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LAND USE TREATMENT EFFECTS ON CLAYPAN SOIL RUNOFF AND EROSION

by

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SUMMARY:
Water yield and erosion data from 88m^2 research plots for a ten-year study period of various land use treatments and a seven-year study period of various corn crop tillage systems are presented. The Universal Soil Loss Equation and Modified Universal Soil Loss Equation were used to predict erosion from observed rainfall-runoff events from continuous corn, conventional tillage land use for a seven-year period.

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Land Use Treatment Effects on Claypan Soil Runoff and Erosion[1/]

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Introduction

The effects of various land treatments on runoff and erosion are often estimated from limited data. Water yield and erosion data were measured by the USDA Science and Education Administration from erosion research plots on the Midwest Claypan Experiment Station near Kingdom City, Missouri. Data are reported for a ten-year study period, 1960-1969, for land use treatments of fallow, continuous corn, and a four-year rotation of corn, wheat, meadow, and meadow. Data are also reported for a six-year study period 1971-1976 for continuous corn grown under six different tillage-residue treatments.

The Universal Soil Loss Equation (USLE) (6) and the Modified Universal Soil Loss Equation (MUSLE) (5) were applied to continuous corn under spring plow and conventional tillage land use for a seven-year period, 1963-1969. Observed erosion data are compared to predicted erosion data on an event and seasonal basis.

Claypan Soil

A very important crop production region in Missouri, Illinois, and Oklahoma is the claypan prairie land resource area. The research plots are located on a Mexico silt loam soil (Mesic Udollic Ochraqualfs) typical of the central part of this land resource area. This soil has

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a dark silt loam topsoil of 178 to 280 mm depth. Below the topsoil is a silty clay horizon of .3 to .6 m depth which has a high montmorillonitic clay content of 45 to 50 percent. This is the claypan horizon which has formed during soil development and maturity. The claypan layer has very low saturated hydraulic conductivity. The silty clay loam subsoil below the claypan is moderately permeable.

Experimental Plot Design

The experimental erosion plots are 27.4 m long along the slope and 3.2 m wide across slope. The plot area is 88 m^2. The surface slope varies from 2.5 to 3.5 percent. A standard system of collecting runoff water and sediment in storage tanks was installed at the lower end of each plot (1, 2, 3). The plot runoff and sediment collection tanks were serviced after each runoff producing storm period. Runoff rate measuring flumes were also installed on two plots with continuous corn land use. The data reported were compiled from individual storm records during the study periods.

Land Use Cover Treatments

During the 1960-1969 study period, land treatments of fallow, continuous corn, and a four-year rotation of corn, wheat, meadow, meadow were in effect each year. The fallow plot was plowed and disked in the spring and cultivated as needed during the crop season to keep the surface loose and weed-free. The continuous corn plot was plowed and disked in the spring to prepare a seedbed and cultivated for weed control as needed. The rotation corn plot was managed the same as the continuous corn plot. The wheat plots were disked and sown in early fall after corn harvest and inter-seeded with grass and legumes. The first and second-year meadow plots were harvested as hay as the season permitted each year.

During the 1971-1976 study period, various tillage and crop management systems for continuous corn were in effect each year. For corn harvested for grain, plant residues were left on the plots. For corn harvested for silage, all plant growth was removed from the plots at silage harvest. The different management treatments were as follows:

Corn harvested for grain

1. Conventional tillage - Spring plowed, disked, planted, cultivated for weed control, harvested.
2. Conventional tillage - Fall plowed, disked in spring, planted, cultivated for weed control, harvested.
3. Field cultivation - Spring field cultivated, field cultivated before planting, planted, cultivated for weed control, harvested.
4. No-Till - No-till planted, harvested.

Corn harvested for silage

1. Winter cover crop - No-till planted, winter cover killed by herbicides, harvested, rye grain sown, rye growth harvested twice in spring before corn planting.
2. No winter cover - No-till planted, harvested.

The fertility of each treatment was maintained each year at recommended levels according to soil tests.

