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CONSERVATION ASPECTS OF SELECTED TILLAGE SYSTEMS ON WESTERN IOWA CORNFIELDS[1/]

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ABSTRACT

Hydrologic and sediment variables were measured for 15 years in western Iowa at four watersheds located in the loess soils region of the Missouri Valley. Two watersheds were conventionally farmed with continuous row-cropped corn. One watershed was in grass for 8 years before 1972; since then it has been continuously corn cropped with a till-plant conservation tillage system. A fourth watershed which was level terraced was continuously row cropped to corn from 1964 to 1971; in 1972, parallel terraces with pipe drains replaced the level terraces, and conventional tillage was changed to the till-plant system.

The cropping change from grass to till-plant corn increased total runoff. Sediment yields averaged 1.1 t/ha for the 7 years of record since 1972. The level-terraced watershed, after conversion to parallel terraces with pipe drains, yielded higher surface runoff but decreased baseflow. Sediment yields with parallel terraces and pipe drains increased slightly to 2.9 t/ha from 2.0 t/ha with level terraces.

INTRODUCTION

During the past decade, many Iowa farmers have adopted a variety of conservation tillage practices. Annual statewide Soil Conservation Service (SCS) surveys show that the total area of conservation-tilled land increased rapidly from 178,200 ha in 1962 to 4,374,000 in 1978. Not all conservation tillage practices leave adequate crop residues (about 2,000 kg/ha minimum or 50 percent surface cover, according to Wischmeier, 1975) on the surface to significantly reduce erosion, but farmland with adequate surface residues in Iowa increased from 92,340 ha in 1968 to 1,903,500 ha in 1978, according to SCS surveys.

The erosion potential in western Iowa is greatest during May and June. Vanoni, 1975, reported that sediment yields measured on Agricultural Research watersheds for these two months have averaged more than 80 percent of the annual total. The actual May and June sediment yields, on conventionally-tilled watersheds, 1964-1978, ranged from 0.2 to 222 t/ha, with an average of 27 t/ha.

Conservation tillage practices are most effective in reducing erosion during the early crop stage when erosion potential for rowcrops is normally the greatest (Wischmeier, 1973). Such practices are easily adapted to row-cropping with large-scale farm equipment and reduce tillage operations for preparing the seedbed and planting the crop.

Laflen et al. (1978) demonstrated the benefits of crop residue cover in reducing soil erosion using simulated rainfall on six different tillage practices on three Iowa soils. Their results showed that soil loss was correlated with residue cover when crop canopy was not significant. The objective of our study was to evaluate the effectiveness of a till-plant conservation practice, used alone and in combination with terraces, in reducing soil erosion on field-size areas that are continuously row-cropped to corn.

WATERSHED DESCRIPTION

Four research watersheds near Council Bluffs, Iowa, representative of the deep loess soils region adjacent to the Missouri River flood plain in western Iowa and northwestern Missouri, were studied. Depth of the loess varies from 25 m on the ridges to 5 m in the valleys. The silt-loam soils on these watersheds are classified as Typic Hapludolls, Typic Haplorthents, and Cumulic Hapludolls (Soil Conservation Service, 1975). All of these soils are fine-silty, mixed mesics and have moderate to moderately rapid permeability. The area-weighted land slope of the four study watersheds is 8 to 9 percent, and the maximum slope is 18 percent. Most main and upland valleys have moderate to deeply incised channels. Each watershed is entirely tillable, but erosion is serious if conservation practices are not used. Saxton et al., 1971, described the instrumentation installed in 1964 on the four research watersheds to evaluate the effectiveness of level-terraced and grass conservation practices for controlling gully and sheet-rill erosion.

Watersheds 1 and 2 were contour farmed; Watershed 4 was level terraced, with steep, grassed backslopes. These three watersheds were conventionally tilled (plow, disk, harrow, plant) and continuously corn-cropped, a common practice in the area. Watershed 3 was in bromegrass, bromus inermis, and rotation grazed with no other conservation practice. The complete watershed management history is given in Table 1.

