Runoff and soil losses as affected by corn and soybean tillage systems

F. Ghidey and E. E. Alberts

Interpretive summary

Cropping and tillage are two important factors that influence runoff and soil losses. In this study, conservation tillage (chisel and no-till) significantly reduced soil loss relative to conventional tillage. However, despite leaving most residue at surface, no-till did not reduce surface runoff compared to tillage systems that caused soil disturbance and buried residue. For both corn and soybean cropping systems, surface runoff from no-till was significantly higher than those from conventional and chisel, particularly during the critical chemical loss periods (1-4 weeks after herbicide application). Thus, if herbicide loss by surface runoff is a serious problem in row-cropped land, as it is in the Midwest claypan regions, no-till may not be the most effective management system to use.

Key words: cropping system, runoff, soil loss, tillage.

*ABSTRACT: Runoff and soil loss data were collected from seven cropping and tillage treatments over a 12-year period (1983-1994) from 28 (3.2 m wide by 27.4 m long) natural rainfall erosion plots located on a silt loam soil (*Udollic Ochraqualf*) near Kingdom City, MO. The treatments were continuous corn and soybean cropping under conventional, chisel, and no-till tillage methods, and continuous cultivated fallow. Although cropping slightly influenced runoff and soil loss, the differences were not statistically significant ($p \le 0.05$). When averaged over tillage, mean annual runoff and soil loss from soybean were 3 and 12 % higher than those from corn, respectively. Cropping effect on runoff was only significant ($p \le 0.05$) during the residue (P4) cropstage period. Most of the soil loss (approx. 80% of the annual loss) occurred during the rough fallow (F) and seedbed (SB) periods. For these periods, cropping had no significant effect ($p \le 0.05$) on soil loss. Mean annual runoff and soil loss from continuous fallow were substantially greater compared to those from corn or soybean. Tillage, particularly no-till, had significant effects ($p \le 0.05$) on runoff and soil loss. When averaged over crop, no-till increased mean annual runoff by 14 and 20 % compared to conventional and chisel, respectively. On the other hand, chisel decreased runoff by 5% compared to conventional. Soil loss from no-till method was 7 times lower than conventional and 5 times lower than chisel. Chisel lowered soil loss by 31% compared to conventional. The effects of tillage on runoff and soil loss were substantially greater during the F and SB cropstage periods. Overall, the study showed that (1) cropping had little effect on runoff and soil loss, and (2) no-till significantly increased runoff and substantially reduced soil loss when compared to the conventional method.*

F. Ghidey, Dept. of Biological and Agric. Engineering, Univ. of Missouri, Columbia, MO 65211. Tel: 573-882-1145, Fax: 573-882-1115, E-mail: Fessehaie_ghidey@muccmail.missouri.edu. E. E. Alberts, USDA-Agric. Research Service, Cropping Systems and Water Quality Research Unit, Columbia, MO 65211.

Acknowledgements: The authors acknowledge the technical help provided by Kathleen M. Burgan, Agricultural Research Technician, and Joel D. Haden and W. Dale Clark, Hydrology Technicians. This manuscript was submitted in January of 1997 and accepted in June of 1997.

J. Soil and Water Cons. 53(1) 64-70

Claypan soils occupy about 4 M ha in Missouri and Illinois and are primarily found within Major Land Resource Area (MLRA) 113. Claypan soils are considered poorly drained partially because of an argillic claypan horizon located 15 to 30 cm below the surface. Runoff and soil losses from the Midwest claypan region are relatively high during the seedbed preparation period when agrichemicals are applied; as a result, this region has been identified as a vulnerable area for pesticide and nutrient contamination of surface water. Previous studies indicated that herbicide application to claypan soils contaminate surface water much more than ground water (Burkhart and Koplin 1993; Blanchard et al. 1995). The critical period for contamination of surface water by herbicides and nutrients was 1-4 weeks following application (Ghidey et al. 1994; Ghidey et al. 1996). Previous research indicated that conservation tillage decreased herbicide losses because of the reduction in runoff and soil losses compared to conventional tillage (Baker and Johnson 1979; Sauer and Daniels 1986). However, they also reported that herbicide concentrations from conservation tillage were sometimes higher compared to conventional tillage. Although further study is needed to evaluate whether reducing runoff decreases herbicide losses, management systems that reduce runoff and soil loss are believed to generally improve surface water quality.

Cropping and tillage systems are two important factors that influence runoff and soil losses. Several research studies have been conducted to evaluate the effects of prior cropping on soil loss using field-scale rainfall simulation. Results have ranged from those that have found a prior cropping effect (Oschwald and Siemens 1976) to those that have not found an effect (Laflen and Colvin 1981; Colvin and Laflen 1981). Studies conducted on claypan soils found that soil losses from soybean were greater than corn (Alberts et al. 1985; Buyonovsky and Wagner 1986; Zhu et al. 1989). Several studies have shown that no-till and chisel tillage methods can substantially reduce soil losses compared to conventional systems (Siemen and Oschwald 1976; Laflen et al. 1978; Johnson and Moldenhauer 1979; McGregor and Greer 1982). Results for the effects of tillage systems on runoff, however, were inconsistent. Some studies reported that tillage systems that leave residue on the soil surface reduce runoff and soil loss (Laflen et al. 1978; Larson et al. 1978; Johnson and Moldenhauer 1979; Langdale et al. 1979; McGregor and Greer 1982). Other studies indicated that surface residue does not always reduce runoff, particularly in no-till systems (Mannering et al. 1975; Siemen and Oschwald 1976; Lindstrom et al. 1981; Lindstrom and Onstad 1982).

