Runoff and Erosion as Affected by Sorghum and Soybean Residue

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ABSTRACT

A rainfall simulator was used to measure the effects of varying rates of sorghum and soybean residue on runoff and erosion. In general, increased surface cover caused reduced runoff, sediment concentration and soil loss. Substantial reductions in erosion resulted from the use of small amounts of crop residue.

Regression equations were obtained which related surface cover to residue mass. Equations describing relative runoff, sediment concentration and soil loss as a function of surface cover were also developed. Runoff, sediment concentration and soil loss were all found to be highly correlated to surface cover.

INTRODUCTION

As a result of raindrop impact, a thin surface seal with decreased infiltration capacity may develop near the soil surface (Epstein and Grant, 1967). Soil compaction by impacting raindrops is reduced by crop residue and thus greater infiltration rates are maintained (Mannering and Meyer, 1963). Maintenance of infiltration rate could result in smaller discharge rates (Kramer and Meyer, 1969).

A portion of the soil surface is protected from raindrop impact by residue cover, thus reducing soil detachment (Mannering and Meyer, 1963). Smaller runoff velocities caused by residue could decrease the transport capacity of flow. Reduced sediment concentration could result from both of these factors.

Small ponds in which sedimentation may occur are created by crop residue (Brenneman and Laflen, 1982). The cumulative effect caused by a large number of ponds can be substantial, even though the volume of water stored in individual ponds may be small. Thus, reductions in runoff and sediment concentration caused by crop residue may serve to decrease soil loss.

Wheat straw residue has been utilized in several rainfall simulation studies (Mannering and Meyer, 1963; Meyer et al., 1970; Lattanzi et al., 1974; Harmon and Meyer, 1978; and Dickey et al., 1983). Numerous rainfall simulation investigations have been conducted using varying rates of corn residue (Meyer and Mannering, 1961; Wittmuss and Swanson, 1964; Laflen et al., 1978; Hussein and Laflen, 1982; Dickey et al., 1984; and Gilley et al., 1986). Erosion and runoff as affected by soybean residue on various tillage systems have also been examined (Laflen and Colvin, 1981; Hussein and Laflen, 1982; and Dickey et al., 1985).

Different tillage systems were used in several of the previous studies on the effects of crop residue on runoff and erosion. Many interrelated crop management factors dictate the quantity of residue found on the soil surface for a given tillage system at a particular time. Not only residue cover, but also varying soil and crop-management conditions may influence differences in erosion and runoff rates between tillage systems.

Surface residue was examined as an experimental variable in the present study without other compounding crop management factors. Antecedent soil water content and crop residue rate were the two principal variables examined in the present investigation. The objective of this study was to determine the effects of varying rates of unanchored sorghum and soybean residue on runoff, sediment concentration and soil loss for uniform soil conditions.

PROCEDURE

The study was conducted at the University of Nebraska Rogers Memorial Farm in Lancaster County, approximately 18 km east of Lincoln, NE. The Sharpsburg soil at the site (Typic Argiurdolls, fine, montmorillonitic, mesic) formed in loess under prairie vegetation. Average slope at the location was 6.4%.

Corn residue on the soil surface was first removed. The area was then plowed, disked and roto-tilled to depths of approximately 20, 13 and 8 cm, respectively. Following tillage, the plots were covered with plastic to maintain similarity in soil water conditions.

Prior to simulation testing, sorghum and soybean residue was returned to the plot surface by hand in a random orientation at rates of 0.00, 0.84, 1.68, 3.36, 6.73 and 13.45 t/ha. Two replications of each residue rate were used. The residue remained on the surface in an unanchored condition. Residue cover was measured using the point quadrant method (Mannering and Meyer, 1963). Plots were 3.7 m across the slope by 22.1 m long.

A portable rainfall simulator designed by Schulz and Yevjevich (1970) was used to apply rainfall for a one hour duration at an intensity of approximately 48 mm/h. The first rainfall application (initial run) occurred at existing soil-water conditions. A wet rainfall simulation run was then conducted approximately 24 h later.

