Long-term annual runoff and soil loss from conventional and conservation tillage of corn

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ABSTRACT: Effects of conventional and conservation tillage for corn on runoff and soil loss from a central Missouri claypan soil were studied for 24 consecutive years. Runoff and soil loss for conservation tillage was 85 and 42 percent, respectively, of that for conventional tillage. Observed average annual soil losses for both treatments were less than the soil loss tolerance [6.7 metric tons/hectare/year (3 tons/acre/year)] used for conservation planning on this soil type. Observed average annual soil loss was 54 and 63 percent of the average annual predicted soil loss for conventional and conservation tillage, respectively.

EFFICIENT water management and acceptable soil erosion control continue to be concerns for much of the intensely row-cropped land in the Corn Belt. In a recent Missouri resources appraisal, conducted in compliance with the Soil and Water Resources Conservation Act of 1977 (*12*), many farmers identified soil erosion by water as a major agricultural problem. Their concern is reflected by the fact that many have switched from conventional tillage to some form of conservation tillage. However, conservation management of soil and water resources must be more widely accepted if food production is to be maintained or increased.

Duley (*1*) and Miller and Krusekopf (*7*) compared runoff and soil loss resulting from natural precipitation under various cropping systems on plot studies initiated in 1917 at Columbia, Missouri, by the Missouri Agricultural Experiment Station. Similar studies were conducted at Bethany and McCredie, Missouri; Clarinda, Beaconsfield, Independence, and Castana, Iowa; Urbana, Dixon Springs, and Joliet, Illinois; La Crosse, Wisconsin; and Rosemont and Morris, Minnesota. Many of these studies, conducted during the 1940s, 1950s, and 1960s, resulted in comparisons of runoff and soil loss for various crop management systems under a wide range of soil, topographic, and climatic conditions. Short-term results (less than 10 years and in most cases less than 5 years of data) often were reported only when contrasts in data could be shown among treatments. Consequently, published data is sparse for years of low runoff and soil loss, and the cumulative, long-term effect of management on soil erosion is uncertain. Use of short-term data to predict long-term runoff and soil losses may well result in overestimation because of the omission of data for years of little or no runoff and soil loss.

Over 40 years ago, conservationists recognized that maximum average soil loss rates that would permit maintenance of crop production needed to be specified for conservation system design. Early attempts (*14*) to predict soil loss encouraged efforts to specify soil erosion rates that might be tolerable on specific soils (*3*, *9*). The concept of tolerance level or T-value was developed. Much difference of opinion exists over the criteria for selecting tolerable erosion levels for specific soils (*2*, *5*).

Frequency distributions developed from long-term soil loss data can be used for conservation system design. However, long-term soil loss data for specific land management, soil, and topographic conditions often do not exist. Consequently, soil loss data often must be estimated by such methods as the universal soil loss equation (USLE) (*13*) to develop design information. There is limited discussion on the frequency distributions of computed soil loss.

The objectives of our analyses reported here were threefold: First, to determine long-term relationships between cumulative annual precipitation and runoff and soil loss as well as to determine the exceedance probability levels for annual precipitation, runoff, and soil loss based on 24 years of data for corn using conventional and conservation tillage on a central Missouri claypan soil.

Second, to compare the 24-year, observed average annual soil losses to T-values.

Third, to compare observed annual soil losses with those predicted by the USLE for corn using conventional and conservation tillage on a central Missouri claypan soil for a 24-year period.

Experimental procedures

Precipitation, runoff, and soil loss data were collected for 24 consecutive years (1954-77) from standard runoff-erosion plots (*4*). The runoff-erosion plots, located at Kingdom City, Missouri, were on Mexico silt loam (fine Montmorillonitic Mesic Udollic Ochraqualfs). The dark silt loam topsoil was 0.2 to 0.3 meter (8-11 inches) deep. Beneath the topsoil was a claypan layer—a silty clay horizon 0.3 to 0.6 meter deep with a montmorillonitic clay content of 45 to 50 percent. The runoff-erosion plots were 3.2 meters x 27.4 meters on a 3 to 3.5 percent slope.

Annual runoff and soil loss data were collected from plots in corn following corn under conventional and conservation tillage. Each tillage treatment was replicated at least once each year (Table 1). During some years, there were an unequal number of replicates for the two tillage treatments. The maximum number of replicates were seven and five for conventional and conservation tillage, respectively. Total plot years of data for conventional and conservation tillage were 92 and 66, respectively.