The main objective of this study was to evaluate the long-term effects of continuous corn and continuous soybean cropping systems under conventional, chisel, and no-till tillage methods on runoff and soil losses.

Materials and methods

Runoff and soil losses were measured at the Claypan Experimental Farm (previously called the McCredie Erosion Station) located near Kingdom City, MO. Forty natural rainfall erosion plots have been operated continuously since their establishment in 1941. Each plot is 3.2-m wide by 27.4-m long. The soil is a Mexico silt loam (fine, montmorillonitic, mesic Udollic Ochraqualf) on a slope of 3.0 to 3.5%.

Each erosion plot is instrumented with two runoff collection tanks in series. Runoff leaving a plot moves into a 3.2-m wide collector which is connected to the first tank with a 125-mm diameter pipe. When the volume of the first tank is exceeded (6.4 mm of plot runoff), additional runoff and sediment move through a 9-slot vertical divisor in a trough which connects the two tanks. One-ninth of the runoff enters the second tank. Total collection capacity of both tanks is about 150 mm of plot runoff.

After each runoff event, the depth of water in each tank was measured. The sediment was resuspended by vigorously stirring the contents of each tank using specially designed paddles. Two samples were then collected from each tank to determine the sediment concentration using gravimetric procedures. The water depth and sediment concentration data were used with the tank calibrations to calculate runoff and soil losses. Where multiple rainfall events occurred that prohibited tank sampling and cleaning, measured losses represent multiple rainfall and runoff events.

From 1941 through 1977, several studies of management effects on runoff and soil loss were conducted and management of individual plots varied. In 1978, each plot was reshaped to reestablish uniformity. All plots were cropped to soybean in 1979 and 1980 and were maintained in cultivated fallow in 1981. In 1982, a study evaluating the effects of seven cropping and management treatments on runoff and soil loss was initiated on 28 erosion plots. The experimental design for the treatments was a completely randomized block design with four blocks. The treatments were continuous cultivated fallow, continuous corn conventionally tilled, continuous corn chisel-plowed, continuous corn in no-till, continuous soybeans conventionally tilled, continuous soybeans chisel-plowed, and continuous soybeans in no-till. Conventional tillage consisted of spring moldboard plowing, primary and secondary disking, planting, and cultivation for weed control. Chisel tillage had similar cultural operation dates and types to conventional tillage except that a chisel plow was used instead of a moldboard plow. Minor soil disturbance occurred at planting in no-till from a fluted coulter which prepared a narrow seedbed. Continuous fallow consisted of spring moldboard plowing, disking, and cultivations after each major rainfall event that caused soil crusting. Data collected in 1982 were not used in the analysis.

Surface runoff and soil loss data were summarized by cropstage periods through

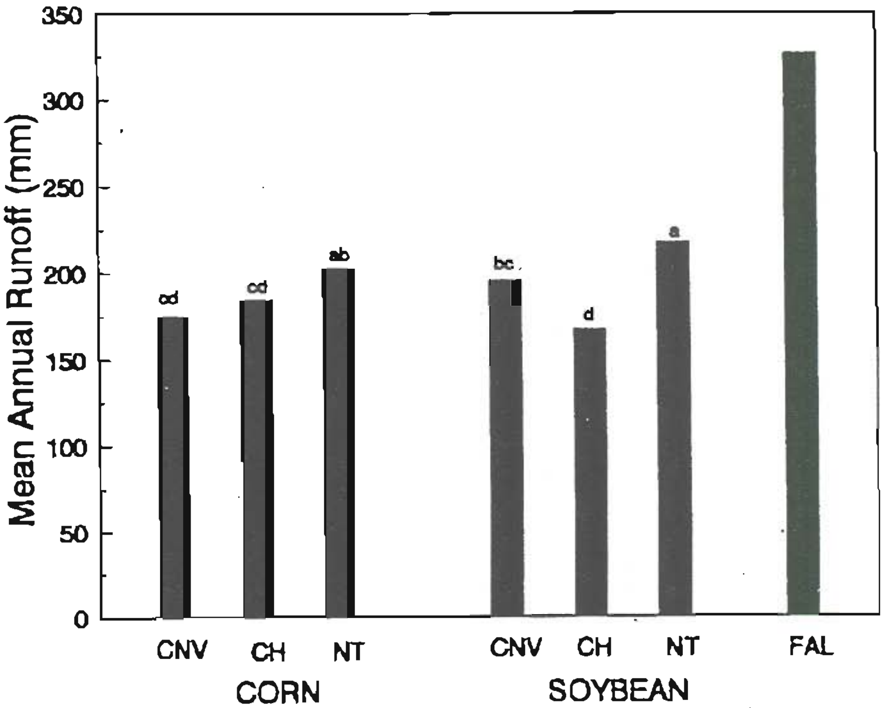

Figure 1. Mean annual runoff for calendar years 1983 through 1994 from continuous corn and soybean cropping systems under conventional (CNV), chisel (CH), and no-till (NT) methods

Treatment means with the same letter are not significantly different at the 5% level.