In 1972, till-planting was initiated on Watershed 3 to determine whether this practice would limit soil loss (Spomer et al., 1975) to acceptable levels and optimize farmability of the steep loess terrain. The terrace system on Watershed 4 was changed in 1972 to parallel terraces and an underground pipe drainage system with risers (perforated pipe) in the low point of the terrace channel. Terrace intervals were 89 m, twice the 1972 Soil Conservation Service recommended terrace spacing for row-cropped land having a 14 percent slope. Up- and downhill farming was used in the terrace interval. Because of favorable topsoil depth, intraterrace erosion is permitted so that topography modification and "benching" will occur. Accumulated runoff is drained through the underground pipe system to an outlet in a grass waterway. The system was designed to drain 5 cm of runoff from the contributing area in 24 hours. To evaluate the combination of a wide terrace interval and conservation tillage, the till-plant system was also used on Watershed 4.

HYDROLOGIC RESPONSE

There are 15 years of record summarized in Table 2 to evaluate clean tillage and resultant erosion on the rolling loess terrain of contour-corn Watersheds 1 and 2. Rainfall averaged 82 cm per year, 10 cm above the long-term average annual rainfall recorded by the National Oceanic and Atmospheric Administration at nearby Omaha, Nebraska. Annual variation in precipitation amounts and storm characteristics resulted in large fluctuations in runoff and sediment yields. For example, from 1964 to 1971, the baseflow (continuous flow between storm events) for Watersheds 1 and 2 was about half the surface runoff, whereas, from 1972 to 1978, it was more than twice the surface flow for those same watersheds (Table 2).

[1/] Contribution of the Watershed Research Unit, U. S. Department of Agriculture, Science and Education Administration, in cooperation with the Iowa Agriculture and Home Economics Experiment Station, Ames, IA.

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This indicated a difference in the character of the pre- and post-1972 storms. These climatic variations make analysis of annual rainfall and runoff data for an isolated watershed difficult. A more fruitful approach was to compare conservation watersheds with a control watershed. In this case, Watersheds 1 and 2 served as the controls. A double-mass diagram was used for this comparison (Linsley et al., 1975). Consider the influence on total runoff of the two types of terrace systems investigated on Watershed 4 (Fig. 1). The standard level terraces were changed to level terraces at double spacing with pipe outlets in the fall of 1971 and the spring of 1972. This transition appears as an obvious break in the double-mass diagram, which may have been caused by a reorganization of the total hydrologic regime of the field. Except for the break from 1971 to 1972, the total runoff from either of the terrace systems was not distinguishable from that of the contour-corn watersheds, as is indicated by the slope of the double-mass curve. This was expected because total runoff should be closely related to consumptive water use of the corn.

The annual runoff occurs in the form of surface flow during the storm and as baseflow. The original terraces had no outlet for the stored water. Infiltration was enhanced, and baseflow was quite high as a result. The modified terrace system included a pipe outlet to reduce ponding in terrace channels. Opportunity for infiltration was reduced and, as a consequence, baseflow was reduced (Fig. 2). Flows from the terrace pipe outlets at Watershed 4 were included as surface runoff. A dramatic increase in surface flow occurred from 1972 to 1975, the years after terrace modification (Fig. 3). In summary, the annual water yield from the two terrace systems was not significantly different. There was, however, a change in the baseflow-surface flow components.

Two crops, grass (1964 to 1971) and corn with till-plant tillage (1972 to present), have been studied on Watershed 3. Total runoff increased with corn cropping on Watershed 3 as shown by the transition in 1972 (Fig. 1). This indicates that grass had a larger consumptive use than corn. Baseflow, shown in Fig. 2, increased slightly after the transition. Surface flow occurring in the late 1960's and early 1970's was too small to show a definite transition (Fig. 3). Thus, surface runoff for the grass and till-planted corn may be equal.

In general, total runoff from the corn land was nearly the same regardless of practice. There were, however, significant differences in the separation between baseflow and surface flow. Total runoff from the grass watershed was more than one-third less than that from the corn-cropped watersheds.

Because Watersheds 1 and 2 are located 5 km from Watersheds 3 and 4, individual storms seldom have sufficient areal uniformity to permit direct comparison of watershed response. On May 8, 1977, however, a fairly uniform rainfall event occurred on all four research watersheds for which direct comparisons can be made. The total rainfall was 4.1 cm on Watersheds 1 and 2 and 4.8 cm on Watersheds 3 and 4. The effective duration of the rainfall was about 25 min. The runoff hydrographs are compared in Fig. 4 using a logarithmic discharge scale. Peak discharges on conservation Watersheds 3 and 4 were one-tenth and one-twentieth, respectively, of those from the conventional contoured Watersheds 1 and 2. Over the history of the project, the peak discharges and surface runoff volumes for the conservation watersheds have been about one-tenth and one-third, respectively, of the values measured from the conventionally tilled, contoured watersheds.