Precipitation

The period of record, 1960-1969, includes dry and wet years which range from 625 to 1487 mm per year. During the last 4 years of the period, irrigation water was applied to the plots to supplement rainfall. The average annual precipitation and irrigation was 962 mm which is nearly the same as the long-term, 87-year average precipitation for Columbia, Missouri. During the period 1971-1976, irrigation water was applied to the plots to supplement rainfall the first five years at an average annual rate of 79 mm. The annual rainfall, plus irrigation for this period, ranged from 553 to 1338 mm. The annual average rainfall was only about 10 mm less than the long-term average precipitation.

Runoff and Erosion, 1960-1969

The rainfall, runoff, and erosion data were summarized for the years 1960-1969 for seasons defined by crop growth stages or tillage events and for growing season, dormant season and annual periods. The periods used for data summary generally follow those defined in Agriculture Handbook 282 to establish seasonal factors of the Universal Soil Loss Equation (7) for corn cropping.

Season 1 (May 15 - June 13) represents the seedbed condition defined from corn planting to one month after planting. Season 2 (June 14 to July 13) is the crop establishment period from 1 to 2 months after planting. Season 3 (July 14 to October 16) is the crop growth period from two months after planting to harvest. Season 4 (October 16 to December 31) is a post harvest-residue period ending at the end of the calendar year. Season 5 (January 1 to April 21) is a post harvest-residue period from the first of the year to the primary tillage date. Season 7 (April 21 to May 15) is the rough fallow period from spring plowing to corn planting. Runoff and erosion from snowmelt events (Season 6) were minor contributions to the data and varied greatly from year to year. Therefore, Season 6 data were included in Season 5.

Runoff and erosion data for all the land use treatments studied were summarized by these season definitions based on the spring plow continuous corn land use treatment. Average annual values for each study period and season were tabulated. For the 1960-69 period, average annual rainfall and runoff per season for the study land cover treatments are summarized in Table 1. Two plots were used for each cover treatment each year and the data represent plot average observations. Average annual runoff of 207 mm from the fallow cover treatment was the most of all the treatments. The average annual runoff of 104 mm from the continuous corn was about one-half the fallow runoff. The four-year rotation corn and rotation wheat average annual runoffs were each about 80% of the continuous corn runoff. The average annual runoff of first and second year meadow was only 70% and 60%, respectively, of the continuous corn treatment runoff.

Average annual rainfall and irrigation was 962 mm. An average of 60% was received during the corn growing season which includes periods 1, 2 and 3, or 42% of the year. For all cover treatments, the growing season runoff volume was a greater (65% to 78%) part of the annual total than the growing season rainfall.

In seasons 1 and 2 after corn planting, runoff was much higher for the fallow and corn treatments than for the wheat and meadow treatments which had more ground cover and plant growth in this period. Season 3 runoff from rotation wheat was higher than from either rotation corn or rotation meadow treatments. This period is

Table 1 .--Average Annual Observed Rainfall and Runoff per Season, 1960-69

Season[1/]	Rainfall[2/]	Cover Treatment					
		Fallow	Continuous Corn	Rotation Corn <u>C</u>WMM	Rotation Wheat C<u>W</u>MM	Rotation Meadow CW<u>M</u>M	Rotation Meadow CWM<u>M</u>
	mm						
1	136	27	22	16	10	10	8
2	122	25	17	13	8	7	6
3	316	83	39	33	41	34	32
4	120	20	8	5	5	5	5
5	191	45	17	12	13	15	13
7	77	7	1	1	1	3	2
Growing Season[3/]	574	135	78	62	59	51	46
Dormant Season[4/]	388	72	26	18	19	23	20
Annual Total	962	207	104	80	78	74	66

1/ Season Definition and Average Calendar Period

Season Definition	Average Calendar Period
1 - 0 to 30 days after corn planting,	(May 15 - June 13)
2 - 31 to 60 days after corn planting,	(June 14 - July 13)
3 - 61 days after planting to corn harvest,	(July 14 - October 16)
4 - corn harvest to end of year	(October 16 - December 31)
5 - first of year to spring plowing	(January 1 - April 21)
7 - spring plowing to corn planting	(April 21 - May 15)

2/ Includes irrigation applications in seasons 1, 2, 3, and 4 to supplement rainfall.

