1983

Effects of Tillage on Soil Erosion in a Wheat-Fallow Rotation

Elbert C. Dickey
University of Nebraska at Lincoln, edickey1@unl.edu

C. R. Fenster
University of Nebraska-Lincoln

J. M. Laflen
USDA-ARS, Ames, IA

R. H. Mickelson
USDA-ARS, Akron, CO

Effects of Tillage on Soil Erosion in a Wheat-Fallow Rotation

E. C. Dickey, C. R. Fenster, J. M. Laflen, R. H. Mickelson
MEMBER ASAE — MEMBER ASAE — MEMBER ASAE

This article is reprinted from the TRANSACTIONS of the ASAE (Vol. 26, No. 3, pp. 814–820, 1983)
Published by the American Society of Agricultural Engineers, St. Joseph, Michigan

ABSTRACT

EROSION from alternative tillage systems in winter wheat-fallow rotations was measured using a rainfall simulator. The Nebraska study, conducted at the High Plains Agricultural Laboratory, showed that during the fallow period between harvest and tillage, soil erosion was not affected by the tillage systems studied. However, erosion following tillage was different for the systems evaluated and moldboard plowing with the slope had the largest amount. The no-till system reduced erosion by about 95% during this period. Although contour plowing was effective in reducing erosion when compared to plowing with the slope, no differences were measured between with the slope and contour tillage for the no-till or stubble-mulch treatments.

OBJECTIVES

A large portion of the wheat production in the United States occurs in the Great Plains where rainfall is insufficient to grow row crops on a continuous basis. In this region, land is often farmed continuously in a wheat-fallow rotation. The traditional wheat-fallow rotation, where wheat is harvested once every two years, uses tillage to control weeds during the fallow period. This tillage incorporates residue and leaves the soil surface exposed to erosive forces for about 14 months out of each 24-month period. Conservation tillage systems, such as stubble-mulch and no-till, leave residue covers that reduce soil erosion and conserve moisture while potentially increasing wheat yields from 200 to 350 kg/ha (Fenster and Peterson, 1979).

The objectives of this study were to measure and compare soil erosion losses from various tillage systems used in winter wheat-fallow rotations. The effectiveness of wheat residues in reducing erosion on long slopes was also evaluated since long slopes are characteristic of much of the Great Plains.

PROCEDURE

In 1969, a site for measuring runoff and erosion was established at the High Plains Agricultural Laboratory near Sidney, NE. The soil was an Alliance silt loam, which is classified as a fine silty, mixed mesic Aridic Argiustoll residium over weathered sandstone. The experiment was initiated with alternate winter wheat-fallow rotation. Twelve plots, 8.5 m wide and 36.6 m long, were established on a 4% slope facing southwest. Six plots were fallowed and six were in winter wheat each year. The fallow period was 14 months followed by a 10-month period of winter wheat production.

Tillage treatments included no-till, stubble-mulch, and moldboard plow systems. Each treatment was evaluated on the contour and with (up and down) the slope. Initial tillage operations with conventional machinery were 100 to 150 mm deep and subsequent operations were at a decreasing depth to control weeds as necessary and to develop a seedbed. The moldboard plow plots were plowed about May 1 followed by at least two operations each with a spring tooth harrow and a rotary rodweeder. The stubble-mulch plots were tilled at least three times with 1.8 m V-blades having a 75-deg angle followed by two operations with a rotary rodweeder.

The herbicides paraquat, cyanazine, glyphosate, 2,4-D and dicamba were used to control weeds in the no-till plots. After harvest, grassy weeds were controlled with paraquat at 0.56 kg/ha and a surfactant. Early in the spring, paraquat at 0.28 kg/ha plus 3 kg/ha of cyanazine was used. Later in the summer, grassy weeds were controlled with glyphosate at 0.84 kg/ha. If only broadleaf weeds were present, 2,4-D at 1.1 kg/ha plus dicamba at 0.28 kg/ha was used. Weeds were sprayed when 50 to 100 mm tall.

"Centurk" winter wheat was planted at 50 kg/ha on September 10 after the 14-month fallow period. All plots were planted with an experimental drill equipped with 460 mm diameter rolling coulters, slot openers and seed press wheels. The row spacing was 300 mm.