Conventional tillage consisted of moldboard plowing (about mid-April) and disking, as needed, for seedbed preparation the day before planting (about mid-May). Conservation tillage plots were tilled with a field cultivator at the same times the conventional plots were plowed and disked. Weeds were controlled on both treatments with one or two cultivations each year and application of herbicides as preemergent and postemergent spray. Primary and secondary tillage as well as planting were performed in the upslope direction for both tillage treatments. Nitrogen and phosphorus were applied annually on both treatments at rates considered adequate for near optimum corn production. Corn residue remained on the plots for both treatments.

Precipitation data were collected at an agricultural weather station adjacent to the plots. Data were tabulated on a tillage-year basis. The tillage year was defined as the period beginning on the date of primary tillage and ending the day before primary tillage the following year. Annual precipitation, runoff, and soil loss data were accumulated for each tillage treat-

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ment by tillage year for the 24-year period. Analysis involved the accumulation of annual increments to establish time trends.

Cumulative frequency distributions for precipitation, runoff, and soil losses were constructed to illustrate long-term data variability. Precipitation data were plotted on a normal probability scale, and a normal distribution curve was fitted to the data. Runoff and soil loss data were transformed to logarithmic values because of nonnormal distribution characteristics. The transformed runoff and soil loss data were plotted on a normal probability scale, and the data were fitted to a Log-Pearson Type III distribution. The exceedance probabilities of annual observations for each data set were computed using the Wiebull plotting position formula:

$$p = \frac{m}{n+1} \times 100$$

where p is the probability (in percent) of exceedance in any one year, m is the order number in descending rank of data set, and n is the 24 observations in the data set.

Frequency distributions of data observed over a period may be biased if the data from the period are not representative of the true or parent population. The true population is best described by the longest homogeneous record near the data site. Precipitation observations are the only long-term observations that can readily be used to test the representativeness of the 24-year study period. The representativeness of runoff and erosion data can be implied by correlation with the precipitation data. A 41-year precipitation record at the Kingdom City, Missouri, plot site and a 95-year precipitation record at Columbia, Missouri, 40 kilometers (25 miles) west of the study site, were used to test representativeness of the 24-year data set using the U-test *(6)*.

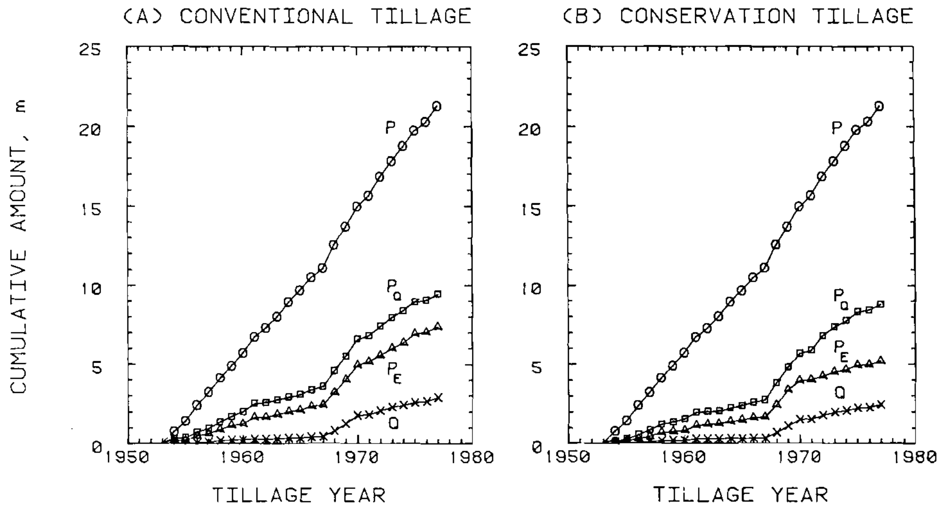

Figure 1. Cumulative annual precipitation (P), precipitation associated with runoff (P_Q), precipitation associated with soil loss (P_E), and runoff (Q) from corn plots under conventional tillage (A) and conservation tillage (B) over a 24-year period, 1954-1977.