SOIL EROSION

A 15-year record of measured sediment yields (eroded soil delivered to a watershed outlet) with conventional contour corn cropping is available to evaluate the reduction of soil erosion with till-plant tillage. Measured sediment yields for Watersheds 1 and 2 during the first 8 yrs, 1964 to 1971, ranged from 2.2 to 222 t ha^{-1} yr^{-1} (Table 2) and were, generally, considered excessive.

Watershed 3 was in grass for the first 8 yrs and has never been deep tilled; thus, soil structure was good, bulk density low, and infiltration rapid. A small sediment yield, 1.1 t ha^{-1} yr^{-1}, was recorded for Watershed 3 for the period 1972 to 1978. This exceptional performance can be partially attributed to planting directly into the chemically-killed bromegrass sod and to the favorable infiltration condition of the porous soil profile created by the dead and decaying grass roots.

Since 1972, the sediment yield from Watershed 4 (with double-spaced terraces and pipe drains) has averaged 2.9 t ha^{-1} yr^{-1}, well below the permissible soil loss but higher than 2 t ha^{-1} yr^{-1} measured from 1964 to 1971, with the level terraces without pipe drains. Some of this increase can be attributed to sediment transported through the underground pipe drainage system and to the increased drainage area below the lower terrace with the 1971 terrace revision. Terraced Watershed 4 has been continuously cropped to corn since 1964. Large areas were disturbed by terrace construction in 1964 and 1971, which damaged soil structure and removed some topsoil. Failure of some pipe drains and resultant terrace breakovers in the newly constructed terrace system during an intense storm in May 1972 increased sediment yield to 14.6 t/ha that year.

The bar graph in Fig. 5 depicts average annual soil losses since 1972 for the watersheds and graphically demonstrates the effectiveness of the conservation treatments to reduce sediment yield. The 2:1 sediment yield ratio for paired Watersheds 1 and 2 was partially explained by a resurvey of established main waterway cross sections on Watersheds 1 and 2 in 1979. On Watershed 1, the survey revealed that 451.4 t of sediment was deposited in 1/3 ha of the outlet waterway. This sediment, distributed over the 14-year period, June 1965 to August 1979, accounts for an additional 1.1 t ha^{-1} yr^{-1} of sediment for the watershed. If added to the 13.7 t ha^{-1} yr^{-1} shown in Fig. 5, the average sediment yield would be 14.8 t/ha for the period 1972 to 1978. The survey on Watershed 2 showed 1243 t of sediment deposited in a similar 1/3-ha waterway for the same period. This amounts to an additional 3.1 t ha^{-1} yr^{-1} of sediment. If added to the 6.9 t ha^{-1} yr^{-1} shown in Fig. 5, the average sediment yield would be 10.0 t ha^{-1} yr^{-1} for the period 1972 to 1978. Watershed 1 has always had a larger sediment yield than Watershed 2; its area-weighted slope is 9 percent as compared with 8 percent for Watershed 2. This steeper slope on Watershed 1 makes the expected soil loss 20 percent greater, based on the increase of the topographic (LS) factor in the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). The expected average annual sediment yield for Watershed 2, adjusted to a 9-percent slope, would be 12.0 t/ha.

Soil loss is the total quantity of soil displaced, whereas sediment yield is the quantity of soil leaving the watershed. Wischmeier and Smith (1965) define excessive annual soil loss as a rate that will deplete long-term productivity (about 11 t ha^{-1} for western Iowa). The ratio of sediment yield to soil loss is termed the sediment delivery ratio. Sediment yield was measured, and soil loss can be estimated using the USLE so that the delivery ratio can be determined.

On conventionally-tilled Watersheds 1 and 2, the delivery ratio has averaged 55 percent. Using the 55-percent delivery ratio, soil loss for these watersheds was estimated at 61 t ha^{-1} yr^{-1}, or five and one-half times the permissible soil loss that will sustain soil capability and crop production. The 15-year average annual sediment yield for conventionally-tilled Watersheds 1 and 2 was about 33.5 t ha^{-1}. The soil loss predicted by the USLE for Watershed 3 for a till-plant system was 17 t ha^{-1} yr^{-1}. Based on 7 years of data, the sediment yield was 1.1 t ha^{-1} yr^{-1}. The resulting delivery ratio, 6.5 percent, seemed unreasonably low. This might indicate a low R factor in the USLE during these years, but the computed average annual R factor was 157, compared to a long-term average R factor of 160. Because 80 percent of the soil loss occurs during May and June, we determined the R factor for these months for the period of record. For 1965 through 1971, the average May and June R factor was 95; for 1972 through 1978, it averaged a near-normal 59. This would suggest that larger soil losses from till-planted Watershed 3 may be experienced in the future when rainfall events again produce high R values during the erosive period of May and June. It is unlikely that erosion will average the predicted 17 t ha^{-1} yr^{-1}, although it could occur during a year with excessive rainfall.