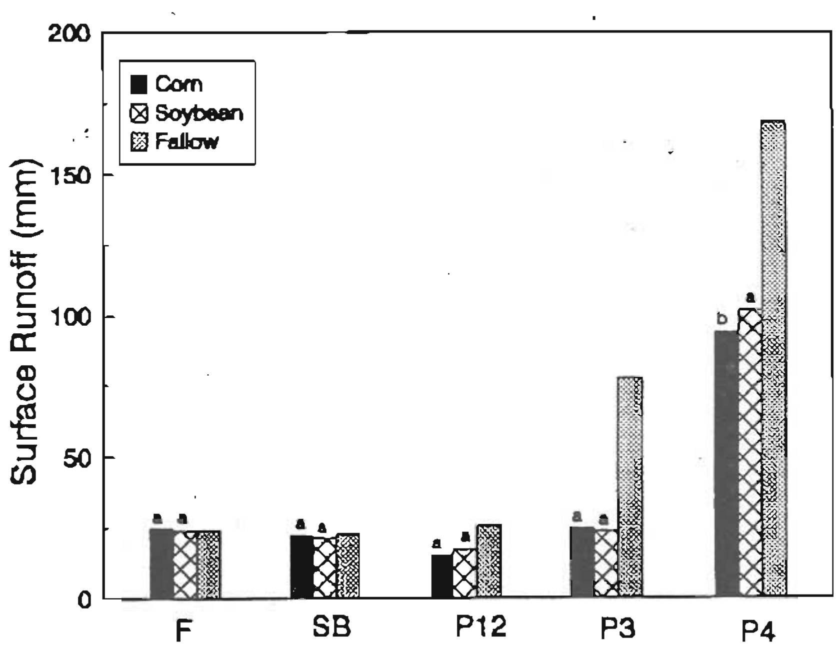

Figure 2. Mean annual tillage year runoff for the cropstage periods summarized by crop type

Within each period values followed by the same letter are not significantly different at the 5% level.

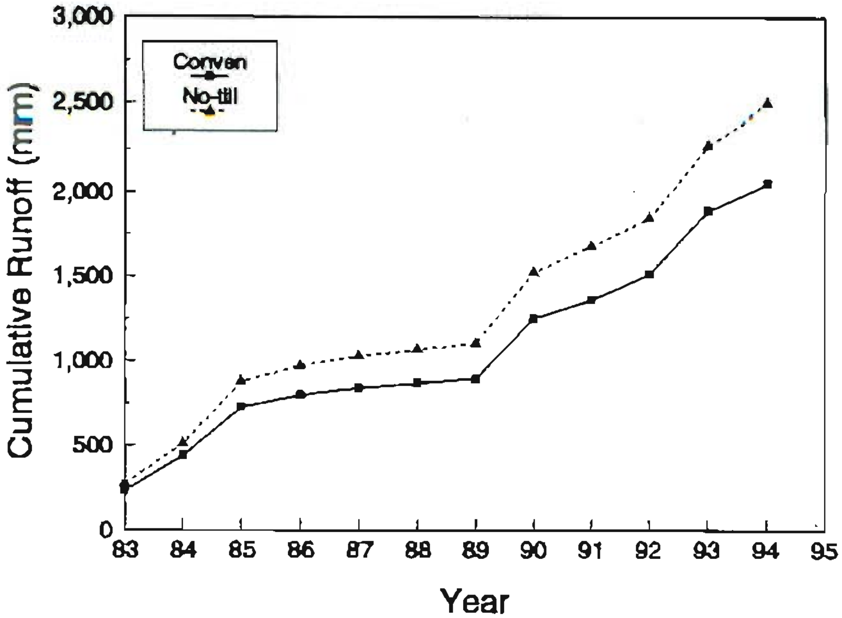

Figure 3. Cumulative surface runoff for conventional and no-till tillage methods averaged over crop

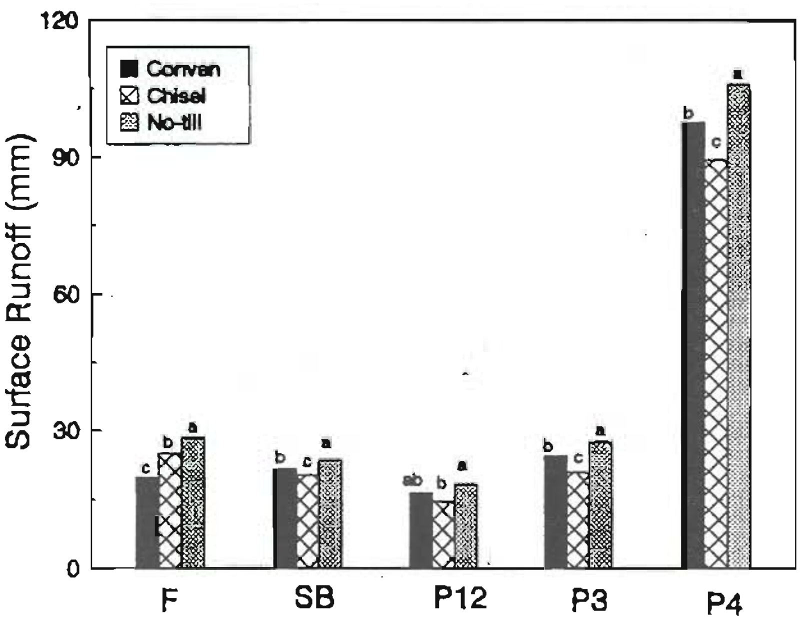

Figure 4. Mean annual tillage year runoff for the cropstage periods summarized by tillage type

Note: Within each period values followed by the same letter are not significantly different at the 5% level.