Results and discussion

Representatives of the study period. For our study we applied a U-test of annual precipitation for the 24-year record in two ways. Results indicated annual precipitation at Columbia, Missouri, for the 24-year period was representative of the 95-year record (1887-1981) at Columbia. We also found that annual precipitation during the same 24-year period at Kingdom City, Missouri, was representative of the 41-year record (1941-1981) there. In each case, our hypothesis that the frequency distributions of 24-year record and the longer period records were identical was significant in a t test at the 5-percent significance level. Also, annual precipitation for the 24-year period at Kingdom City correlated closely with that for the same 24-year period at Columbia ($r = 0.91$). By a t test of means with pooled variances, the hypothesis that the 24-year Columbia and Kingdom City precipitation data were equal was accepted at a 5-percent significance level. Based on these tests, we considered the 24-year annual precipitation record at Kingdom City to be representative of the 95-year period.

Observed runoff and erosion data over extended time periods were not available

Table 1. Plot-year data source for corn after corn under conventional (C) and conservation (R) tillage on a central Missouri claypan soil.

Plot	Tillage Year*																								
Number	1954	'55	'56	'57	'58	'59	'60	'61	'62	'63	'64	'65	'66	'67	'68	'69	'70	'71	'72	'73	'74	'75	'76	'77	Total
3	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R									
4																				C	C	C	C	C	
6	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C									
8																		C	C	C	C	C	C	C	
13																					C	C	C	C	
15																				C	C	C	C	C	
17																				C	C	C	C	C	
19	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R									
22	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	
27															C										
28															C		C	C	C	C	C	C	C	C	
29															C										
30												C					R	R	R	R	R	R	R	R	
32							R	R	R	R		R													
33						C	C	C	C	C	C														
34						C	C	C	C	C	C														
35							R	R	R	R	R	R													
37						R	R	R	R	R	R	R					R	R	R	R	R	R	R	R	
38															C										
39															C										
Totals																									
C	2	2	2	2	2	4	4	4	4	4	4	3	2	2	7	2	2	3	3	6	7	7	7	7	92
R	2	2	2	2	2	3	5	5	5	5	4	5	2	2	2	2	2	2	2	2	2	2	2	2	66

*Beginning on primary tillage date and ending on primary tillage date the following year.

to test the representativeness of the runoff and erosion data reported herein. Because the correlation of annual precipitation with runoff for conventional tillage was significant at the 5 percent level (r = 0.84), we also assumed the 24-year data period for runoff was representative of a longer time period. Likewise, we assumed annual erosion for the 24-year period for conventional tillage was representative of a longer time period because the correlation with annual rainfall was also significant at the 5-percent level (r = 0.54).

Precipitation. We assumed the precipitation received at all study plots equaled that observed in the recording raingage adjacent to the plots. Figure 1 shows the annual accumulated precipitation, the portion of precipitation associated with runoff, the portion of precipitation associated with soil loss, and runoff for 24 years of continuous, conventionally tilled corn and 24 years of continuous, conservation-tilled corn. The data show that 44 percent of the accumulated precipitation over 24 years caused runoff, and 14 percent of the precipitation actually ran off from conventionally tilled corn plots. Thirty-five percent of the accumulated precipitation over the study period occurred during runoff events that caused soil loss. Annual accumulated precipitation causing runoff and soil loss on conservation tillage plots was 93 and 80 percent, respectively, of that on conventional tillage plots (Figure 1B).

Annual precipitation varied greatly during the study period—0.52 meter (21 inches) in 1976 to 1.45 meters (57 inches) in 1968. However, the distribution of annual precipitation was about normal (Figure 2). The arithmetic average was 0.89 meter (35 inches), and the standard deviation was 0.22 meter (8.8 inches). The extreme annual precipitation in 1968 had an exceedance probability of 1 percent or less on the fitted normal frequency curve. In other words, the likelihood of having 1.45 meters of rain or more for a given year would be 1 year in 100 years. Precipitation for a high, 3-year period, 1968 through 1970, was 45 percent above the 24-year annual average.

Runoff. The 24-year accumulated runoff for conservation tillage was about 13 percent less than for conventional tillage, based on the difference between 92-plot years for conventional tillage and 66-plot years for conservation tillage (Figure 3A). Average annual runoff was 0.12 meter (4.7 inches) for conventional tillage and 0.10 meter (4.0 inches) for conservation tillage. For most years, runoff was lower for conservation tillage than for conventional tillage. From a t test of paired differences, the hypothesis that the tillage treatment means were equal was rejected at the 10-percent significance level, but accepted at the 5-percent significance level.