3/ Seasons 1, 2, and 3 combined.

4/ Seasons 4, 5, and 7 combined.

after wheat harvest when the inter-seeded meadow cover was being established. Consequently, soil cover was much less on the rotation wheat in season 3 than on the corn and established meadow treatments. The runoff from all treatments except fallow during seasons 4 and 5 was less varied. The fallow treatment did not have plant residues on the soil surface, in comparison to the other treatments.

Season 7 was the shortest season and had the lowest runoff for all treatments. Runoff was particularly low for the two corn treatments which were plowed at the beginning of season 7.

Average annual erosion data associated with the runoff data previously discussed are tabulated in Table 2. Average annual erosion for the fallow treatment of 33.33 metric ton/hectare was over 5 times the continuous corn erosion of 6.22 metric ton/hectare. Erosion from the four-year rotation corn was only 70% of the continuous corn erosion. Average annual erosion for the rotation wheat and meadow treatments was only 1 to 2% of the continuous corn erosion. The average annual erosion during the growing and dormant seasons was quite different for the various land cover treatments. The growing season represents 42% of the year. The fallow plot erosion during this period was 77% of the total, but for the continuous corn and rotation corn plots, erosion during this period was about 97% of the total.

Most of the growing season erosion from the corn treatments occurred in seasons 1 and 2 when the corn plants were beginning growth and development. Erosion from the fallow treatment was over twice the corn treatment erosion, but erosion from the rotation wheat and meadow treatments was nearly zero for both seasons 1 and 2.

Season 3 had one-third of the average annual rainfall and about 40% of the annual runoff. There was erosion from all cover treatments.

Table 2 .--Average Annual Observed Erosion per Season, 1960-69

Season[1]	Cover Treatment					
	Fallow	Continuous Corn	Rotation Corn CWMM	Rotation Wheat CWMM	Rotation Meadow CWMM	Rotation Meadow CWMM
	t(metric)/ha					
1	6.38	2.85	1.55	<0.01	0	0
2	7.10	2.60	2.12	0	0	0
3	12.34	0.54	0.70	0.02	0.01	0.08
4	1.45	0.01	0.03	0	0	0.01
5	5.29	0.18	0.01	0.10	0.04	0.03
7	0.77	0.04	0.03	< 0.01	< 0.01	< 0.01
Growing Season[2]	25.82	5.99	4.37	0.02	0.01	0.08
Dormant Season[3]	7.51	0.23	0.07	0.10	0.04	0.04
Annual Total	33.33	6.22	4.44	0.12	0.05	0.12

1/ Seasons are defined in Table 1.

2/ Seasons 1, 2, and 3 combined.

3/ Seasons 4, 5, and 7 combined.

In season 3, when the corn growth and ground cover were maximum, the fallow treatment erosion was about 20 times the corn erosion. Thirty-seven percent of the fallow erosion occurred in season 3.

Season 4, after corn harvest, was a relatively minor season for erosion for all treatments; however, the fallow erosion was much greater than the rest of the treatments because of the absence of plant residues or growth on the fallow plot. In the following season, season 5, the fallow treatment erosion was nearly 30 times the continuous corn treatment. The rotation corn treatment erosion for season 5 was only about 7% of the continuous corn erosion. In this period, the rotation corn treatment was still in meadow sod in the four-year rotation sequence. Season 7 erosion was a small part of the annual erosion for all the treatments.

Runoff and Erosion, 1971-1976

The rainfall, runoff, and erosion data for the years 1971-1976 were summarized in a manner similar to the 1960-1969 data previously discussed. One difference in the season definitions was the inclusion of fall plowing as another season definition. Season 4 previously defined as post-harvest to the end of the calendar year was divided into seasons 4A and 4B. Season 4A (October 15 to November 6) is the post-harvest to fall plow period and season 4B (November 6 to December 31) is the fall plow to the end of the calendar year period.