Table 1. Mean annual runoff by cropstage preriods for corn and soybean cropping systems under conventional, chisel, and no-till methods

		Runoff (mm)				
Crop	Tillage	F	SB	P12	P3	P4
	Conv	20.2[c*]	22.1[ab]	15.5[b]	26.2[ab]	85.5[c]
Corn	Chisel	26.8[ab]	20.5[bc]	14.2[b]	22.8[bc]	92.8[bc]
	No-till	27.2[ab]	23.9[a]	16.5[ab]	25.0[bc]	102.6[b]
	Conv	19.1[c]	21.0[bc]	17.0[ab]	22.5[c]	109.0[a]
Soybean	Chisel	23.0[bc]	19.6[c]	14.9[c]	18.5[c]	85.8[c]
	No-till	29.6[a]	23.2[a]	20.1[a]	29.8[a]	110.0[a]

* Within each period, values containing the same letter are not significantly different at the 5% level.

a tillage year. For each tillage year, five periods were identified based on uniform ground cover and management effects (Wischmeier and Smith 1965; Laflen and Moldenhauer 1979). These periods are: rough fallow period (F) from primary tillage to secondary tillage and planting; seedbed period (SB) from planting to 30 d after planting; rapid growth period (P12) from 30 d after planting to 60 d after planting; reproduction and maturation period (P3) from 60 d after planting to harvest; and residue period (P4) from harvest to primary tillage the next spring. As an example, the tillage year for 1983 started on 26 Apr 1983 and ended on 10 May 1984. The average durations for cropstages F, SB, P12, P3, and P4 were 30, 30, 30, 98, and 177 days. The tillage year seasonal period dates and time periods for chisel plow and no-till were the same period as for conventional tillage.

Results and discussion

Precipitation. Annual precipitation from the runoff/erosion plots in 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993 and 1994 were 881, 755, 958, 504, 398, 436, 406, 1210, 684, 549, 1102, and 712 mm, respectively. The mean annual precipitation during the 12-yr period was 716 mm. The average distributions of the precipitation for the F, SB, P12, P3, and P4 periods were 66, 80, 80, 178, and 312 mm, representing 9.2, 11.0, 11.0, 24.8, and 44.0% of the total tillage year precipitation, respectively.

Cropping effects on surface runoff. Mean annual runoff measured from the seven treatments during the 12-yr study period is given in Figure 1. For conventional and no-till, mean annual runoff from soybean were slightly higher than corn; however, the differences were not statistically significant ($p \leq 0.05$). Mean annual runoff from soybean was 11 and 7% higher than corn for conventional and no-till methods, respectively. For chisel, runoff from soybean was 9% lower than that from corn. When averaged over tillage, the mean annual runoff for soybean was only 3% higher than corn. Runoff from continuous cultivated fallow was more than 70% higher than that from corn or soybean.

Mean annual runoff for the cropstage periods summarized by crop type is given in Figure 2. The mean percent distribution of measured runoff for the F, SB, P12, P3, and P4 periods was 13.7, 12.3, 8.5, 13.7, and 51.8% for corn; 12.7, 11.4, 9.2, 12.6, and 54.1% for soybean;

and 7.5, 7.2, 8.0, 24.3, and 53.0% for fallow, respectively. Except P4, there were no significant differences ($p \leq 0.05$) in runoff between corn and soybean. During P4, runoff from corn was significantly lower than soybean, particularly for the conventional and no-till methods (Table 1). The difference in runoff between corn and soybean cropping systems during P4 was mainly due to difference in residue amount and cover. P4 was the period from harvest until primary tillage the following year during which the soil was covered with residue. Residue data collected from the plots from 1983-87 showed that corn produced more residue after harvest than soybean. The average residue cover at harvest was 94% for corn and 82% for soybean. Average residue cover measured before primary tillage operation (i.e. at the end of P4) was 89% for corn and 69% for soybean which indicated that corn had slower decomposition rate than soybean, particularly during P4. Thus, corn plots had more surface residue cover than soybean plots, which probably allowed more infiltration and consequently less runoff.

Runoff losses from continuous cultivated fallow were similar to those from continuous corn and soybean during F and SB (Figure 2). However, runoff losses from continuous fallow during P12, P3, and P4 were substantially higher than those from continuous corn or soybean. During these periods, corn and soybean plots were covered by either canopy or residue.

Tillage effects on surface runoff. For both corn and soybean, runoff from no-till was significantly higher ($p \leq 0.05$) compared to conventional or chisel methods (Figure 1). Mean annual runoff from no-till was 15 and 10 % higher for corn and 11 and 30% higher for soybean than those from conventional and chisel, respectively. Compared to conventional, chisel decreased runoff by 14% for soybean, and increased runoff by 5% for corn. When averaged over crop, mean annual runoff from no-till was 14 and 20% higher than conventional and chisel methods, respectively.

Cumulative runoff for conventional and no-till methods averaged over crop is shown in Figure 3 to determine whether the behavior of no-till relative to conventional tillage system changed over time in response to soil quality improvements usually associated with no-till. Throughout the study period, runoff from no-till was significantly higher than those from conventional. The difference in runoff between no-till and conventional has not been affected with time. The percent differences in cumulative runoff between no-till and conventional during the first and second halves of the study period were similar. Cumulative runoff amounts from no-till were 22.6 and 21.6% higher in the first and second halves of the study periods, respectively, than those from conventional. Thus, no-till has not improved the quality of the soil with time to increase infiltration and reduce runoff.