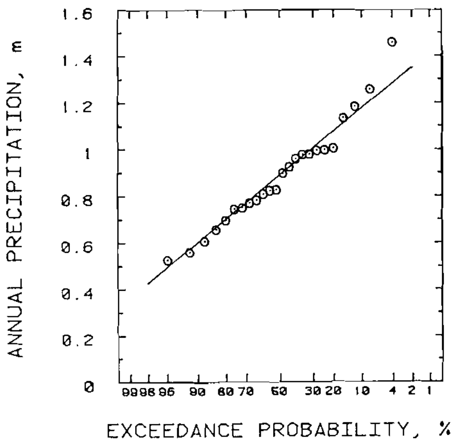

Figure 2. Exceedance probability for 24 years (1954-77), observed annual precipitation at University of Missouri Claypan Research Farm near Kingdom City. The curve is a normal distribution fit to the data.

At a given exceedance probability level, annual runoff for conventional tillage was about 20 percent greater than for conservation tillage (Figure 3B). At the 50-percent exceedance probability, the most probable level, annual runoff was 0.053 meter (2.1 inches) for conventional tillage and 0.043 meter (1.7 inches) for conservation tillage. At the 10-percent exceedance probability level, annual runoff was 0.33 meter (13 inches) for conventional tillage, compared to 0.29 meter (11.3 inches) for conservation tillage.

There were three distinct annual runoff regimes plotted (Figure 3A). Low annual runoff occurred from 1954 to 1967, followed by a three-year period (1968-1970) of high annual runoff. Average annual runoff over the three-year period of greatest runoff was more than 2.5 times greater than long-term (24 years) average annual runoff for each tillage treatment. Cumulative runoff for 1968 through 1970 was 1.30 meters (51 inches) or 45 percent of the 24-year accumulated runoff from conventionally tilled corn. Cumulative runoff from conservation tillage for the same 3 years was 1.14 meters (45.0 inches) or 46 percent of the 24-year accumulated runoff. Runoff from conservation tillage plots for the 3 successive wet years was 88 percent of that for conventional tillage. The third runoff regime, from 1971 through 1977, more nearly represented the 24-year average runoff for both treatments.

Soil loss. The 24-year cumulative soil loss for the conventional tillage treatment was 141.1 metric tons per hectare (63.4 tons/acre), compared to 60.3 metric tons per hectare (26.9 tons/acre) for the conservation tillage treatment (Figure 4A); average annual soil losses were 5.9 and 2.5 metric tons per hectare (2.6 and 1.1 tons/acre), respectively. From a t test of the paired differences, the hypothesis that the treatment means were equal was rejected at the 5-percent significance level.

Soil losses for the 24-year study were about log-normally distributed (Figure 4B). Almost 60 percent of the 24-year soil loss for conventional tillage occurred during only two years. This is typical of soil loss data; a large portion of total soil loss is often associated with an extremely limited number of observations. The annual soil loss for conventional tillage was about two times greater than that for conservation tillage at all exceedance probability levels. At the 50-percent exceedance probability level, the most probable level, annual soil losses were 1.84 and 0.98 metric tons per hectare (.82 and .44 ton/acre) for conven-

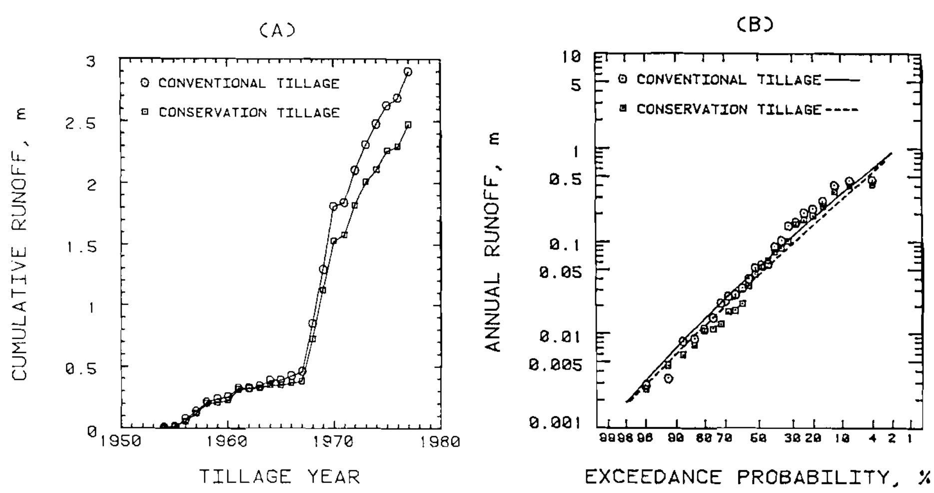

Figure 3. Cumulative runoff (A) and annual runoff exceedance probability (B) for corn plots under conventional and conservation tillage over a 24-year period, 1954-1977. The curved lines in part (B) are Log-Pearson distribution fits to the data.