Soil erosion was measured from plots 2.4 m wide and 10.7 m long within the larger plots. A rotating boom rainfall simulator (Swanson, 1965) was used to apply water at 63.5 mm/h until runoff flow rates reached equilibrium, usually after 90 min. Every three minutes, the runoff rate was measured gravimetrically and a one-liter runoff sample was collected to determine sediment concentration.

Rainfall simulator runs on both fallow and cropped plots at two different times resulted in erosion measurements from four cropping periods within the wheat-fallow rotation. The first cropping period (October, 1979) was after wheat harvest but prior to any tillage. The second (May, 1981) was immediately after the first tillage operation which occurred early in the summer fallow period. The third (October, 1979) was when the wheat was 100 mm tall and the final period (May, 1981) was when the wheat was 460 to 635 mm tall and was heading.

Canopy and residue amounts were measured using the photographic grid method described by Laflen et al. (1978). Residue and vegetation were collected from a square meter area and oven dried to determine weight.

Article was submitted for publication in July, 1982; reviewed and approved for publication by the Soil and Water Div. of ASAE in November, 1982.

Published as Paper Number 6920, Journal Series, Nebraska Agricultural Experiment Station.

The authors are: E. C. DICKEY, Extension Agricultural Engineer, Agricultural Engineering Dept., University of Nebraska-Lincoln; C. R. FENSTER, Extension Crops Specialist, University of Nebraska, Panhandle Station; J. M. LAFLEN, Research Leader, USDA-ARS, Ames, IA; and R. H. MICKELSON, Agricultural Engineering, USDA-ARS, Akron, CO.

TABLE 1. CANOPY AND RESIDUE COVER (PERCENT OF SOIL SURFACE COVERED) AT DIFFERENT WHEAT-FALLOW PERIODS.

Wheat-fallow period	Tillage system	Percent cover With slope tillage	Percent cover Contour tillage	Average
Fallow after harvest* Oct., 1979	Plow	67.6	55.5	61.6
	Stubble mulch	90.5	91.9	90.7
	No till	87.8	93.8	90.8
Fallow after tillage* May, 1981	Plow	3.7	4.8	4.3
	Stubble mulch	95.3	89.1	92.2
	No till	95.6	96.7	96.2
100 mm wheat† Oct., 1979	Plow	26.6	24.7	25.7
	Stubble mulch	45.4	31.3	38.4
	No till	87.4	82.6	85.0
460 mm wheat‡ May, 1981	Plow	76.2	78.9	77.6
	Stubble mulch	81.9	84.2	83.1
	No till	88.9	87.1	88.0

*Primarily residue
†Crop Residue and canopy
‡Primarily canopy

To evaluate the effectiveness of residues for erosion control on longer slopes, clear water was introduced at the upper end of each plot to simulate runoff volume from a longer length. Water was applied during rainfall simulation after runoff had reached a constant rate. The rainfall simulation continued during the flow addition. The usual procedure was to increase the added flow increment in four to eight steps until the maximum runoff volume measured seven to 12 times more than with simulated rainfall alone. More specific details on flow addition have been reported by Laflen et al. (1978) and Hussein and Laflen (1982).

RESULTS AND DISCUSSION

Soil Surface Cover

Rainfall simulation runs were made over a wide range of soil cover conditions (Table 1). For the fallow periods, the soil cover was primarily wheat stubble. However, the surface cover, when the wheat was 100 mm tall, consisted of a 15% canopy with the balance being crop residues. When the wheat was 460 mm tall, the wheat canopy was the primary surface cover. Only slight differences in residue cover were measured for a given tillage treatment used on the contour or with the slope.

Following harvest, both the stubble-mulch and no-till systems had about a 90% surface cover. However, the plow system had only a 62% cover. This difference was attributed to residue accumulations during 10 years of

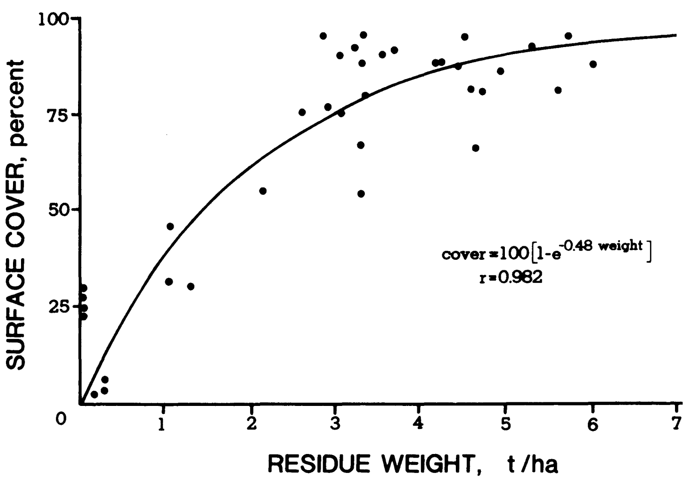

Fig. 1—Relationship between residue weight and percent surface cover.