Mean annual runoff for the cropstage periods when summarized by tillage is given in Figure 4. Runoff losses from no-till were significantly higher ($p \leq 0.05$) than conventional and chisel methods for all cropstages periods, except P12 (Figure 4 and Table 1). Except for the period F, runoff from chisel was generally significantly lower ($p \leq 0.05$) compared to conventional. The study generally had two important findings. First, no-till, despite leaving most of the residue at the surface, did not reduce runoff as indicated in some studies (Laflen et al. 1978; Larson et al. 1978; Johnson and Moldenhauer 1979; Langdale et al. 1979; McGregor and Greer 1982). In fact, runoff was highest from no-till relative to chisel or conventional methods. Runoff from no-till was significantly higher compared to conventional and chisel during the F and SB periods. During these periods, for the conventional and chisel methods, tillage has broken the surface soil seal, increased micro relief and soil drying, all of which would have resulted in increased infiltration and reduced runoff. Thus, the effect of tillage associated with conventional and chisel was greater than the effect of residue associated with no-till in reducing runoff. Blanco (1995) investigated selected hydraulic properties of the erosion plots at Kingdom City, MO. He found that plots under the no-till system had lower saturated hydraulic conductivity, higher bulk density, and higher soil water content than those under conventional and suggested that these factors had probably contributed to high runoff from no-till. Lindstrom and Onstad (1982) reported similar results.

Second, runoff from the chisel method was significantly lower than the conventional method. The chisel method left more residue on the surface relative to conventional method, which was probably more effective in increasing infiltration, preventing the development of surface crusting, and consequently decreasing runoff.

Cropping effects on soil loss. Mean annual soil loss measured from the seven treatments during the 12-year study period is shown in Figure 5. Mean annual soil loss from soybean was 5, 21, and 24% higher than corn for the conventional, chisel, and no-till methods. When averaged over tillage, soil loss from continuous

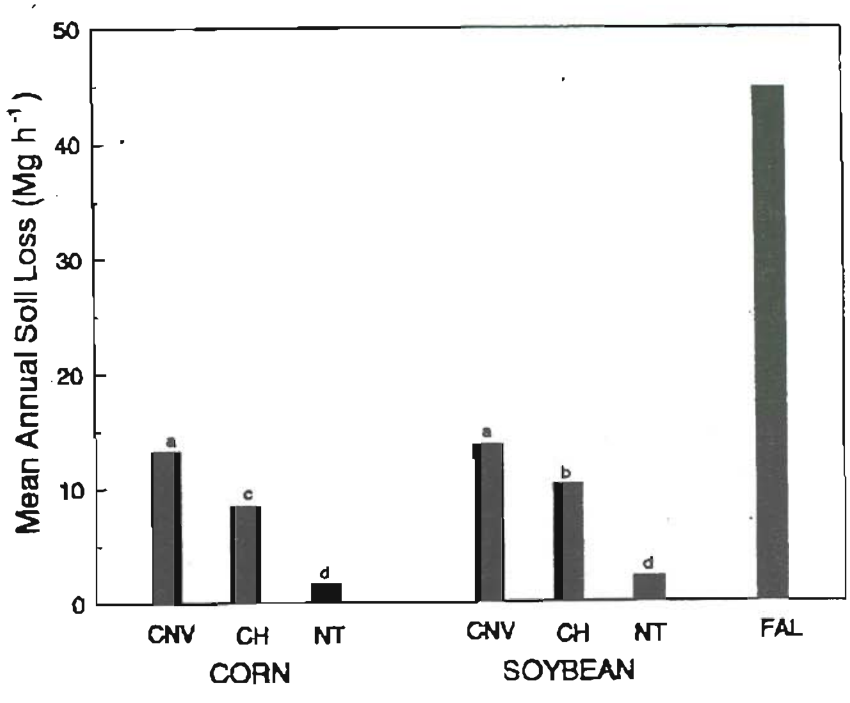

Figure 5. Mean annual calender year soil loss from continuous corn and soybean systems under Conventional (CNV), chisel (CH), and no-till (NT) methods
Treatment means with the same letter are not significantly different at the 5% level.

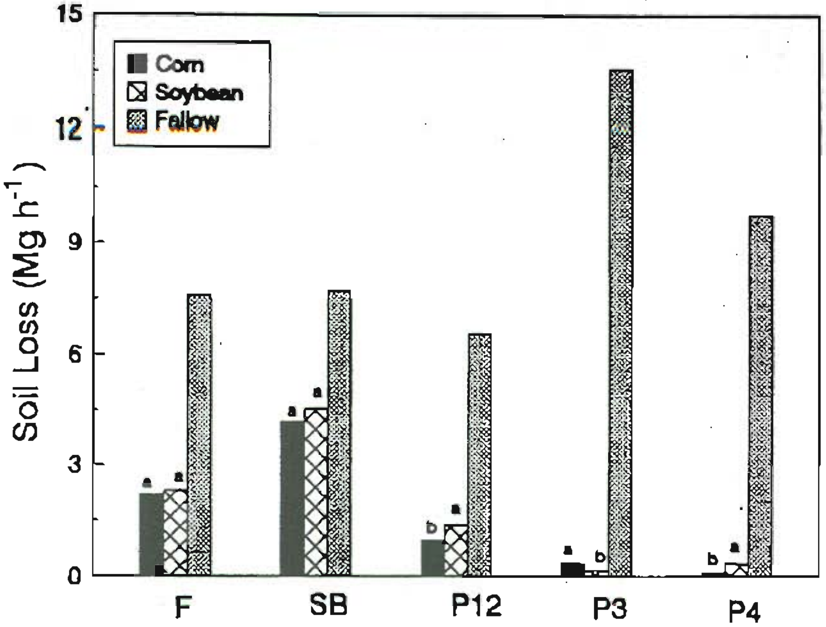

Figure 6. Mean annual tillage year soil loss for the cropstage periods summarized by crop type

Within each period values followed by the same letter are not significantly different at the 5% level.

