7 a	55900 a
Chisel Plow	40.1 a	55.4 a	46900 ab
Disk	38.9 a	57.4 a	37900 b
Till-plant	38.4 a	59.9 a	37600 b
No-till	32.0 b	54.9 a	22200 c
Northeast Station - 1981			
Moldboard Plow	16.3 a	38.6 a	104600 a
Chisel Plow	11.2 ab	27.7 ab	32600 b
Disk	11.9 ab	31.8 ab	41800 b
Till-plant	9.9 ab	29.2 ab	21700 b
No-till	7.6 b	23.6 b	21400 b
Rotary-till	11.2 ab	30.0 ab	36400 b
Northeast Station - 1982			
Moldboard Plow	18.8 a	43.4 ab	196500 a
Chisel Plow	16.5 ab	41.1 ab	72900 b
Disk	13.5 b	35.3 b	63700 bc
Till-plant	16.3 ab	40.6 ab	76100 b
No-till	18.5 a	35.8 b	10000 c
Rotary-till	21.1 a	46.7 a	64300 bc
Strip Rotary-till	16.8 ab	44.5 ab	43300 bc

*Water runoff after 51 mm water applied.
†Runoff rate after reaching equilibrium conditions between runoff and water application.
‡Concentrations were determined by dividing the total soil removed by the total runoff after 51 mm of simulated rainfall.
aNumbers with the same superscript are not significantly different (Duncan's multiple range test, 10% level) at each site for each year for each column.

Soil Erosion and Surface Cover

The data on soil erosion at 51 mm of water applied and crop residue cover were analyzed using non-linear curve fitting techniques (SAS Institute Inc., 1982). The equation:

$$\text{erosion} = Ae^{B \cdot RC} \quad [2]$$

where A and B are constants and RC is the percent residue cover, was fitted to the data. The data were separated by site because of different soil types and slopes. The statistical procedure was one that, through an iterative procedure, minimized the residual sum of squares.

For the tillage treatments at the Rogers Farm, the equation developed had an r value of 0.810 (Fig. 6). The value of B was −0.0346 and is at the upper end of the range of −0.03 to −0.07 reported for row cropped land (Laflen, Moldenhauer and Colvin, 1980; Laflen and Colvin, 1981). The intercept value A, which indicates the erosion when no residue cover exists, was 23.02 t/ha. The r value for the Northeast Station for the erosion-cover relationship was 0.851. The B value, slightly below the range of −0.03 to −0.07, was −0.0805. With no residue cover, the predicted erosion would be 29.42 t/ha.

The amount of residue needed to reduce erosion a specified amount can be estimated by using the

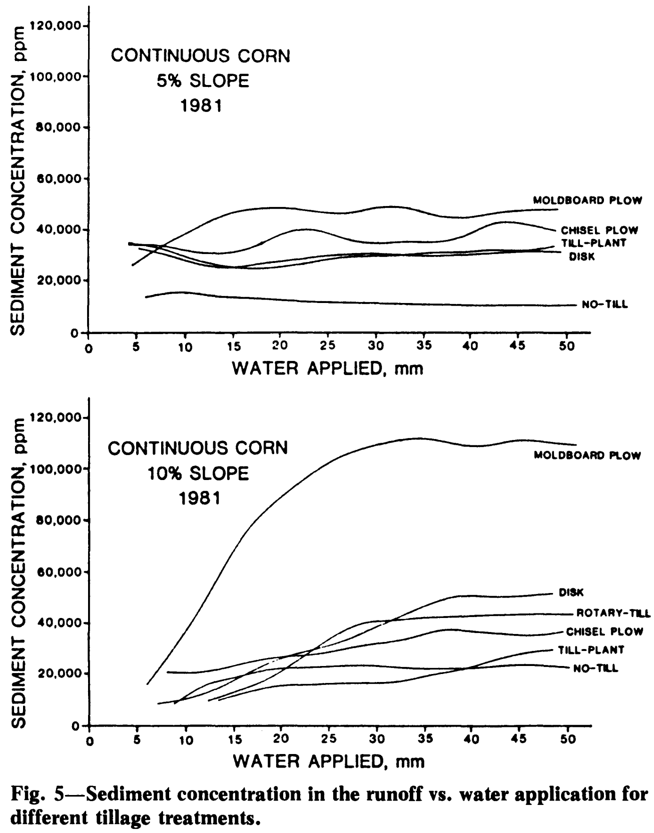

Fig. 5—Sediment concentration in the runoff vs. water application for different tillage treatments.