continuous stubble-mulch and no-till systems. The moldboard plow, which incorporates most of the residue (Table 1), eliminated residue accumulations over time. When the wheat was 100 mm tall, the no-till system had an 85% soil cover compared to 26 and 38% for the plow and stubble-mulch systems, respectively. As the wheat approached maturity, the difference in soil cover was slight, being 78% for plowing and 88% for no-till.

Fig. 1 illustrates the relationship between weight of residue and surface cover. As the weight of residues increases, the surface cover approaches 100%. This relationship is very similar to one presented by Wischmeier and Smith (1978). Percent surface cover, highly correlated with residue weight per unit area, was used to develop erosion residue relationships because percent cover is relatively easy to measure.

Soil Erosion

Cumulative soil losses from the four wheat-fallow periods and six tillage treatments are shown in Fig. 2. For the fallow period following harvest, only slight differences in erosion among the tillage treatments were observed because of the high level of residue remaining on all treatments. Plowing with the slope had the largest amount of soil loss, 1,080 kg/ha after 76 mm of rain (Table 2) while contour plowing had the lowest, 250 kg/ha. One possible reason that contour plowing had a lower loss than either stubble-mulch or no-till, was because of a damming effect caused by plowing on the contour. Even though slight differences among the tillage treatments were measured, the differences in soil loss (Table 2) show that contour tillage can reduce erosion on fallow before tillage to about one-half of that which occurs from tilling with the slope.

The greatest soil loss occurred during the fallow after tillage period for plowing with the slope. After 76 mm of rainfall, the measured soil loss was more than 15,000 kg/ha. However, contour plowing resulted in a soil loss of only about 3,500 kg/ha, which was 76.7% less than that from plowing with the slope. Both the stubble-mulch and no-till systems, when used either with the slope or on the contour, had soil losses which were less than 350 kg/ha after 76 mm of rain.

When the wheat was 100 mm tall, the plow system used with the slope had soil losses approaching 12,000 kg/ha after 76 mm of rain. Stubble-mulching with the slope, having a 45% cover, had a soil loss of about 3,200

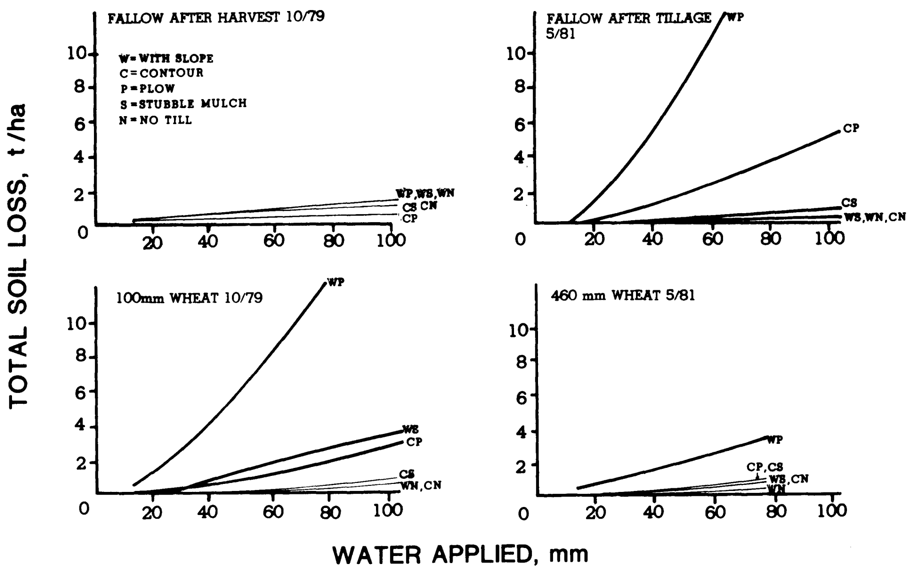

Fig. 2—Soil loss from rainfall simulation tests on various tillage treatments within different wheat-fallow periods.

kg/ha which was 73.3% less than plowing with the slope. The no-till treatment, used either on the contour or with the slope, reduced soil losses by more than 95% when compared to the plowing with the slope.