Average application rates were determined by collecting rainfall in 2.5 cm wide channels placed diagonally at four locations across each of the plots. A trough extending across the bottom of each plot gathered

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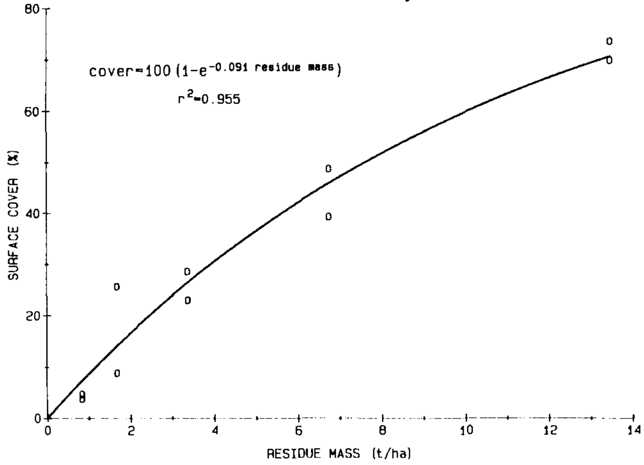

Fig. 1—The relationship between surface cover and residue mass for sorghum.

runoff, which was measured using an HS flume with stage recorder. Runoff samples for sediment content determinations were collected at five minute intervals during the runoff events. Additional information on rainfall intensity, runoff and soil loss measuring procedures is given by Meyer, 1960.

RESULTS

Surface cover—residue mass relationships obtained using regression analysis are presented below. The effect of sorghum and soybean residue on runoff, sediment concentration and soil loss is evaluated. Equations describing relative runoff, sediment concentration and soil loss as a function of surface cover are also given.

Surface Cover

Placement of sorghum residue at rates of 0.84, 1.68, 3.36, 6.73 and 13.45 t/ha produced an average surface cover of 4, 17, 26, 44 and 72%, respectively, as shown in Fig. 1. The data presented in Fig. 1 were used to develop the following regression equation:

$$\text{Sorghum surface cover} = 100\,(1 - e^{-0.091\ \text{residue mass}}) \quad \ldots\ldots [1]$$

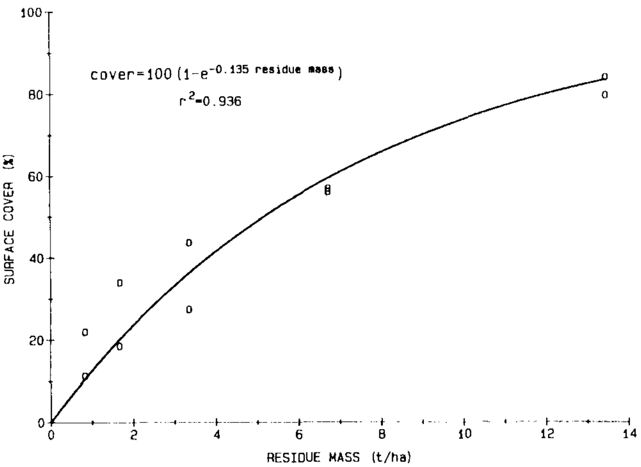

Fig. 2—The relationship between surface cover and residue mass for soybeans.