The 1971-1976 data all represent land cover of continuous corn grown for grain or for silage. For the grain plots, all crop residues after harvest were left on the plot. The four primary tillage treatments on the corn grain plots resulted in different runoff amounts. As shown in Table 3, average annual runoff for the spring-plow treatment was 142 mm. The fall-plow runoff was only 80% and the field cultivation treatment runoff was 90% of the spring-plow treatment runoff. However, the no-till treatment runoff of 171 mm was 20% greater than the spring plow runoff.

For the two silage corn treatments which were no-till planted, all the corn plant above ground was removed. Small grain was seeded on one silage treatment to provide a winter cover for comparison. The treatment with the winter cover had one-half the average annual runoff of the silage plot with crop residues removed. The no-till silage plot with winter cover had the lowest no-till treatment runoff and was comparable to the field cultivation corn grain treatment where stalk residues provided surface cover.

Compared to the spring plow corn grain treatment runoff, the growing season runoff for fall plow was nearly the same. However, the runoff for seasons 4B and 5 in the dormant season was much lower for the fall plow than the spring plow treatment. In season 7, from spring plowing to planting, the opposite was observed.

Compared to the spring plow corn grain treatment runoff, the growing season runoff for the field cultivation treatment was nearly the same. There was some reduction in runoff in the dormant season for the field cultivation treatment, which maintained a greater amount of crop residues on the soil surface throughout the year.

Table 3 .--Average Annual Observed Rainfall and Runoff per Season from Continuous Corn 1971-1976

Season[1/]	Rainfall[2/]	Corn Harvested for Grain: Spring Plow	Corn Harvested for Grain: Fall Plow	Corn Harvested for Grain: Field Cultivation	No Primary Tillage: Crop Residue (Corn Harvested for Grain)	No Primary Tillage: Winter Cover (Harvested for Silage)	No Primary Tillage: No Crop Residue (Harvested for Silage)
	mm	mm	mm	mm	mm	mm	mm
1	85	12	16	9	11	11	18
2	105	12	10	15	24	15	23
3	274	22	19	20	26	16	58
4A	64	2	2	2	3	<1	13
4B	121	18	8	10	24	6	29
5	202	71	46	63	65	67	92
7	98	5	14	9	18	14	24
Growing Season[3/]	464	46	45	44	61	42	99
Dormant Season[4/]	485	96	70	84	110	87	158
Annual Total	949	142	115	128	171	129	257

1/ Season Definition and Average Calendar Period

Season Definition	Average Calendar Period
1 - 0 to 30 days after planting,	(May 14 - June 14)
2 - 31 to 60 days after planting,	(June 15 - July 15)
3 - 61 days after planting to harvest,	(July 16 - October 15)
4A - harvest to fall plow,	(October 15 - November 6)
4B - fall plow to end of year,	(November 6 - December 31)
5 - first of year to spring plow,	(January 1 - April 10)
7 - spring plow to planting,	(April 10 - May 14)

2/ Includes irrigation applications in seasons 2 and 3 to supplement rainfall.

3/ Seasons 1, 2, and 3 combined.

4/ Seasons 4A, 4B, 5, and 7 combined.

Runoff from the no-till corn grain treatment was 32% greater than runoff from the spring plow treatment during the growing season and 15% greater in the dormant season. Compared to the spring plow treatment in the growing season, the soil of the no-till treatment was more consolidated and had more surface sealing due to weathering, rainfall, and farm equipment traffic. The soil on the spring plow treatment was tilled periodically by plowing and weed cultivation, which provided for less consolidation of the soil surface condition.

For all seasons, the silage corn treatment with crop residues removed had greater runoff than the silage corn treatment with a small grain winter cover. This was most evident in seasons 3, 4A, and 4B during the time after silage harvest when there was no soil cover on this treatment.