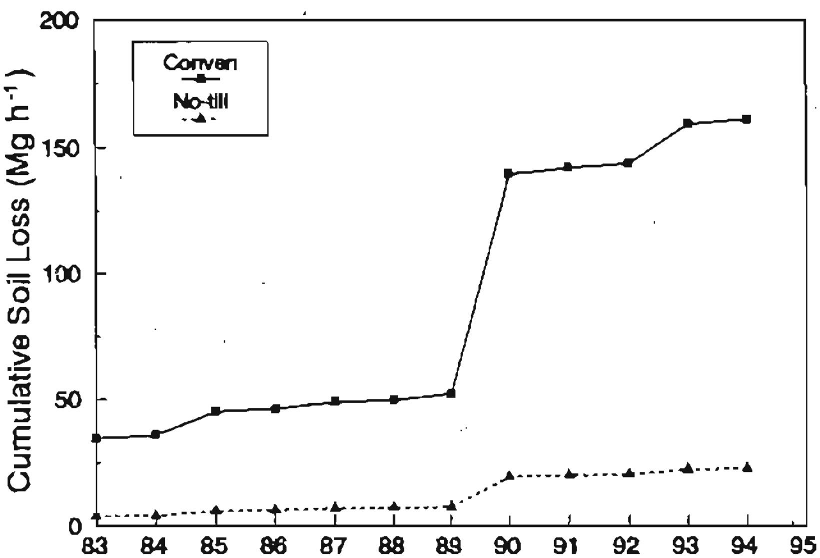

Figure 7. Cumulative soil loss for conventional and no-till tillage methods averaged over crop

Table 2. Mean annual soil loss by cropstage prerlods for corn and soybean cropping systems under conventional, chisel, and no-till methods

		Soil loss (Mg h^{-1})				
Crop	Tillage	F	SB	P12	P3	P4
Corn	Conv	3.46a*	7.12^{a}	1.60^{a}	0.84^{a}	0.12^{c}
	Chisel	2.54^{b}	4.52^{b}	0.98^{b}	0.20^{b}	0.10c^{d}
	No-till	0.54^{c}	0.80^{c}	0.26^{c}	0.02^{c}	0.04^{d}
Soybean	Conv	3.54^{a}	7.33^{a}	2.10^{a}	0.18^{b}	0.52^{a}
	Chisel	2.67^{b}	5.30^{b}	1.60^{a}	0.22^{b}	0.33^{b}
	No-till	0.62^{c}	0.91^{c}	0.40^{c}	0.03^{c}	0.14^{c}

*Within each period, values containing the same letter are not significantly different at the 5% level.

soybean was 12% higher than that from continuous corn. Except for chisel, the differences in soil loss between corn and soybean were not statistically significant ($p \leq 0.05$). Soil loss from continuous fallow was almost five times higher than that from continuous corn or continuous soybean.

Mean annual soil losses for the cropstage periods when summarized by crop type are shown in Figure 6. The mean percent distribution of measured soil losses for the F, SB, P12, P3, and P4 periods were 28.2, 53.8, 12.3, 4.5, and 1.2% for corn; 26.5, 52.3, 15.8, 1.6, and 3.8% for soybean; and 16.8, 17.0, 14.5, 30.1, and 21.6% for fallow, respectively. Most of the soil losses occurred during F and SB after the soil has been tilled and planted. Soil losses during P3 and P4 for corn and soybean were very low because the soil was covered by canopy during P3 and residue during P4.

Soil losses from soybean were higher than corn during all the cropstage periods except P3 (Table 2 and Figure 6). However, the difference in soil loss between corn and soybean was not significant ($p \leq 0.05$) for the high soil loss periods (F and SB). Although soil losses during P3 and P4 were quite small compared to F and SB, differences in soil losses between corn and soybean cropping systems were statistically significant ($p \leq 0.05$). This can be attributed to the effects of canopy and residue covers. P3 was the period when the soil was mostly covered by crop canopy. Soybean plots were believed to have more canopy cover with lower canopy height which probably resulted in less soil loss compared to corn plots. P4 was the period when the soil was covered with residue, and as previously mentioned, corn plots had more residue cover than soybean plots, which resulted in significantly lower soil loss.

During all the cropstage periods, soil loss from continuous fallow was substantially higher when compared with those from continuous corn or soybean (Fig 6). Soil loss from continuous fallow was particularly higher during P12, P3, and P4 when the soil under continuous corn and soybean was well covered by either canopy or residue.

Tillage effects on soil loss. No-till and chisel methods significantly reduced soil loss when compared to conventional. For both corn and soybean, soil loss from no-till was significantly lower ($p \leq 0.05$) than conventional or chisel method (Figure 5). When averaged over crop, mean annual soil loss from no-till was seven times lower than conventional and five times lower than chisel plow. Chisel reduced soil loss by 31% compared to conventional.

Cumulative soil losses from conventional and no-till methods averaged over crop are shown in Figure 7. Throughout the study period, soil loss from no-till was substantially lower than conventional. Percentage difference in cumulative soil loss between no-till and conventional in the first half of the study period was similar to the difference in the second half. Cumulative soil losses from no-till were 85 and 86% lower in the first and second halves of the study period, respectively, than those from conventional. Thus, the effect of tillage on soil loss has not changed with time.

During the 12-yr period, four events accounted for 73, 71, 71, and 59% of the total soil loss for conventional corn, conventional soybean, no-till corn, and no-till soybean, respectively. These events occurred during the F and SB periods when the soil was more erodible. One event that occurred in 1990 accounted for 41, 40, 38, and 25% of the total soil loss for conventional corn, conventional soybean, no-till corn, and no-till soybean, respectively.