When the wheat was 460 mm tall, cover and soil erosion amounts were quite similar to those from the fallow after harvest period. Although the tillage system had little effect when used on the contour, differences were observed for treatments used with the slope. While the surface cover consisted primarily of canopy when the wheat approached maturity, the no-till and stubble-mulch systems also had residue lying on the surface. Residue lying on the soil surface probably caused the difference in erosion on tillage treatments used with the slope. For the contour tillage treatments, the same differences in residue existed, but the damming effect created by the contour farming operation further reduced the erosion in the moldboard plow and stubble-mulch systems. This resulted in nearly equal erosion rates from all the contour tillage treatments.

To assess the effectiveness of contouring for the wheat-fallow rotation, soil loss data in Table 2 was used to calculate the erosion ratio of contour to that of with the slope farming. The ratio P, as used in the Universal Soil Loss Equation, has a single value of 0.5 for 3 to 5% slopes (Wischmeier and Smith, 1978). The value of P, when averaged over the cropping periods, was 0.24 for the moldboard plow treatment, indicating a 76% erosion reduction. However, the value of P for stubble-mulch and no-till ranged from 0.5 to more than 1.0 indicating that contouring was not as important with these systems as it was with plowing. A P-value of 1.0 signifies no additional erosion control from contouring. In some cases the erosion from contour treatments was more than that from treatments used with the slope for the stubble-mulch and no-till systems. There was a trend to a larger P-value as the residue level increased.

Runoff

The cumulative runoff for the different wheat-fallow periods and tillage treatments is shown in Fig. 3. With the exception of the fallow period after harvest, plowing with the slope always had the largest amount of runoff. Equilibrium runoff conditions were approached after about 38 mm of water had been applied, except for the fallow after tillage period when runoff did not begin until more than 64 mm of water had been applied to both the stubble-mulch and no-till treatments used with the slope.

Runoff measurements when the wheat was 100 mm tall represents the cumulative effect of all tillage

TABLE 2. SOIL LOSS AND RUNOFF AFTER APPLICATION OF 76 MM OF SIMULATED RAINFALL.

Wheat-fallow period	Tillage system	Soil Loss: With slope tillage	Soil Loss: Contour tillage	Water Runoff: With slope tillage	Water Runoff: Contour tillage
		kg/ha		mm	
Fallow after harvest	Plow	1,080	250	15.5	2.8
	Stubble mulch	1,030	570	19.8	10.9
	No till	850	580	11.2	10.7
Fallow after tillage	Plow	15,240	3,530	45.0	26.4
	Stubble mulch	90	330	1.8	16.5
	No till	20	10	0.8	0.5
100 mm wheat	Plow	11,790	2,680	44.5	25.4
	Stubble mulch	3,250	1,890	25.7	21.8
	No till	520	580	4.1	6.6
460 mm wheat	Plow	3,330	850	54.6	31.8
	Stubble mulch	750	920	24.9	33.8
	No till	70	610	9.7	22.1

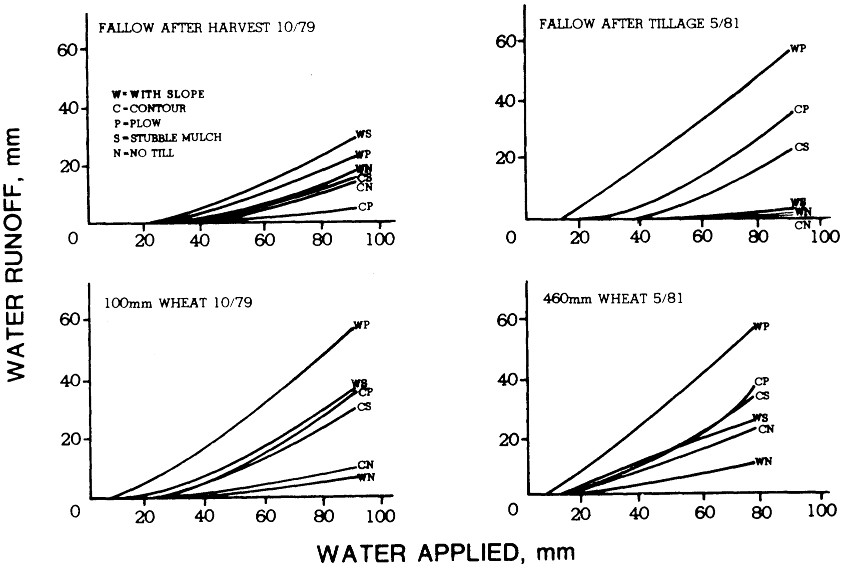

Fig. 3—Water runoff as compared to water applied for various tillage treatments and wheat-fallow rotation periods.