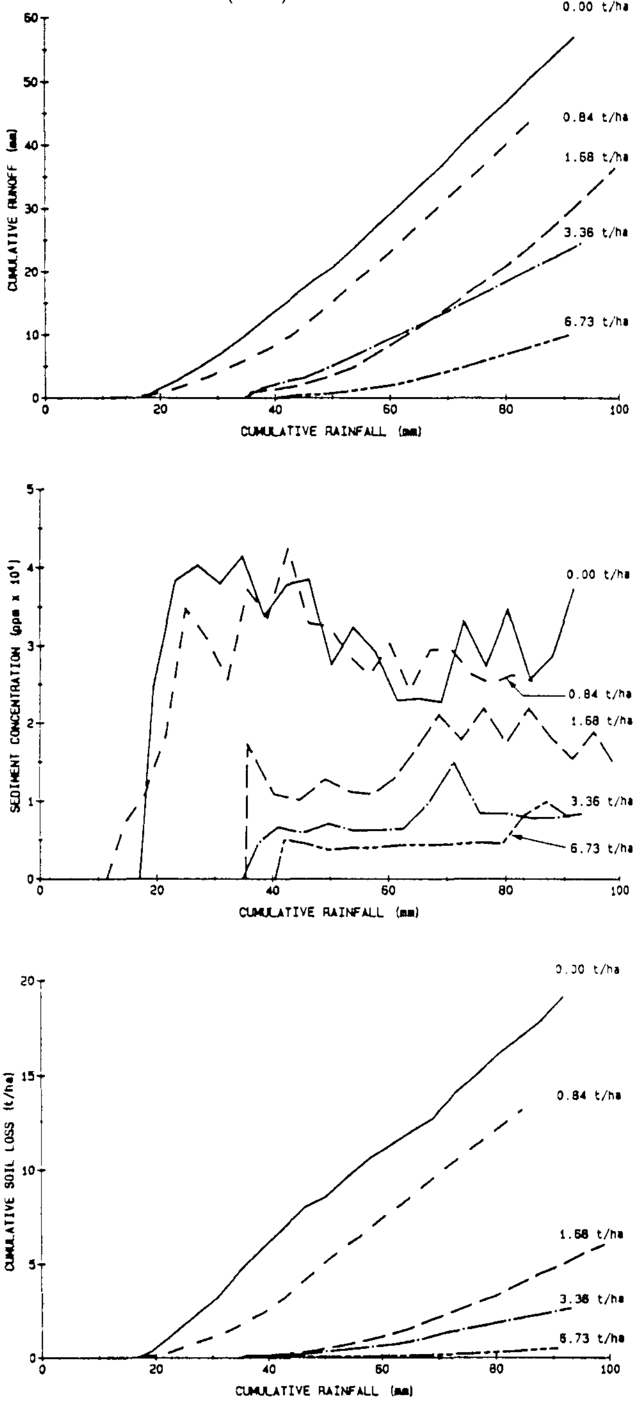

Fig. 3—The relationship between cumulative runoff, sediment concentration and cumulative soil loss and cumulative rainfall for five sorghum residue treatments.

where surface cover is given as a percentage and sorghum residue mass is measured in t/ha. The coefficient of determination, r^2, for the above equation is 0.955.

Average surface cover of 17, 27, 36, 56 and 82% was produced by placement of soybean residue at rates of 0.84, 1.68, 3.36, 6.73 and 13.45 t/ha, respectively, as shown in Fig. 2. The following regression equation was obtained from data presented in Fig. 2:

$$\text{Soybean surface cover} = 100\,(1 - e^{-0.135\ \text{residue mass}}) \quad \ldots\ldots [2]$$

where soybean residue mass is measured in t/ha and

TABLE 1. RUNOFF, RUNOFF RATE, SEDIMENT CONCENTRATION, SOIL LOSS AND SOIL LOSS RATE FOR SIX SORGHUM RESIDUE TREATMENTS.*

Residue rate, t/ha	Runs	Runoff, mm	Runoff rate, mm/h†	Sediment concentration, ppm x 10^3	Soil loss, t/ha	Soil loss rate, t/ha h†
0.00	All runs	56.9a‡	35.4a	31.5a	19.10a	14.01a
0.84	All runs	43.9ab	29.5a	27.5a	13.15ab	9.53b
1.68	All runs	36.2ab	28.3a	12.8b	6.03bc	4.34c
3.36	All runs	34.0b	22.8ab	6.7bc	2.63c	2.38cd
6.73	All runs	9.9c	9.7bc	5.1bc	0.51c	0.57cd
13.45	All runs	0.0c	0.0c	0.0c	0.00c	0.00d
0.00	Initial	18.4a	32.5a	34.3a	8.00a	13.55a
0.84	Initial	9.9ab	22.2ab	26.8ab	3.22a	9.41ab
1.68	Initial	4.8b	18.3abc	8.2bc	0.70a	3.06ab
3.36	Initial	2.4b	20.9ab	5.1c	0.13a	1.40b
6.73	Initial	0.5b	5.3bc	4.8c	0.03a	0.24b
13.45	Initial	0.0b	0.0c	0.0c	0.00a	0.00b
0.00	Wet	38.5a	38.2a	28.7a	11.10a	14.47a
0.84	Wet	34.0a	36.7a	28.1a	9.93a	9.64ab
1.68	Wet	31.4a	38.2a	17.3ab	5.33ab	5.61bc
3.36	Wet	31.6a	24.6a	8.3bc	2.50	3.35bc
6.73	Wet	9.4b	14.0b	5.4bc	0.48b	0.90bc
13.45	Wet	0.0b	0.0c	0.0c	0.00b	0.00c

*Plots were 3.7 by 22.1 m with an average slope gradient of 6.4%. Values given are the average of two replications. Runs lasted for a 60-min duration. Rainfall intensity was approximately 48 mm/h.

† Average rate during the final 5 min of the run. Averages were calculated only for those runs in which runoff occurred.

‡Within each type of run and for each column, differences are significant at the 5% level (Duncan's multiple range test) if the same letter does not appear.

surface cover is given as a percentage. For the above equation, a coefficient of determination of 0.936 was obtained.

Equations [1] and [2] were derived for estimating surface cover for residue which had undergone winter weathering. Much of the leaf material, especially for the soybean residue, was no longer present at time of collection. Regression equations relating residue mass at harvest to surface cover would probably be different from equations [1] and [2].