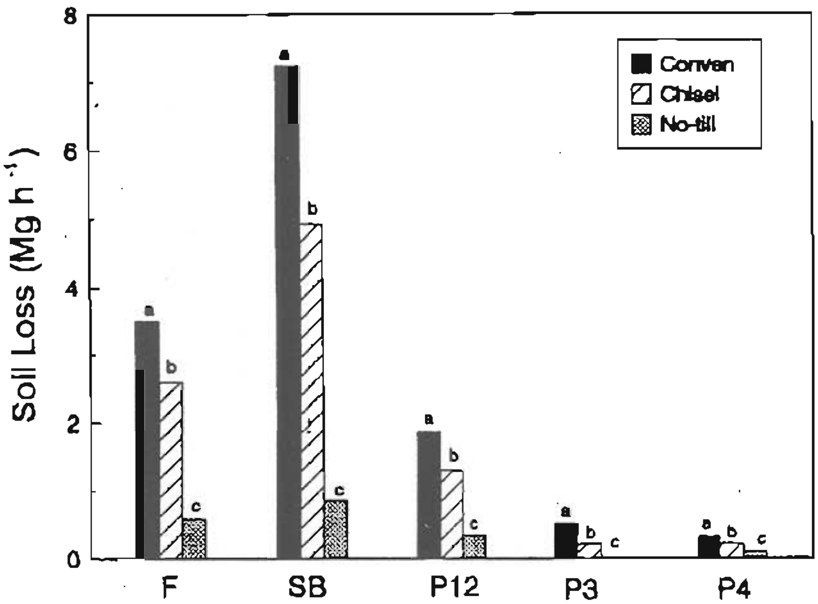

Figure 8. Mean annual tillage year soil loss for the cropstage periods summarized by tillage type
Within each period values followed by the same letter are not significantly different at the 5% level.

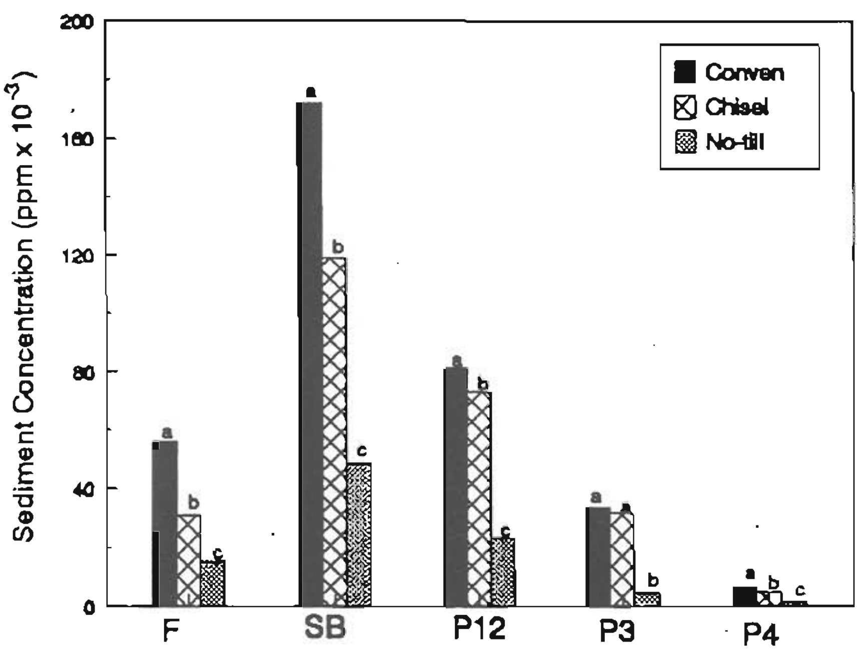

Figure 9. Mean annual tillage year sediment concentration for the cropstage periods summarized by tillage type
Within each period values followed by the same letter are not significantly different at the 5% level.

Soil losses during the cropstage periods were significantly different ($p \leq 0.05$) among the tillage systems (Table 2 and Figure 8). Differences were particularly large for F and SB. During these periods, the conventional and chisel plots had received primary and secondary tillage that buried surface residue and loosened the soil. Soil losses from chisel were less than those for conventional primarily because of higher surface residue cover after chiseling. For no-till, the soil surface was well protected by crop residue and may have undergone less weathering and aggregate breakdown which substantially lowered soil loss compared to conventional.

Generally, the study showed that conservation tillage (chisel and no-till methods) significantly reduced soil loss relative to conventional which indicated the effectiveness of residue cover and less soil disturbance in reducing soil losses. The reduction in soil loss for the chisel system may be attributed to the reduction in both runoff volume and sediment concentration since both runoff and sediment concentration from chisel were significantly lower than conventional. However, for no-till because runoff was significantly higher than conventional, the reduction in soil loss was only the result of lower sediment concentration in runoff water. Sediment concentration from no-till was significantly lower ($p \leq 0.05$) than conventional during all the cropstage periods (Figure 9). This could be attributed to the differences in residue cover and soil disturbance particularly for the F, SB, P12, and P3 cropstage periods. During P4, the difference in residue cover between no-till and conventional was small, and the soil was also well consolidated. Thus, at this period, the difference in soil loss was probably due to higher soil resistance to detachment for the plots under no-till than those under conventional.

Summary and conclusions

Runoff and soil losses were measured from continuous fallow and continuous corn and soybean cropping systems under conventional, chisel, and no-till tillage methods. Runoff and soil loss data were collected over a 12-yr period from the study plots at the Midwest Mexico silt loam claypan soil (Udollic Ochraqualf) located near Kingdom City, MO. We found the following:

1. When averaged over tillage, mean annual runoff and soil losses from soybean cropping system were slightly higher than those for corn; however, cropping effects on runoff and soil losses were not statistically significant ($p \leq 0.05$), except soil loss for chisel. Mean annual soil loss from soybean was significantly higher than corn for the chisel method.