operations within each tillage treatment. Plowing with the slope had 44.5 mm of runoff after 76 mm of water was applied while stubble-mulching with the slope had 25 mm of runoff for a 42% reduction in runoff (Table 2). No-till had the greatest water retention, losing only 5 mm of the 76 mm applied. The runoff difference between the plow and no-till system is considerably larger than data reported by Siemens and Oschwald (1978) for corn and soybean plots on similar slopes. One explanation for this difference is the wheat residue accumulation over time on the no-till treatments created a large surface storage capacity causing large differences in rainfall required to initiate runoff (Fig. 3).

On the average, runoff volumes were reduced by 50% when plowing on the contour rather than with the slope. For the fallow after harvest period, the reduction was more than 80%. However, there was no reduction in runoff volumes because of contouring for the stubble-mulch and no-till treatments.

Sediment Concentration

The sediment concentrations in the runoff were always highest for the plow treatment, except for plowing with the slope during fallow after harvest (Table 3). Also, with the exception of this period, the sediment concentrations from plow treatments used with the slope were more than double of that from contour plowing. Runoff samples taken during the fallow after harvest period indicated that the tillage treatment had little effect on sediment concentrations.

Stubble-mulch and no-till systems used with the slope reduced the sediment concentration by more than 50% of that occurring from moldboard plowing with the slope in the three remaining wheat-fallow periods. Using stubble-mulch and no-till on the contour further reduced the sediment concentrations for the fallow after tillage period. However, as the wheat matured, the contour stubble-mulch and no-till treatments had only slightly lower sediment concentrations than treatments used with the slope.

Overall, there was little difference in sediment concentrations between the contour and with the slope treatments of stubble-mulch and no-till. However, both tillage systems had average sediment concentrations that were 66% lower than plowing with the slope and 47% lower than contour plowing. While contour plowing reduced sediment concentration by about 50%, contouring for the stubble-mulch and no-till treatments only reduced sediment concentrations by 25%.

Soil Erosion and Surface Cover

The data on soil erosion and crop residue cover were analyzed using nonlinear curve fitting techniques (Helwig and Council, 1979). The equation,

$$\text{Erosion} = Ae^{B \cdot RC} \quad [1]$$

where A and B are constants and RC is the percent surface cover, was fitted to the data. The data were separated into contour and with the slope treatments (Fig. 4). The statistical procedure was one that, through an iterative procedure, minimized the residual sum of squares.

TABLE 3. AVERAGE SEDIMENT CONCENTRATIONS AT DIFFERENT WHEAT-FALLOW PERIODS FOR VARIOUS TILLAGE TREATMENTS.

	With slope tillage	ppm*	Contour tillage
Fallow after harvest			
Plow	7,000		8,700
Stubble mulch	5,200		5,300
No till	7,600		5,400
Fallow after tillage			
Plow	35,000		13,300
Stubble mulch	5,000		2,000
No till	3,100		1,800
100 mm wheat			
Plow	26,600		10,500
Stubble mulch	12,700		8,600
No till	13,000		9,000
460 mm wheat			
Plow	6,100		2,700
Stubble mulch	3,000		2,700
No till	700		2,700

*Concentrations were determined by dividing the total soil removed by the total runoff after 76 mm of simulated rainfall.