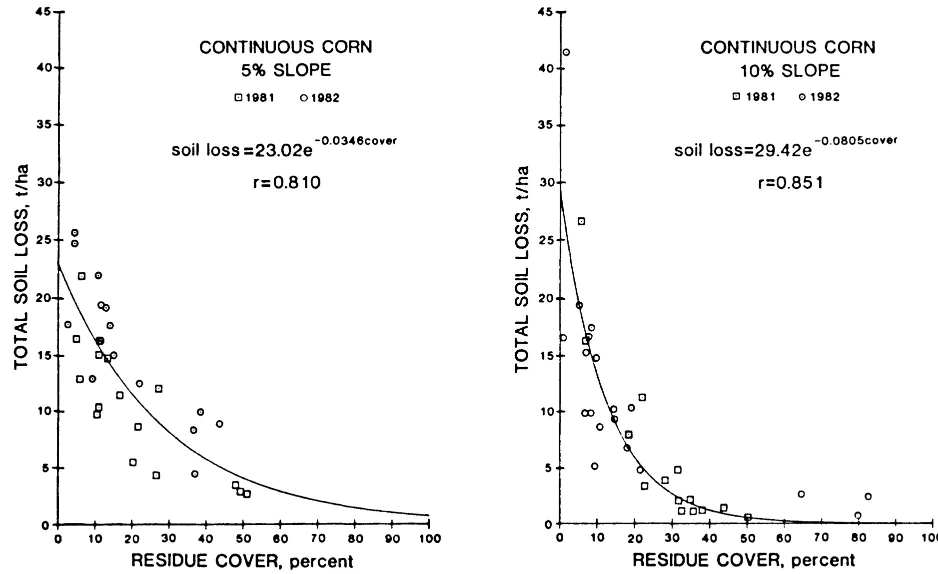

Fig. 6—Soil loss at 51 mm of water applied vs. residue cover.

equations relating soil erosion to residue cover. For instance, if a 50% reduction in the erosion from a cleanly tilled or residue free soil surface on the silty clay loam at the Rogers Farm having a 5% slope is desired, then the amount of surface cover needed is 20%. Similarly, to achieve a 50% erosion reduction from the cleanly tilled silt loam soil on the 10% slope at the Northeast Station, a 9 percent cover is needed. Thus, for both the Rogers Farm and the Northeast Station, any tillage system which leaves at least a 20% surface cover will reduce soil erosion from cleanly tilled, residue free conditions by at least 50%.

In addition to reducing the total amount of soil loss, crop residue covers are also effective in limiting sediment concentrations in the runoff. Using the equation:

$$\text{sediment concentration} = Ae^{B \cdot RC} \qquad [3]$$

relationships between residue cover and average sediment concentration for the different treatments were obtained (Fig. 7). The r values for these relationships were 0.792 and 0.873 for the Rogers Farm and Northeast Station, respectively. Similar to the erosion results, about 24% cover was necessary to achieve a 50% reduction in sediment concentration from cleanly tilled conditions at the Rogers Farm. An 8% cover was necessary to obtain a 50% reduction at the Northeast Station.

SUMMARY AND CONCLUSIONS

Soil loss from various tillage systems used on a silty clay loam having a 5% slope and a silt loam soil having a 10% slope was evaluated using rainfall simulation techniques. The moldboard plow treatment always had the greatest soil loss while the no-till treatment had the least. Generally, decreasing the amount of tillage resulted in a decrease in soil erosion with the chisel plow system tending to have more erosion than the disk system. However, erosion rates from the chisel plow, disk, rotary-till and till-plant systems were not different