Average annual erosion per season for 1971-1976 for continuous corn under various tillage-residue treatments previously described is tabulated in Table 4. The average annual erosion of the no-till corn grain treatment was .73 metric ton/hectare, which was the lowest erosion of all corn land use treatments tested. Erosion of .80 metric ton/hectare from the no-till silage corn with a seeded winter cover crop was similar to the no-till corn grain results. The no-till silage corn treatment without crop residues on the soil had the highest average annual erosion of 21.45 metric ton per hectare. Of the three different primary tillage treatments for corn grown for grain, the field cultivation treatment had the lowest average annual erosion of 1.86 metric ton/hectare, the spring plow treatment had the next lowest erosion of 2.84 metric ton/hectare, and the fall plow treatment had the greatest erosion of 7.84 metric ton/hectare. For these three primary tillage treatments, 45 to 63% of the annual erosion occurred in season 1, within one month after planting,

Table 4.--Average Annual Observed Erosion per Season from Continuous Corn 1971-1976

Season[1/]	Corn Harvested for Grain					Harvested for Silage
				No Primary Tillage		
	Spring Plow	Fall Plow	Field Cultivation	Crop Residue	Winter Cover	No Crop Residue
	t(metric)/ha					
1	1.80	4.48	0.84	0.15	0.10	2.68
2	0.34	0.48	0.35	0.26	0.12	2.36
3	0.25	0.37	0.12	0.10	0.15	1.45
4A	0.01	0.01	<0.01	0	0.02	0.75
4B	0.07	0.05	0.05	0.02	0.01	0.71
5	0.28	1.00	0.25	0.10	0.31	7.88
7	0.09	1.45	0.25	0.10	0.09	5.62
Growing Season[2/]	2.39	5.33	1.31	0.51	0.37	6.49
Dormant Season[3/]	0.45	2.51	0.55	0.22	0.43	14.96
Annual Total	2.84	7.84	1.86	0.73	0.80	21.45

1/ Seasons are defined in Table 3.

2/ Seasons 1, 2, and 3 combined.

3/ Seasons 4A, 4B, 5 and 7 combined.

but only 7 to 14% of the annual runoff occurred in this season. For the no-till treatment of corn grown for grain, only 12 to 21% of the annual erosion occurred in season 1.

Dormant or winter season erosion for the fall plow treatment was greater than dormant season erosion for all the other treatments which had soil cover from either crop residues or seeded small grain.

The tolerable annual soil loss for the Mexico soil type is about 6.6 metric ton per hectare (4). Considering all treatments studied in 1960-1969 and 1971-1976, the tolerable soil loss was exceeded by only three treatments. The fallow cover (which was an experimental reference treatment and not an agricultural practice), the fall plow continuous corn, and the no-till silage corn with all crop residues removed (not an extensive practice) were treatments with excessive erosion. Erosion from the common practice of spring plow continuous corn was less than the tolerable soil loss for this 16-year study period. The 16-year average annual rainfall was nearly the same as the long-term 87-year average for this area, and the 16-year average annual erosion index (EI) factor of the Universal Soil Loss Equation (6) was 3.7% greater.

Prediction of Erosion from Continuous Corn Land Use

The Universal Soil Loss Equation (USLE) is one method of predicting soil erosion from upland field areas (7). It was designed to predict long-time average erosion from specific land cover-management systems. It is proposed to compute average soil loss for particular cropstage seasons within a crop year. Erosion is predicted by USLE as a product of five factors by the equation:

$$A = R * K * LS * C * P, \quad t/ac$$

where

R = rainfall erosion index factor

K = soil erodibility factor

LS = slope length-steepness factor

C = cover-management factor

P = conservation support practice factor

For the study erosion plots, the equation simplifies to:

$$A = R * .28 * .31 * C * 1$$

$$= .0868 * R * C$$

The C factors for each cropstage period for spring-plowed continuous corn, with good management and high productivity were obtained from Handbook 537 to represent the study plot conditions. Seasonal C factors are listed in Table 5.