Runoff

Cumulative runoff for each of the sorghum treatments is shown in Fig. 3. Cumulative rainfall varied between treatments because of differences in rainfall intensity induced principally by wind. The 1.68 and 3.36 t/ha

TABLE 2. RUNOFF, RUNOFF RATE, SEDIMENT CONCENTRATION, SOIL LOSS AND SOIL LOSS RATE FOR SIX SOYBEAN RESIDUE TREATMENTS.*

Residue rate, t/ha	Runs	Runoff, mm	Runoff rate, mm/h†	Sediment concentration, ppm x 10^3	Soil loss, t/ha	Soil loss rate, t/ha h†
0.00	All runs	56.9a‡	35.4a	31.5a	19.10a	14.01a
0.84	All runs	51.0ab	33.6a	22.3a	12.18b	9.96a
1.68	All runs	33.7bc	28.5a	10.9b	4.03c	3.42b
3.36	All runs	39.3ab	29.1a	7.8bc	3.04c	2.65b
6.73	All runs	14.4cd	11.5b	3.7bc	0.46c	0.34b
13.45	All runs	0.0cd	0.0c	0.00c	0.00c	0.00b
0.00	Initial	18.4a	32.5a	34.3a	8.00a	13.55a
0.84	Initial	17.2a	32.1a	21.6ab	4.42a	10.57a
1.68	Initial	10.4ab	26.1a	11.9bc	1.52a	3.84a
3.36	Initial	6.3ab	20.0a	8.3bc	0.66a	3.04a
6.73	Initial	0.4b	2.0b	4.3bc	0.03a	0.09a
13.45	Initial	0.0b	0.0b	0.0c	0.00a	0.00a
0.00	Wet	38.5a	38.2a	28.7a	11.10a	14.47a
0.84	Wet	33.8ab	35.0a	22.9b	7.76a	9.35ab
1.68	Wet	23.3bc	30.8a	9.9c	2.51b	2.99bc
3.36	Wet	33.0ab	38.2a	7.3cd	2.38b	2.25bc
6.73	Wet	14.0c	20.9b	3.1de	0.43b	0.59c
13.45	Wet	0.0d	0.0c	0.0e	0.00b	0.00c

*Plots were 3.7 by 22.1 m with an average slope gradient of 6.4%. Values given are the average of two replications. Runs lasted for a 60-min duration. Rainfall intensity was approximately 48 mm/h.

† Average rate during the final 5 min of the run. Averages were calculated only for those runs in which runoff occurred.

‡Within each type of run and for each column, differences are significant at the 5% level (Duncan's multiple range test) if the same letter does not appear.