To increase our understanding of sediment delivery, we can compare our sediment yield data with plot studies of conservation tillage practices performed using simulated rainfall. This comparison does present some problems because all tillage on the simulated rainfall plots was up- and downhill, whereas tillage on the Treynor research Watersheds 1, 2, and 3 was across the slope but only approximately maintained on level contours. Estimated soil losses for the various tillage practices shown by Laflen et al. (1978) are shown in Table 3. Based on the simulated rainfall plot data, the only practice that restricted soil loss to allowable limits was the no-till practice. The simulated rainfall studies showed that the till-plant system allowed 74 t/ha soil loss--more erosion than the conventional plow-plant practice (Table 3). Using 55 percent as the sediment delivery ratio, the sediment yield estimated from the data for the Laflen et al. till-plant plot would be 41 t/ha (Table 3). The measured sediment yield for the till-plant system on Watershed 3 where approximate contour planting is practiced was 1.1 t/ha, nearly 40 t/ha less than the plot value.

Sediment delivery for till-planting on the approximate contour was significantly less than all other practices in Table 3. Contouring, although approximate, is important since it increases the effectiveness of till-planting. The till-planter leaves a 36-cm clean row area exposed where erosion can be excessive. A 61-cm interrow interval of crop residue and loose soil enhances infiltration. The second cultivation in June forms a high ridge (10 cm) and creates a series of barriers that impede downhill surface runoff when approximate contouring is practiced.

Additional research from plots, fields, and watersheds is needed to determine erosion, deposition, and sediment transport, to improve the accuracy of delivery ratios. These data are also needed in developing and testing models in the search for reasonably accurate methods of predicting soil loss.

Simulated rainfall plot data permit scientists to determine total soil movement representative of areas within a watershed, but these data do not consider the deposition that occurs where slopes moderate or the filtering effect of fence rows, grass waterways, and headlands. Both plot and watershed data are required to determine sediment delivery ratios. Watershed and plot studies complement each other and provide additional insights into the processes of soil loss and sediment yield. Thus, simulated rainfall plot tests provide much useful information; however, a tillage or conservation system cannot be evaluated solely on the basis of such studies.

SUMMARY

Continuous corn cropping with till planting increased total runoff of a watershed as compared with the previous grass management. The new terrace system with underground pipe drains and conservation tillage increased surface runoff compared with level terraces without drains.

The till-plant tillage system with continuous corn cropping restricted sediment yield to 1.1 t ha^{-1} yr^{-1}, whereas with terraces and till-planting, sediment yield averaged 2.9 t ha^{-1} yr^{-1}; these sediment yields are considered to be within allowable limits. Much of the additional sediment yield on the terraced watershed was the result of terrace failures, scalped areas during terrace construction, and the 15 years of continuous corn versus 7 years for the contour till-planted watershed.

Plot data from simulated rainfall show up- and downhill till-planting to be extremely erosive; 74 t/ha soil loss was measured and sediment yield was estimated at 41 t/ha from a total simulated rainfall of 21.6 cm in a 2-day period. This is contrasted with till-planting on the contour where sediment yield averaged 1.1 t ha^{-1} yr^{-1}, although no storms approaching the magnitude of the simulated rainfall studies were recorded during the 7 years of data. Contouring with the till-plant system on the non-terraced watershed has also contributed to low sediment yield values. The surface residues effectively retarded overland flow and increased infiltration.

Predicted soil loss for the till-plant tillage system using the USLE was 17 t ha^{-1} yr^{-1}, much higher than the measured 1.1 t ha^{-1} yr^{-1} sediment yield.

These widely divergent soil loss values indicate a need for additional plot and watershed data to improve sediment delivery ratios. Improved relationships are needed to upgrade present models used to estimate soil loss. Plot studies on several slopes with continuous contour corn have been initiated to reconcile the wide variations in data reported in this paper.