R values were determined from detailed rain data obtained from a recording rain gage adjacent to the plot study location. For the period 1963-1969, the rain events which produced runoff were determined. The R values for all rain events producing runoff each season of each year were determined and annual soil loss per season was computed. The average annual observed erosion, and USLE predicted erosion for each season are tabulated in Table 6. Average annual total erosion predicted by USLE was 16% higher than the observed. Except for season 2, USLE predicted erosion was more than the season average observed erosion for all seasons. In season 2 there were several large events observed in 1969 which were the greatest erosion amounts for all events observed. A regression of USLE predicted and observed event erosion is shown in Figure 1. Over one-half the data points are clustered near the origin

Table 5.--USLE Seasonal C Factors for Continuous Corn

Season	Crop Stage Periods	C Factor (High Productivity)
1	Seedbed, (Planting to 10% Canopy, 20 Da)	.55
2	Establishment, (10% Canopy to 50% Canopy, 20 Da)	.48
3A	Development, (50% Canopy to 75% Canopy, 20 Da)	.38
3B	Maturation, (75% Canopy to Harvest)	.20
4-5	Residue, (Harvest to Plowing)	.23
7	Rough Fallow, (Plowing to Planting)	.31

Table 6.--Average Annual Observed and Predicted Erosion Per Season From Continuous Corn 1963-1969

Season[1/]	Observed	USLE Predicted	MUSLE Predicted
	----------t(metric)/ha----------		
1	1.72	2.32	1.83
2	5.37	2.40	3.27
3A	.16	.46	.16
3B	.74	3.31	1.49
4-5	.22	.90	.48
7	.04	.21	.04
Growing Season[2/]	7.99	8.49	6.75
Dormant Season[3/]	.26	1.11	.52
Annual Total	8.25	9.60	7.27

1/ Season Definition and Average Calendar Period

Season Definition	Average Calendar Period
1 - 0 to 20 days after planting,	(May 19 - June 3)
2 - 21 to 40 days after planting,	(June 4 - June 22)
3A - 41 to 60 days after planting,	(June 23 - July 12)
3B - 61 days after planting to harvest,	(July 13 - October 19)
4-5 harvest to spring plow	(October 19 - April 23)
7 - spring plow to planting	(April 23 - May 14)

2/ Seasons 1, 2, 3A, and 3B combined.

3/ Seasons 4-5 and 7 combined.