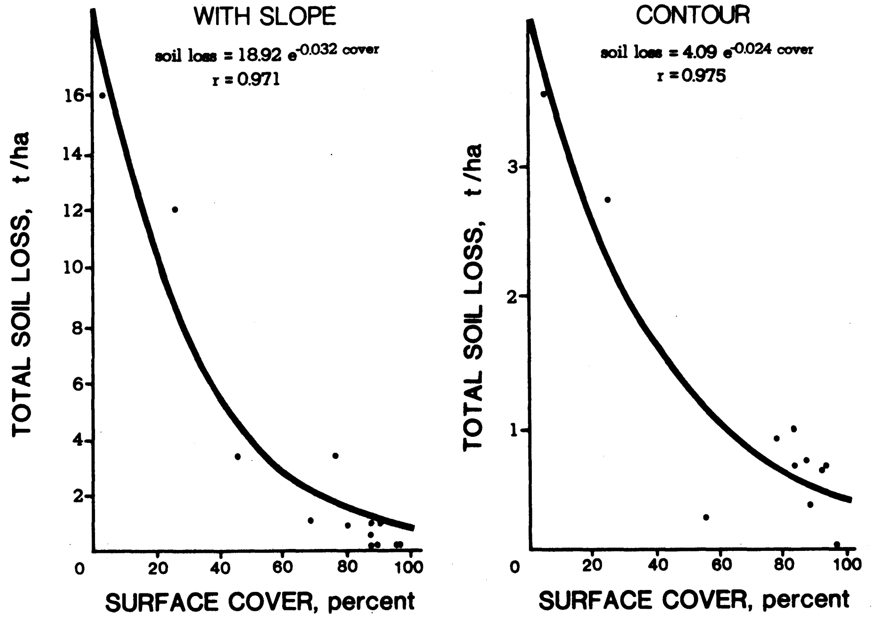

Fig. 4—Soil loss as compared to surface cover for with the slope and contour tillage treatments (76 mm of water applied).

For tillage treatments used with the slope, the equation had a correlation coefficient (r) of 0.97 (Fig. 4). The fit obtained for the contour treatments had an r value of 0.97. The value of B for treatments used with the slope was -0.032 as compared to -0.024 for the contour treatments. These B values for wheat residues are close to but slightly lower than 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 exists, was 18,950 kg/ha for treatments used with the slope and only 4,100 kg/ha for contour treatments.

By using equations relating soil erosion to residue cover for contour and with the slope tillage treatments, the amount of residue needed to reduce erosion by a specified amount can be calculated. For instance, if a 50% reduction in the erosion from plowing with the slope is desired, then the amount of surface cover needed is 26%. Similarly, to achieve a 50% reduction in the amount of erosion occurring from contour plowing, a 33% cover is required.

In addition to reducing the total amount of soil loss, surface covers of wheat residues and canopy are also effective in limiting sediment concentrations in the runoff. Using the equation

$$\text{Sediment Concentration} = Ae^{B \cdot RC} \quad \text{. . . . .} \quad [2]$$

relationships between surface cover and average sediment concentration for contour and with the slope tillage treatments were obtained (Fig. 5). The r values for relationships were 0.96 and 0.97 for the contour and with the slope tillage treatments, respectively. Similar to the erosion results, about 30% cover was necessary to achieve a 50% reduction in sediment concentration from plowing with the slope. A 44% cover was necessary to obtain a 50% reduction from contour plowing.

Length Simulation

As discussed by Hussein and Laflen (1982) and using theory presented by Foster et al. (1977), the erosion from the lowest portion of a slope was linearly related to the erosion from the total slope length. Using the erosion rates after reaching steady state conditions with rainfall simulation alone, and the steady state erosion rates at each increment of flow addition, linear relationships were developed between erosion rate and simulated slope length for each tillage treatment within the wheat-fallow rotation. Simulated slope length was the length which would generate the measured runoff rate at the runoff