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Table 1.--Management History of Treynor Research Watersheds

Watershed number	Watershed size (ha)	Tillage	Crop	Conservation practice
		1964-1978		
1	30.4	Clean	Corn	Contour (approx.)
2	33.6	Clean	Corn	Contour (approx.)
		1964-1971		
3	43.3	None	Grass	Rotation grazed
4	60.8	Clean	Corn	Level terraced
		1972-1978		
3		Conservation Tillage	Corn	Contour (approx.)
4		Conservation Tillage	Corn	Parallel terraces with pipe drains

Table 2. Water and Sediment Yield Summary of Treynor, Iowa, Watersheds, 1964-1978

Year	Watershed No.	Annual Precip.	Runoff			Sediment Yield
			Base	Surface	Total	Sheet-rill source
		cm	cm	cm	cm	t/ha
1964	1	90.4	4.9	11.6	16.5	56.0
	2	89.3	5.5	10.2	15.7	56.0
	3	85.1	6.0	1.1	7.1	0.7
	4	88.4	14.4	2.0	16.4	1.6
1965	1	115.2	9.0	27.0	36.0	98.6
	2	112.6	7.5	27.1	34.6	81.6
	3	112.5	11.7	11.7	23.4	0.9
	4	114.0	26.8	6.4	33.2	2.0
1966	1	51.6	6.4	1.6	8.0	15.0
	2	52.2	6.1	2.2	8.3	19.3
	3	55.9	6.4	1.0	7.4	0.2
	4	55.6	15.0	0.5	15.5	1.3
1967	1	97.2	5.8	29.4	35.2	222.2
	2	95.5	6.4	26.5	32.9	168.6
	3	86.9	8.4	6.7	15.1	1.3
	4	87.8	18.5	1.8	20.3	6.5
1968	1	82.0	4.2	2.9	7.1	8.3
	2	82.6	4.6	2.9	7.5	9.2
	3	79.0	4.0	2.6	6.6	0.4
	4	81.7	10.7	0.3	11.0	0.7
1969	1	79.8	8.1	6.4	14.5	4.0
	2	80.1	7.5	6.0	13.5	2.2
	3	77.8	8.4	4.4	12.8	0.2
	4	78.0	15.5	0.7	16.2	0.2
1970	1	80.0	5.6	5.4	11.0	26.5
	2	78.3	6.0	4.6	10.6	16.6
	3	73.3	5.6	0.9	6.5	<0.2
	4	73.1	10.1	0.3	10.4	0:2
1971	1	73.8	5.2	12.6	17.8	44.8
	2	74.1	6.6	9.8	16.4	29.8
	3	75.7	7.2	3.9	11.1	0.9
	4	76.4	14.0	1.7	15.7	3.4
Averages for 8 years 1964-1971	1	83.8	6.2	12.1	18.3	59.4
	2	83.1	6.3	11.2	17.5	48.0
	3	80.8	7.2	4.0	11.2	0.7
	4	81.9	15.6	1.7	17.3	2.0

Table 2. Water and Sediment Yield Summary of Treynor, Iowa, Watersheds, 1964-1978 (continued)

Year	Watershed No.	Annual Precip. cm	Runoff Base	Runoff Surface	Runoff Total	Sediment Yield Sheet-rill source t/ha
			----------cm----------			
1972	1	86.2	6.8	3.8	10.6	16.8
	2	86.5	7.6	3.9	11.5	17.7
	3	95.2	15.8	2.1	17.9	2.7
	4	95.2	14.7	10.7	25.4	14.6
1973	1	105.9	20.8	6.6	27.4	2.2
	2	104.6	25.6	7.5	33.1	1.1
	3	103.2	37.0	2.7	39.7	0.2
	4	102.4	30.5	8.5	39.0	2.2
1974	1	63.0	16.4	1.4	17.8	1.1
	2	62.2	21.8	1.4	22.2	0.7
	3	56.0	20.7	0.2	20.9	<0.2
	4	53.8	18.9	0.6	19.5	<0.2
1975	1	78.3	12.0	2.6	14.6	3.6
	2	78.7	19.8	2.1	21.9	1.8
	3	74.4	16.7	0.3	17.1	<0.2
	4	73.8	16.0	3.0	19.0	0.4
1976	1	54.0	10.1	0.5	10.6	<0.2
	2	53.9	12.3	0.4	12.7	<0.2
	3	60.7	12.6	1.0	13.6	2.5
	4	64.1	10.4	1.8	12.2	1.6
1977	1	106.6	7.1	16.0	23.1	56.0
	2	109.2	8.7	10.4	19.1	18.2
	3	97.0	14.6	0.8	15.4	0.2
	4	95.9	12.3	4.0	16.3	0.7
1978	1	88.6	10.4	9.0	19.4	15.5
	2	87.4	13.5	8.2	21.7	9.2
	3	82.6	21.2	4.0	25.2	1.1
	4	81.4	16.2	8.0	24.2	0.9
Averages for 7 years 1972-1978	1	83.2	11.9	5.7	17.6	13.7
	2	83.2	15.6	4.8	20.4	6.9
	3	81.3	19.8	1.6	21.4	1.1
	4	81.0	17.0	5.3	22.3	2.9
AVERAGES FOR 15 YEARS 1964-1978	1	83.5	8.8	9.1	17.9	38.1
	2	83.1	10.6	8.2	18.8	28.9
	3	81.0	13.1	2.9	16.0	0.7
	4	81.5	16.3	3.4	19.7	2.2