tional and conservation tillage, respectively. At the 10-percent exceedance probability level, average annual soil losses were 14.53 and 6.74 metric tons per hectare (6.5 and 3.0 tons/acre) for conventional and conservation tillage, respectively.

Observed soil losses versus T-values. Observed average annual soil losses (Figure 4A) appear low relative to the 6.7-metric ton per hectare per year (3-ton/acre/year) T-value (*10*) currently used for conservation planning on the Mexico soil. This indicates that long-term erosion is not a major problem for some areas represented by the study plots and that erosion control practices are not needed for the soil, crop, tillage, and precipitation conditions studied. This may not be a realistic conclusion, however, because Scrivner and Gantzer (*8*), in modeling effects of erosion on productivity, have suggested a T-value of 2.0 metric tons per hectare per year (.89 ton/acre/year) for the claypan soil. The 24-year average annual soil loss for corn under conventional tillage was three times greater than the tolerance level proposed by Scrivner and Gantzer. Average annual soil loss measured for conservation tillage was close to the lower T-value. Based on more recent evaluations of tolerable soil loss levels, our data indicate that erosion control provided by conservation tillage for corn is needed to maintain productivity on the claypan soil.

We recognize that the 24-year soil loss data reported here were obtained on plots with a 27.4-meter slope length. To extrapolate the data to longer slope lengths, we used the observed average annual soil loss in conjunction with the slope length factor provided by the USLE to estimate the average annual soil loss for a hypothetical 150-meter (492-foot) slope length. The longer slope is more representative of the natural topography on the eroded phase of Mexico silt loam. Those calculations yielded soil loss values of 8.74 and 3.59 metric tons per hectare per year (3.9 and 1.6 tons/acre/year) for the conventional and conservation tillage treatments, respectively. Even for the assumed maximum slope length, the estimated annual soil loss did not appear to greatly exceed the T-value.

The T-value had an exceedance probability level of 20 percent for conventional tillage and 10 percent for conservation tillage. The likelihood of having a soil loss of 6.7 metric tons per hectare or more was 2 years in 10 for corn under conventional tillage and 1 year in 10 for conservation tillage. In contrast, the exceedance probability level for a soil loss of 2.0 metric tons per hectare per year was within the range of 40 to 50 percent for conventional tillage

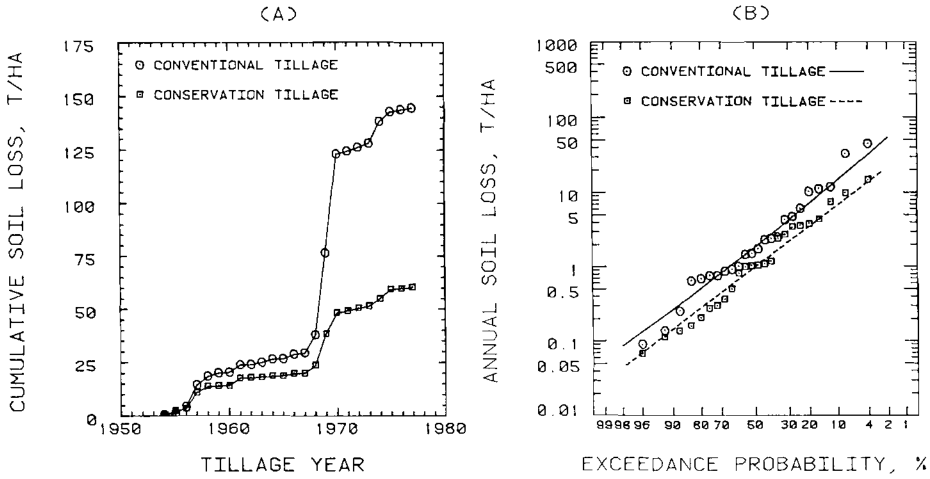

Figure 4. Cumulative soil loss (A) and annual soil loss exceedance probability (B) for corn plots under conventional and conservation tillage over a 24-year period, 1954-1977. The curved lines in part (B) are Log-Pearson distribution fits to the data.