2. Tillage effects on runoff and soil losses were significantly greater than those related to cropping system. No-till significantly increased runoff compared to conventional or chisel methods. Chisel method significantly reduced runoff for soybean, and slightly increased runoff for corn compared to conventional tillage. Chisel and no-till (conservation tillage) significantly reduced soil loss relative to conventional tillage. Soil loss from no-till was seven times lower than conventional and five times lower than chisel..

The important finding of this study was that long-term no-till on a claypan soil increased runoff related to tillage systems that caused soil disturbance and buried residue cover. Thus, if herbicide loss by runoff is a serious problem in row-cropped land, as it is in the Midwest claypan soil, no-till method may not be the most effective management system to use. For the Midwest claypan soils region, herbicide contamination of surface water is a serious problem. Because no-till increase surface runoff for the F and SB periods associated with the critical chemical loss periods (1-4 weeks after herbicide application), the increase in the use of no-till for soil conservation may be increasing levels of herbicide contamination.

REFERENCES CITED

Alberts, E. E., R. C. Wendt, and R. E. Burwell. 1985. Corn and soybean cropping effects on soil losses and C factor. Soil Sci. Soc. Am. J. 49(3):721-728.

Baker, J. L. and H. P. Johnson. 1979. The effect of tillage systems on pesticides in runoff from small watershed. Trans ASAE 22:554-559.

Blanchard, P., W. W. Donald, and E. E. Alberts. 1995. Herbicide concentration in a claypan soil watershed. Clean Water- Clean Environment-21st Century. ASAE Conference Proceedings, Volume I:21-24. Kansas City, MO.

Burkhart, M. R. and D. W. Koplin. 1993. Hydrologic and land use factors associated with herbicides and nitrates in near surface aquifers. J. Environ. Qual. 22:646-656.

Buyanovsky, G. A. and G. H. Wagner. 1986. Post-harvest residue input to cropland. Plant Soil, 93:57-65.

Colvin, T. S. and J. M. Laflen. 1981. Effects of corn and soybean row spacing on plant canopy, erosion, and runoff. Trans ASAE 24:1227-1229.

Ghidey, F., E. E. Alberts, and S. J. Birrell. 1996. Variability and distribution of agrichemicals in a claypan soil. ASAE paper no. 96-2082. St. Joseph, MI.

Ghidey, F., E. E. Alberts, and S. J. Birrell. 1994. Spatial and temporal variability of agrichemicals in a claypan soil. ASAE paper no. 94-2556. St. Joseph, MI.

Humberto, Blanco. 1995. Saturated hydraulic conductivity and runoff for a Mexico claypan soil. M. S. thesis. University of Missouri, Columbia MO.

Johnson, C. B. and W. C. Moldenhauer. 1979. Effects of chisel versus moldboard plowing on soil erosion by water. Soil Sci. Soc. Am. J. 43:177-179.

Laflen, J. M. and T. S. Colvin. 1981. Effects of crop residue on soil loss from continuous row cropping. Trans ASAE 24:605-609.

Laflen, J. M. and W. C. Moldenhauer. 1979. Soil and water losses from corn-soybean rotations. Soil Sci. Soc. Am. J. 43:1213-1215.

Laflen, J. M., J. L. Baker, R.G. Hartwig, W. F. Buchele, and H. P. Johnson. 1978. Soil and water losses from conservation tillage systems. Trans ASAE 21:881-885.

Langdale, G. W., A. P. Barnett, R. A. Leonard, and W. G. Fleming. 1979. Reduction of soil erosion by no-till system in southern piedmont. Trans ASAE 22:82-86, 97.

Larson, W. E., R. F. Holt, and C. W. Carlson. 1978. Residue for soil conservation. P. 1-15. In W. R. Oschwald (ed.). Crop residue management systems. Spec. Publ. 31. American Society of Agronomy, Madison, WI.

Lindstrom, M. J. and C. A. Onstad. 1982. Tillage systems influence on soil physical parameters and infiltration after planting. Minn. Agr Exp. Stn. Sci. J. Series 12:123.

Lindstrom, M. J., W. B. Voorhees, and G. W. Randall. 1981. Long-term tillage effects on interrow runoff and infiltration. Soil Sci. Soc. Am. J. 45:945-948.

Mannering, J. V., D. R. Griffith, and C. B. Richey. 1975. Tillage for moisture conservation. ASAE paper no. 75-2523. St. Joseph, MI.

McGregor, K. E., and J. D. Greer. 1982. Erosion control with no-till corn for silage and grain. Trans ASAE 25:154-159.

Oschwald, W. R., and J. C. Siemens. 1976. Soil erosion after soybean. In World Soybean Res., ed. L. D. Hill, 74-81. Interstate Printers and Publishers. Danville, IL.

Sauer, T. J. and T. C. Daniels. 1986. Effect of tillage system on runoff losses of surface-applied pesticide. Soil Sci. Soc. Am. J. 51:410-415.

Siemens, J. C. and W. B. Oschwald. 1976. Erosion for corn and tillage systems. Trans ASAE 19:69-72.

Wischmeier, W. H. and D. D. Smith. 1965. Predicting rainfall-erosion losses from cropland east of the Rocky mountains. USDA Agric. Handbook 282. Washington D. C: U. S. GPO.

Zhu, J. C., C. J. Gantzer, S. H. Anderson, E. E. Alberts, and P. R. Beuselinck. 1989. Runoff, soil loss, and dissolved nutrient losses from no-till soybean with winter cover crops. Soil Sci. Soc. Am. J. 53:1210-1214.