Table 3. Soil Loss and Sediment Yield Variations According to Tillage Practice[a]

Tillage Practice	Soil Loss	Sediment Yield
	t/ha	t/ha
Rainfall plots (3 x 10.7 m)[b]		
Till-planted	74	41
Conventional plow-plant	65	34
Chisel	50	28
Disk tandem	29	16
Fluted coulter (no till)	7	4
Watershed 3		
Till-planted approximately on the contour	17[c]	1.1[d]

[a] Plot data from Laflen et al., 1978, 21.6 cm simulated rainfall in a 2-day period. Data from Treynor Research Watershed 3 included for comparison.

[b] Sediment yield was estimated using a delivery ratio of 0.55 (watershed sediment yield to subarea soil loss); the delivery ratio was determined using measured sediment yield from research watersheds and USLE relationships.

[c] Computed annual USLE value.

[d] Measured--7 year average.

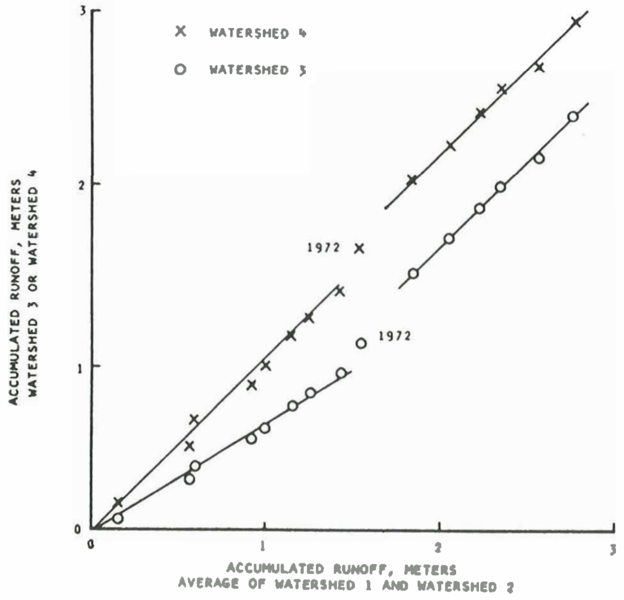

FIG. 1 --DOUBLE-MASS COMPARISON OF TOTAL RUNOFF, 1964-1978

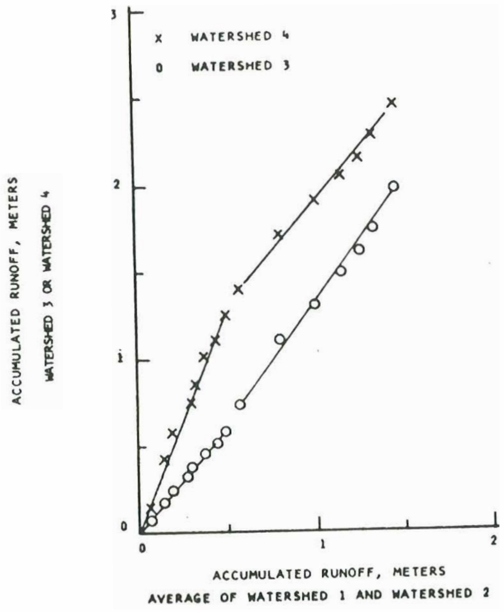

FIG. 2--DOUBLE-MASS COMPARISON OF BASEFLOW, 1964-1978

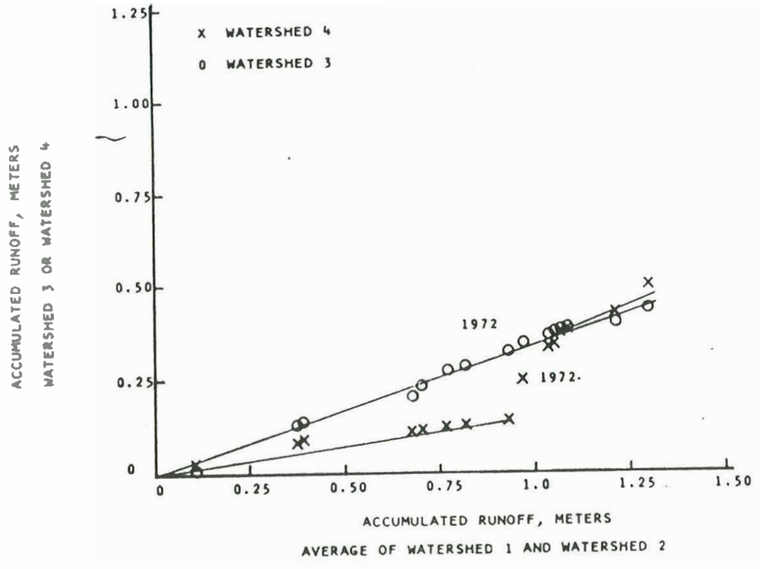

FIG. 3--DOUBLE-MASS COMPARISON OF SURFACE RUNOFF, 1964-1978

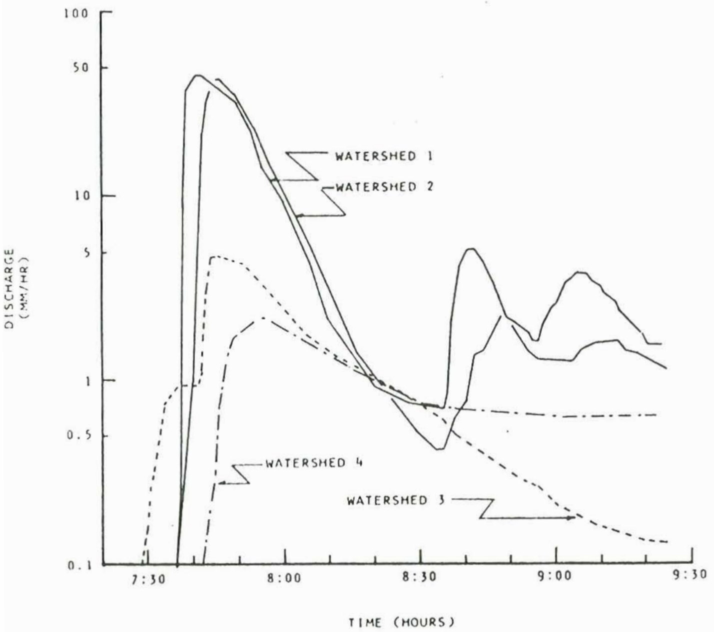

Figure 4--Runoff Hydrographs for Watersheds 1, 2, 3, and 4, for May 8, 1977 Storm

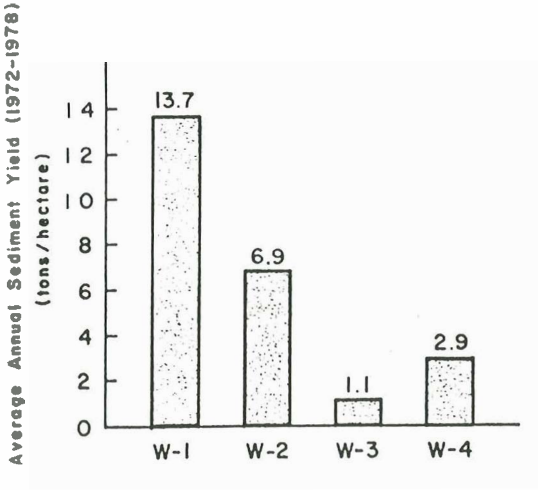

Figure 5--Average annual sediment yield from research watersheds, Treynor, Iowa 1972-1978.