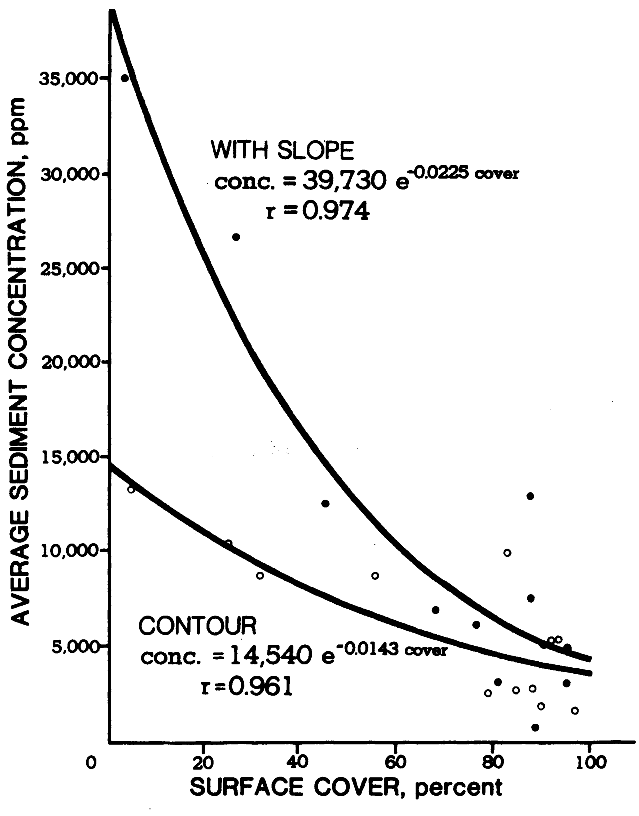

Fig. 5—Relationship between sediment concentration and surface cover for with the slope and contour tillage treatments.

TABLE 4. SLOPE LENGTH SIMULATIONS AND RESULTING CORRELATION COEFFICIENTS FOR THE LINEAR RELATIONSHIPS DEVELOPED BETWEEN EROSION AND SLOPE LENGTH.

	With slope		Contour	
	r value	Maximum length simulated, m	r value	Maximum length simulated, m
Fallow after harvest				
Plow	0.99	160	0.95	540
Stubble mulch	0.90	130	0.97	180
No till	0.96	180	0.99	290
Fallow after tillage				
Plow	0.98	120	0.97	130
Stubble mulch	0.98	920	0.95	210
No till	0.95	738	0.97	1,020
100 mm wheat				
Plow	0.99	70	0.97	90
Stubble mulch	0.99	100	0.99	100
No till	1.00	500	0.91	350
460 mm wheat				
Plow	1.00	120	0.94	160
Stubble mulch	0.99	220	0.98	170
No till	0.92	250	0.98	230

rate per unit length from rainfall alone. The equation has the form

$$\text{Erosion Rate} = A + B\ (\text{Simulated Length}) \quad [3]$$

where A and B are constants. Correlation coefficients for the assumed linear relationships are shown in Table 4. These coefficients show that soil loss from the lowest portion of the slope was linearly correlated with the simulated slope length. The length simulated by the different flow additions ranged from 73 m for plowing with the slope to more than 900 m for the no-till treatments (Table 4). The number of data points in each regression averaged about four in the 1979 runs and five in the 1981 runs. Some data points were deleted because sediment concentrations differed greatly from other nearly equal simulated lengths and tillage treatments. The high values of the correlation coefficients indicate little room for improvement in prediction using nonlinear models.

Hussein and Laflen (1982) indicate that the total erosion rate per unit width, G, from a slope length X can be written as

$$G = K_r X^2 + K_i X \quad [4]$$

where K_r is a coefficient for rill erosion and K_i is a coefficient for interrill erosion. These coefficients were related to the coefficients A and B (equation [3]) by the equations:

$$K_i = \frac{A}{L} + \frac{B}{2} \quad [5]$$

$$K_r = \frac{B}{2L} \quad [6]$$

where L is the lowest part of the slope length, 10.7 m for the wheat-fallow plots. The rill and interrill coefficients calculated with equations [5] and [6] respectively, were defined for the energy-times-intensity (EI) of the rainfall simulation (Wischmeier and Smith, 1978). The EI value per hour for the rainfall simulator was 50.4. When compared to a specific storm, the EI value was the same as the R value reported in the Universal Soil Loss Equation. For Sidney, Nebraska, the R value was about