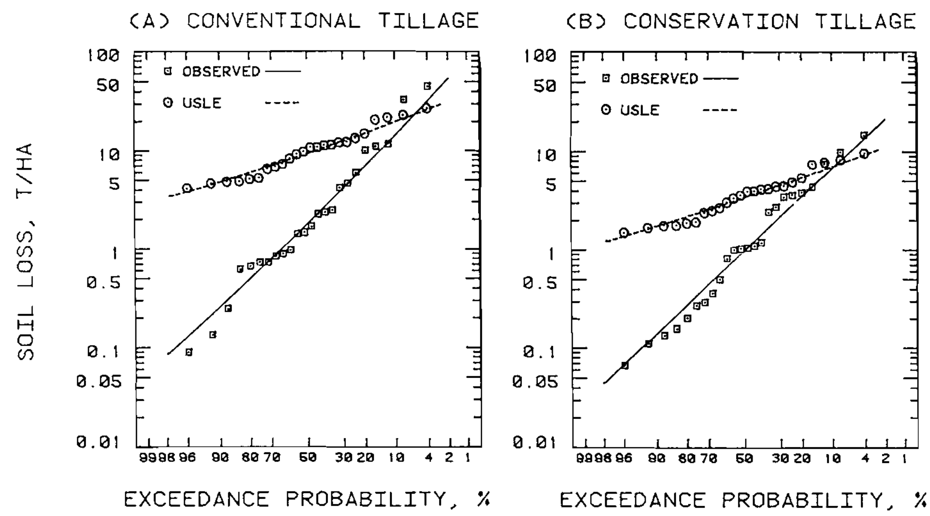

Figure 5. Comparison of observed and USLE-predicted annual soil loss exceedance probability for corn plots under conventional and conservation tillage. The curved lines are Log-Pearson distribution fits to the data.

and 30 to 40 percent for conservation tillage. Our study showed an annual soil loss of less than 2 metric tons per hectare from conventionally tilled corn is more likely to be exceeded than an annual soil loss of 6.7 metric tons per hectare or more.

Observed versus predicted soil loss. Detailed measurements of rain intensity on the plots allowed us to assess the annual rainfall factor (R) in the USLE. We determined other factors in the USLE from Agriculture Handbook 537 (*13*) to estimate soil loss for the conventional and conservation tillage treatments. We determined the soil erodibility factor (K) (*13*) from the soil characteristics of the study plots to be 0.0428 (SI units). We found the slope length-steepness factor (LS) to be 0.31, and defined the practice factor (P) as 1.

We computed the annual crop cover management factor (C) for each tillage treatment from the sum of seasonal crop stage factors derived from soil loss ratios in tables 5 and 5C in the handbook (*13*) and from average tillage (April 17) planting (May 15), and harvest dates (October 12) for the 24-year period. For conventionally tilled corn, we tabulated soil loss ratios for each crop stage period using three assumptions: (1) primary tillage was performed in spring with a moldboard plow; (2) residue was left but shredded most years, resulting in a groundcover of about 90 percent after harvest; and (3) corn yields were in the range of 6,300 to 7,800 kilograms per hectare (100-125 bushels/acre). We computed an annual crop cover management factor of .243 for this tillage treatment.

For conservation-tilled corn we determined soil loss ratios using these assumptions: (1) primary tillage was performed in spring with a field cultivator; (2) residue was about 5,000 kilograms per hectare (4,460 pounds/acre) at the time of primary tillage; (3) groundcover after primary tillage was at least 60 percent; and (4) groundcover after the second tillage with the field cultivator prior to planting was about 50 percent. Under those assumptions, the annual crop cover management factor was 0.087 for conservation-tilled corn.

Predicted annual soil loss for conventionally tilled corn ranged from 4.17 to 26.66 metric tons per hectare (1.9-11.9 tons/acre); average annual soil loss was 11.1 metric tons per hectare (5 tons/acre). The average annual predicted soil loss was 1.9 times the observed average annual soil loss for conventionally tilled corn over the 24-year period on the plots. Predicted annual soil loss for conservation-tilled corn ranged from 1.49 to 9.55 metric tons per hectare (0.7-4.3 tons/acre). Average annual soil loss was 3.96 metric tons per hectare (1.8 tons/acre), nearly 1.6 times the observed average annual soil loss for conservation-tilled corn on the plots.