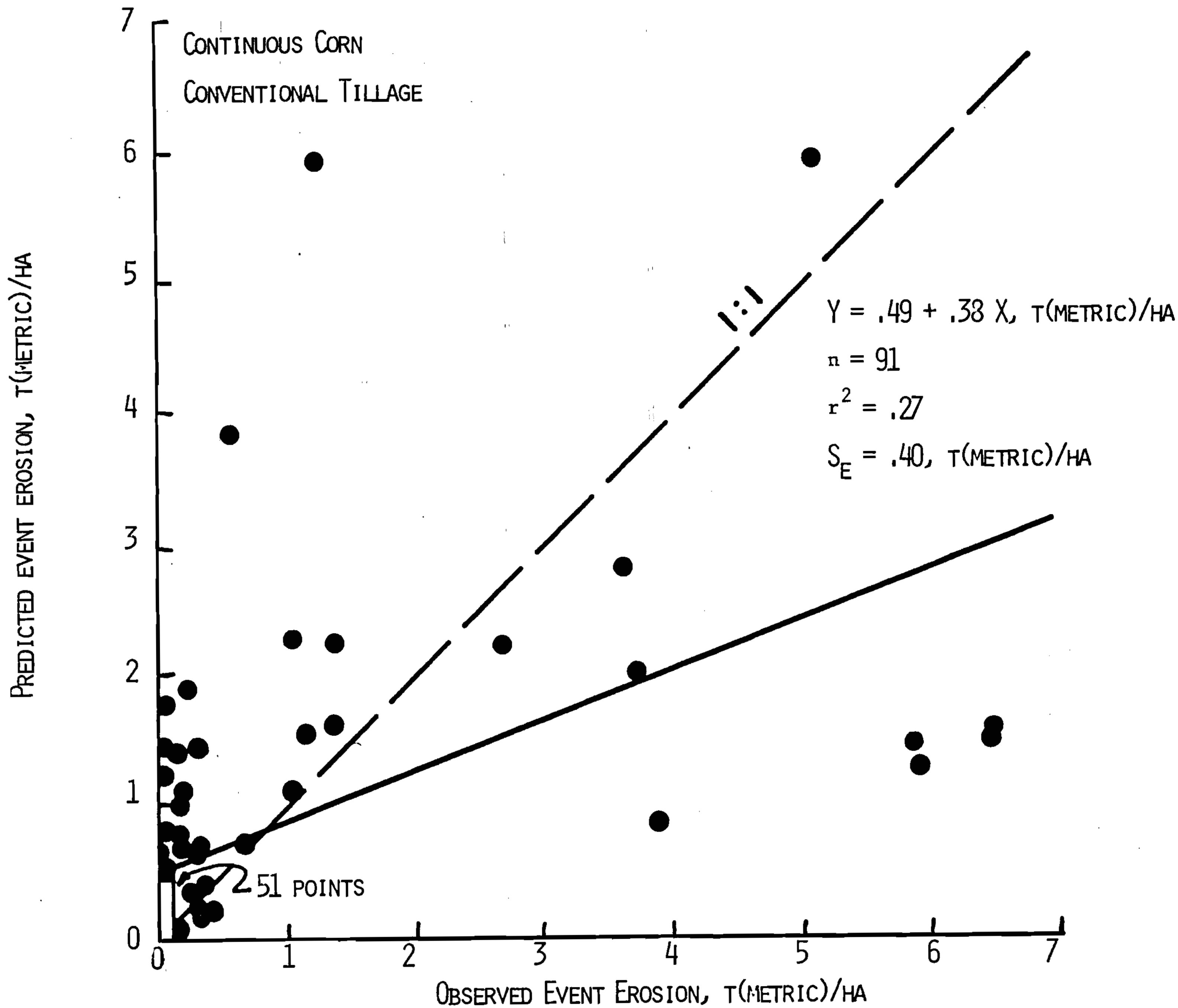

Figure 1. USLE Predicted vs Observed Event Erosion, 1963-1969

was the USLE predicted erosion.

A scatter graph of the observed and MUSLE predicted event erosion is shown in Figure 2. Over half of the points are clustered near the origin. A regression of predicted erosion with observed erosion resulted in an r^2 of .77. The MUSLE equation provided a better prediction of event erosion method than the USLE equation. However, for the largest events there was still considerable scatter and a bias toward under-prediction of large event erosion.

Summary and Conclusions

Water yield and erosion data from 88 m^2 claypan soil research plots were evaluated to determine land use treatment effects. For a 10-year study period (1960-1969), land use treatments of fallow, continuous corn, and a four-year rotation of corn, wheat, meadow, meadow were maintained each year. For a 6-year study period (1971-1976), continuous corn land use with different tillage-residue management treatments were maintained each year. For corn grown for grain with stalk residues left on the ground, primary tillage treatments of spring plow, fall plow, spring field cultivation, and no-till planting were performed. For corn grown for silage with no-till planting, two soil cover management treatments were performed. All plant portions above ground were removed for silage in one treatment and a rye winter cover crop was sown after silage harvest for the second treatment.

Average annual rainfall plus irrigation was about the same as the long-term, 87-year average rainfall for both study periods. The average annual erosion index (EI) of the USLE was 3.7% greater than expected for the combined study period.

of the scatter plot. There is considerable scatter in the event data. These results were not unexpected since the USLE equation is not proposed for event erosion prediction. The coefficient of determination, r^2, value for the regression equation was .27. The regression coefficients suggest the USLE equation over-predicts small events and under-predicts large events.

A modification of USLE was proposed by Williams (5) to predict event runoff. In the Modified Soil Loss Equation (MUSLE), the rainfall factor was replaced with a runoff factor. The MUSLE equation is:

$$S = 95 * (Q * q)^{.56} * K * LS * C * P \quad , \quad \text{ton}$$

where

Q = runoff event volume, ac/ft

q = runoff event peak rate, ft^3/sec

The other equation factors were previously defined for the USLE equation.