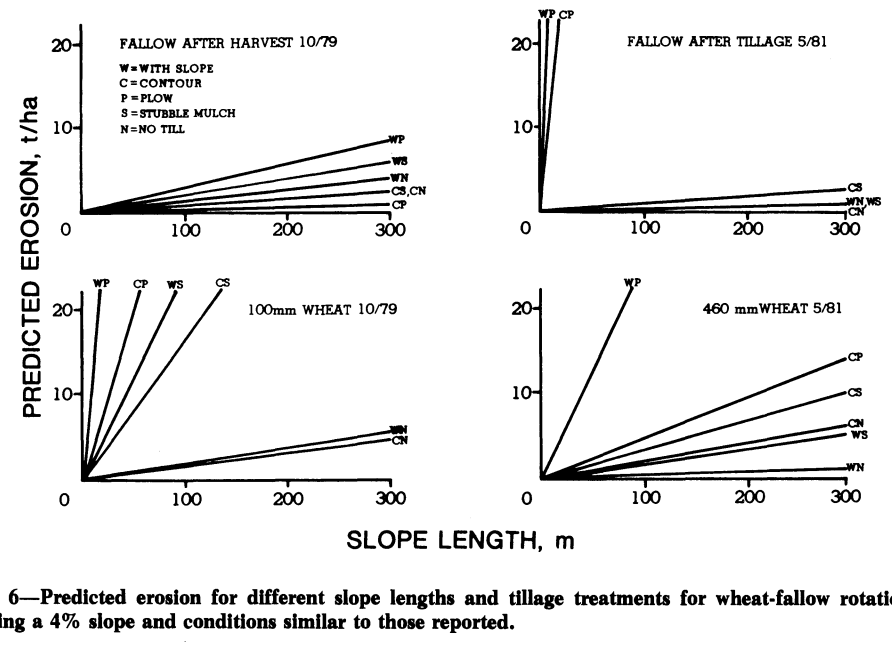

Fig. 6—Predicted erosion for different slope lengths and tillage treatments for wheat-fallow rotations having a 4% slope and conditions similar to those reported.

40 for the wheat-fallow periods measured in the study. Using equation [4] and the appropriate conversion factors, an R value of 40, and the assumed linearity of erosion and slope length, erosion predictions from different length slopes were calculated for the wheat-fallow periods measured (Fig. 6). The plow treatments had appreciable erosion as slope lengths increase in the fallow after tillage and 100 mm wheat period. However, in the fallow after harvest period, all tillage treatments, except plowing with the slope, had erosion rates below 12,000 kg/ha for slope lengths up to 610 m. While stubble-mulch and no-till treatments were effective on long slopes during the fallow after tillage period, only the no-till treatments were effective during the wheat production periods.

CONCLUSIONS

During the fallow after harvest period on the wheat-fallow rotation, soil erosion was not affected by the tillage system. However, during the period from first tillage after harvest to establishment of a crop canopy, erosion rates were high for tillage treatments that removed much of the crop residue cover. Although the plow system reduced soil losses when performed on the contour, the contouring treatment had little effect on the stubble-mulch and no-till systems.

The relationships of soil erosion to percent surface cover for the wheat-fallow rotation, were similar to those of soil erosion to percent residue cover for row cropped fields, except the effect of surface cover was less than the effect of residue cover. This may be because surface cover in this study included crop canopy, while the relationships reported for row cropped land generally included only residue on the ground.

Soil erosion during the fallow after tillage period could be controlled on long slopes with the use of stubble-mulch or no-till systems, either with the slope or on the contour. During the period after planting wheat but prior to canopy establishment, no-till was excellent on long slopes. However, stubble-mulch can adequately control soil erosion on moderate slope lengths. During other periods, such as full canopy wheat and after harvest before tillage, soil erosion on long slope lengths was not viewed as a problem.

References

1. Fenster, C. R. and G. A. Peterson. 1979. Effects of no-tillage fallow as compared to conventional tillage in a wheat-fallow system. Agricultural Experiment Station, University of Nebraska-Lincoln, Research Bulletin 289.
2. Foster, G. R., L. D. Meyer and C. A. Onstad. 1977. An erosion equation derived from basic erosion principles. TRANSACTIONS of the ASAE 20(4):678-682.
3. Helwig, J. T. and K. A. Council. 1979. SAS User's Guide. SAS Institute, Inc., Cary, NC. 495 p.
4. Hussein, M. H. and J. M. Laflen. 1982. Effects of crop canopy and residue on rill and interrill soil erosion. TRANSACTIONS of the ASAE 25(5):1310-1315.
5. 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.
6. 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.
7. Laflen, J. M., W. C. Moldenhauer and T. S. Colvin. 1980. Conservation tillage and soil erosion on continuous row cropped land. Proceedings of Crop Production with Conservation in the 80's. ASAE Publ. 7-81, St. Joseph, MI 49085.
8. Siemens, J. C. and W. R. Oschwald. 1978. Corn-soybean tillage systems: erosion control, effects on crop production, costs. TRANSACTIONS of the ASAE 21(2):293-302.
9. Swanson, N. P. 1965. Rotating-boom rainfall simulator. TRANSACTIONS of the ASAE 8(1):71-72.
10. Wischmeier, W. H. and D. D. Smith. 1978. Predicting rainfall erosion losses. USDA Agr. Handbook 537.