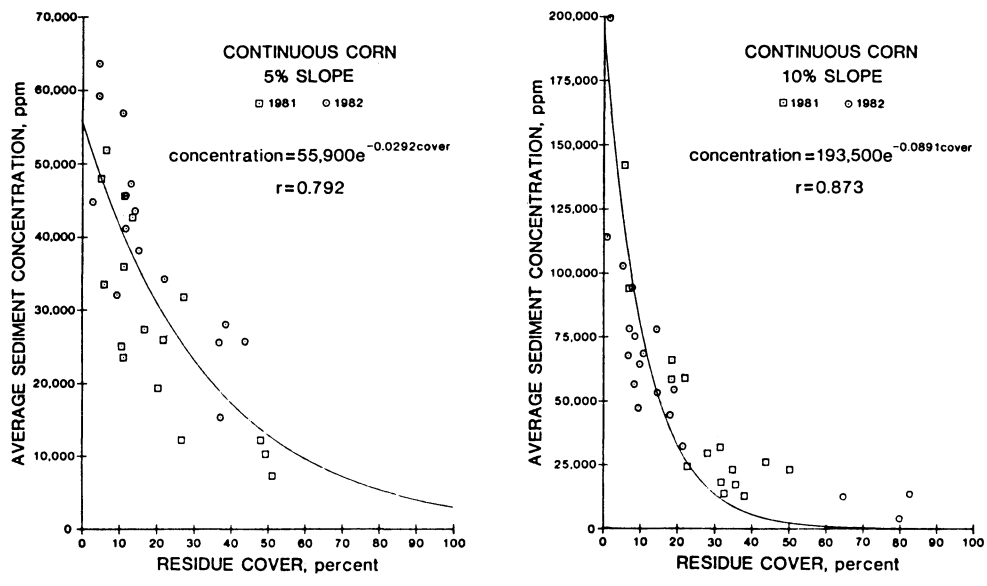

Fig. 7—Sediment concentration at 51 mm of water applied vs. residue cover.

at the 10% significance level. These systems reduced the cumulative soil loss after 51 mm of rainfall by 30% of that which occurred from moldboard plowing on the 5% slope and by 73% on the 10% slope. Similarly, no-till reduced the cumulative soil loss by 75 and 90% on the 5 and 10% slopes, respectively.

The no-till treatment tended to have the lowest cumulative runoff but generally there were few significant differences among tillage treatments. Similarly, moldboard plowing tended to have the largest amount of runoff. Because the runoff rate tended to be the same for all tillage treatments, differences in erosion were primarily due to differences in sediment concentration in the runoff. The sediment concentration was always highest for the moldboard plow treatments and lowest for the no-till treatments.

The soil loss and sediment concentration data were highly correlated with the percent of soil surface covered with residue. For both the 5 and 10% slopes, tillage systems leaving 20% or more of the soil surface covered with residues reduced soil loss by at least 50% of that which occurred from cleanly tilled, residue free conditions.

References

1. Laflen, J. M., J. L. Baker, R. O. Hartwig, W. F. Buchele and H. P. Johnson. 1978. Soil and water loss from conservation tillage systems. TRANSACTIONS of the ASAE 21(5):881-885.
2. Laflen, J. M. and T. S. Colvin. 1981. Effect of crop residue on soil loss from continuous row cropping. TRANSACTIONS of the ASAE 24(3):605-609.
3. Laflen, J. M., W. C. Moldenhauer and T. S. Colvin. 1980. Conservation tillage and soil erosion on continuous row cropped land. Proc. of Crop Production with Conservation in the 80's. ASAE Publ. 7-81, St. Joseph, MI 49085.
4. Nebraska Natural Resources Commission. 1979. Section 208 Water Quality Management Plan for the State of Nebraska. 57 pp.
5. Nicol, K. H., E. O. Heady and H. L. Madsen. 1974. Models of soil loss, land and water use, spatial agricultural structure and the environment. Center for Agr. and Rural Develop., CARD Rpt. 49T. Iowa State Univ., Ames.
6. SAS Institute Inc. 1982. SAS User's Guide: Statistics, 1982 Edition. SAS Institute Inc., Cary, NC. 584 pp.
7. Seay, E. E. 1970. Minimizing abatement costs of water pollutants from agriculture. A parametric linear programming approach. Ph.D. Thesis, Iowa State Univ., Ames.
8. Soil Conservation Service. 1978. Soil survey of Dixon County, Nebraska. USDA-SCS.
9. Soil Conservation Service. 1980. Soil survey of Lancaster County, Nebraska. USDA-SCS.
10. Swanson, N. P., 1965. Rotating-boom rainfall simulator. TRANSACTIONS of the ASAE 8(1):71-72.
11. Wischmeier, W. H. and D. D. Smith. 1978. Predicting rainfall erosion losses. USDA Agr. Handbook 537.