The MUSLE equation was also applied to the continuous corn runoff events for the period 1963-1969 when flume records were available to determine peak flow rates. The average annual predicted erosion per season is listed in Table 6. The average annual total erosion predicted by MUSLE was 12% less than the observed; however, the predicted erosion was lower than the observed erosion only in season 2. In all the other seasons, average predicted erosion was equal or greater than observed erosion. As previously discussed, season 2 included large erosion events of the study period. In all seasons, the MUSLE predicted average annual season erosion was closer to the observed erosion than

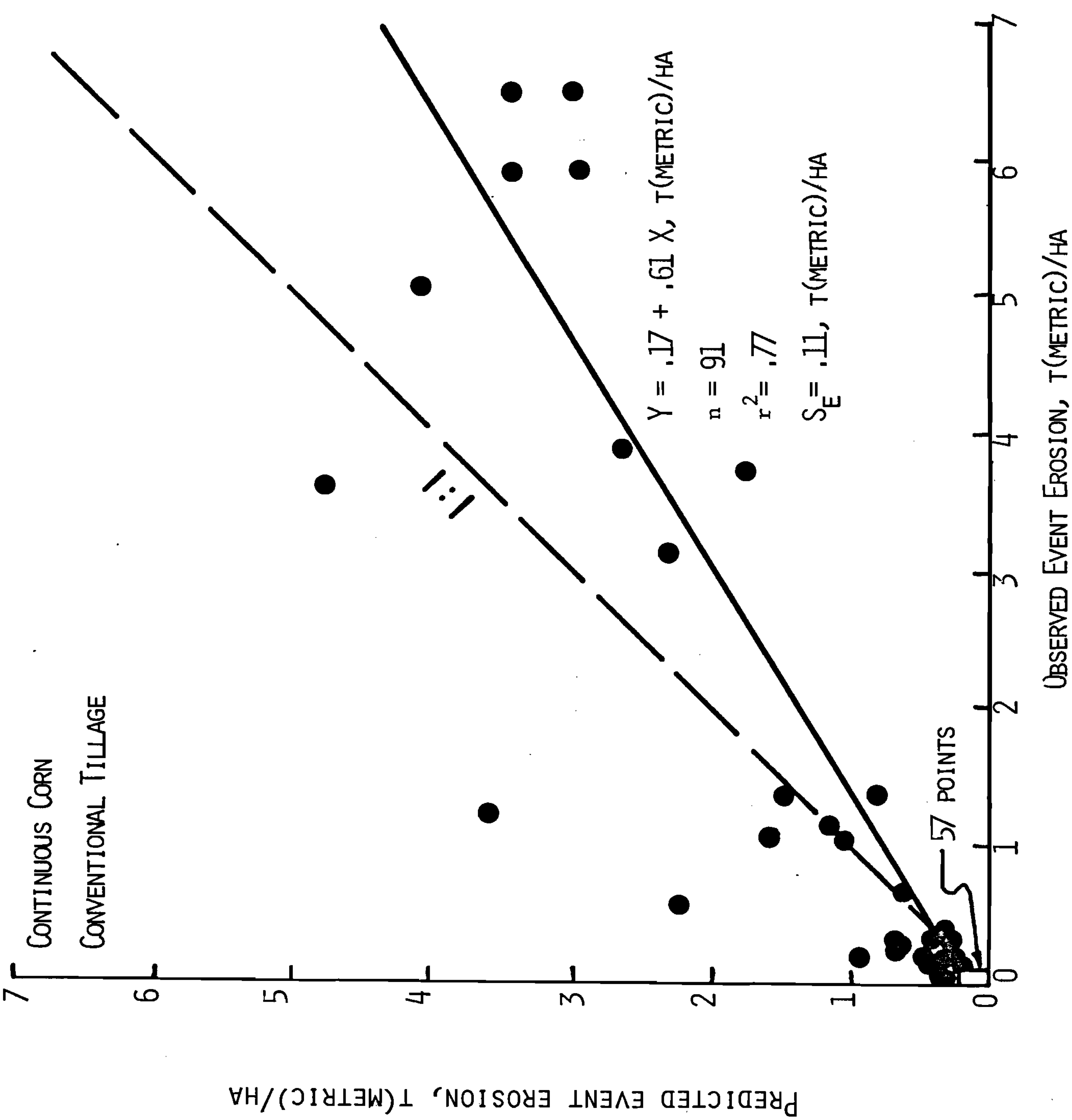

FIGURE 2. MUSLE PREDICTED VS OBSERVED EVENT EROSION 1963-1969

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