Figure 5 shows the exceedance probabilities for observed and predicted soil losses for each tillage treatment. The Log-Pearson III distribution shown by the curves was fitted to the data of each population. The 10-percent exceedance probability of predicted soil loss for conventional tillage was about 19.4 metric tons per hectare (8.7 tons/acre) per year. For the conservation tillage treatment, the 10-percent exceedance probability soil loss was about 7.0 metric tons per hectare (3.1 tons/acre) per year. For both treatments predicted soil loss was less than observed soil loss at exceedance probabilities less than 10 percent, and predicted soil loss was greater than observed soil loss at exceedance probabilities greater than 10 percent. For the conventional tillage treatment, the 90-percent exceedance probability soil loss was 0.26 metric ton per hectare (.12 ton/acre) per year, while 90-percent exceedance probability for predicted soil loss was over 4.84 metric tons per hectare (2.2 tons/acre) per year (Figure 5A). Similarly, for the conservation tillage treatment, observed soil loss at 90-percent exceedance was 0.14 metric tons per hectare (0.06 ton/acre) per year; predicted soil loss at 90-percent exceedance was 1.73 metric tons per hectare (0.77 ton/acre) per year (Figure 5B).

The slope of the curve depicting frequency of observed soil loss was much greater than the predicted soil loss frequency curve for each tillage treatment. This indicates that the variance of observed annual soil loss was much greater than the variance of the observed annual rainfall factor (R), which is expressed by the slope of the curve for USLE-predicted soil loss frequency. These results indicate that for extreme conditions, with less than 10-percent exceedance probability, conservation systems designed for USLE-predicted soil loss values may not be adequate to control extreme soil loss. However, for more common soil loss occurrences of more than 10-percent exceedance probability, the conservation systems designed for USLE-predicted soil loss may provide more soil loss control than is needed.

For the conventional tillage treatment, the 50-percent exceedance soil loss was 1.84 metric tons per hectare (0.82 ton/acre) from the observed data and 9.41 metric tons per hectare (4.2 tons/acre) from the predicted data. For the conservation tillage treatment, soil losses for the 50-percent exceedance were 0.98 metric ton per hectare (0.44 ton/acre) and 3.37 metric tons per hectare (1.5 tons/acre) from the observed and predicted data, respectively.

Because the USLE-predicted soil loss was greater than the observed soil loss on either a mean annual or a 50-percent exceedance basis, one or more of the USLE factor values used for prediction must be too high. By definition, the practice factor (P) cannot be modified. The plot dimensions are closely specified so that the slope length-steepness (LS) factor was well defined. The soil erodibility factor (K) was determined from triplicate-plot soil texture samples from all the plots included in our analysis. Thus, the nomograph value also was well defined. Furthermore, the nomograph value was near the average observed erodibility factor of 0.0454 derived from observed soil loss data from two fallow plots during a 10-year period concurrent with the 24-year period reported here.

The University of Missouri Science and Technology Guide 1560 (*11*) sets the erodibility factor for claypan soils at 0.0527. If the erodibility factor were increased to 0.0527 from the value we used, then predicted soil loss would be higher than reported herein. Thus, even greater differences between observed and predicted values would result. Therefore, the crop cover and management factor (C) would seem to be the USLE factor most likely needing modification for application of the soil loss model to this study area. A reduction of this factor by about 40 percent would be needed to reduce predicted soil loss to levels comparable to the observed soil loss for this 24-year study.

These results illustrate the difficulty in precisely defining USLE factors, particularly the soil erodibility factor and crop cover and management factor for specific field areas, and requiring that the factors be general enough to be applicable to field areas throughout the United States with similar soils, topography, cover, management, and support practices.

Conclusions

Our analysis of annual precipitation, runoff, and soil loss data for the central claypan soil land resource area over 24 years resulted in these conclusions:

- Runoff for corn after corn using conservation tillage was 13 percent less than that for conventional tillage.
- Soil loss for corn after corn using conservation tillage was 58 percent less than that for conventional tillage.
- Average annual soil losses for both tillage treatments on a 27.4-meter-long slope were less than the T-value of 6.7 metric tons per hectare per year currently used in conservation planning.
- Average annual soil losses over 24 years for conventional and conservation tillage were 54 and 63 percent, respectively, of those predicted by the USLE.

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