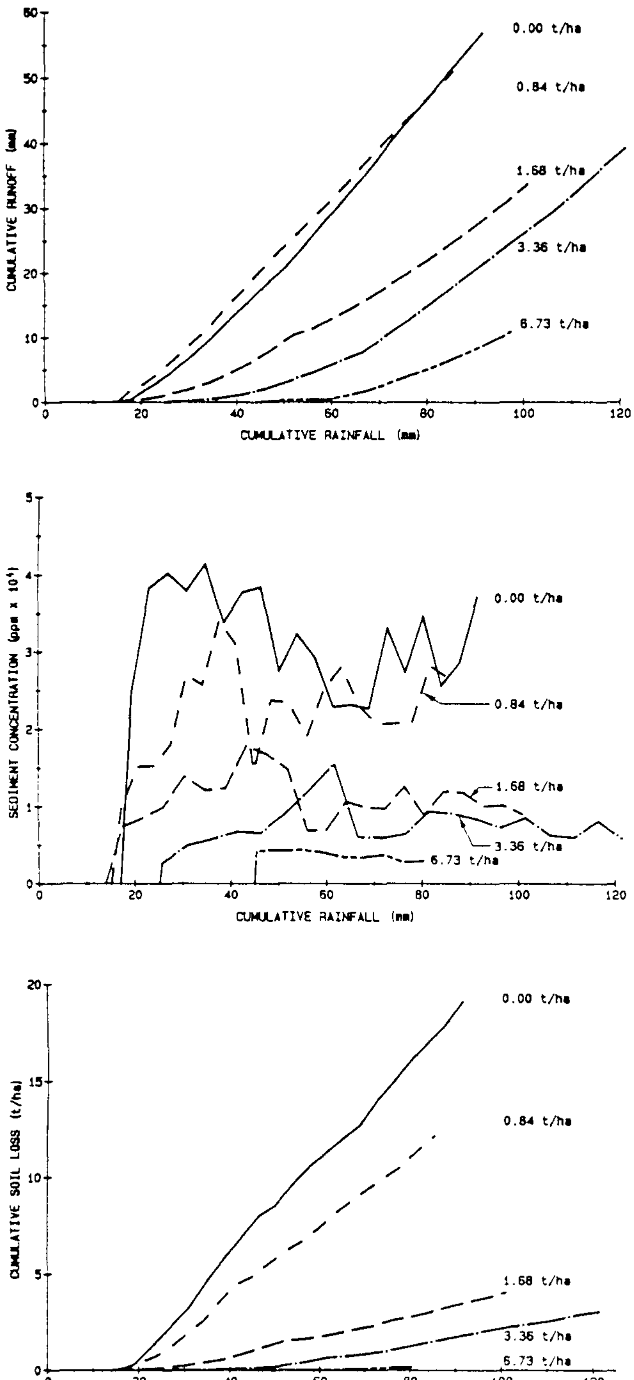

Fig. 4—The relationship between cumulative runoff, sediment concentration, and cumulative soil loss and cumulative rainfall for five soybean residue treatments.

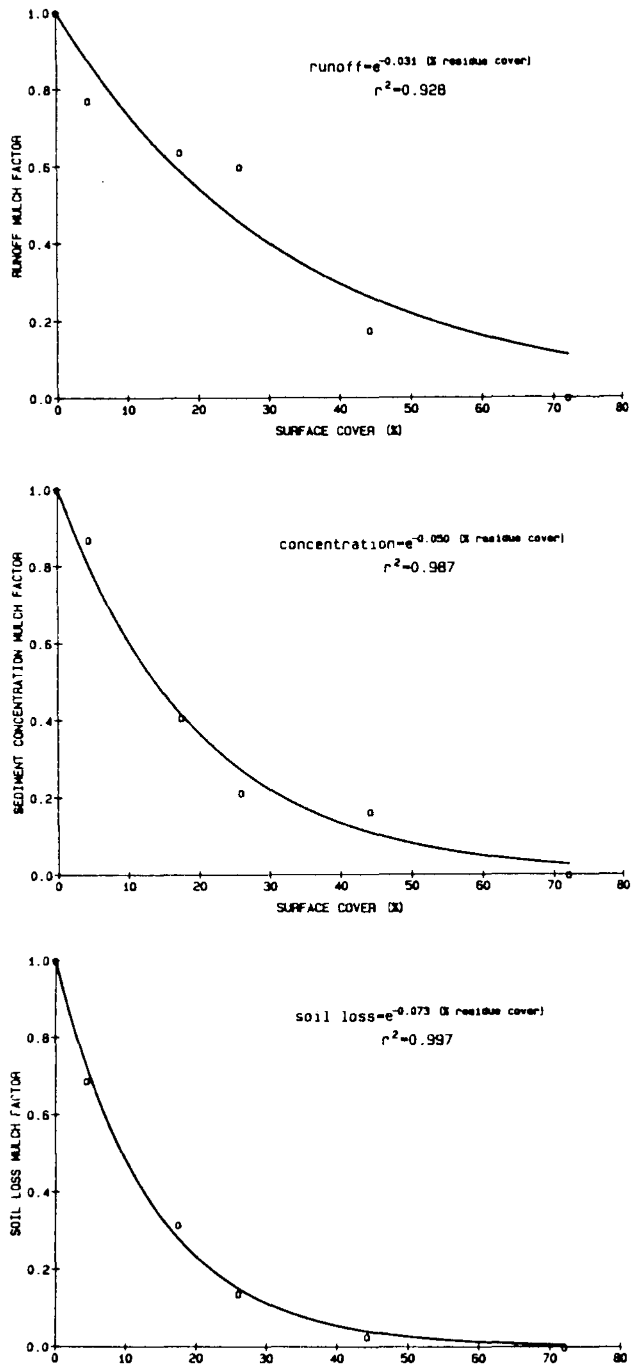

Fig. 5—The relationship between runoff, sediment concentration and soil loss mulch factor and sorghum surface cover.

residue treatments produced similar cumulative runoff curves. Total runoff rate during the final five minutes of each simulation run on the sorghum plots are presented in Table 1. A significant reduction in total runoff occurred for a sorghum residue rate of 3.36 t/ha. A sorghum residue rate of 13.45 t/ha prevented runoff from both simulation events.

Fig. 4 shows cumulative runoff for each of the soybean treatments. Similar cumulative runoff curves were obtained at the 0.00 and 0.84 t/ha residue rates. Table 2 presents total runoff and runoff rate during the final five minutes of each rainfall event on the soybean plots. A soybean residue rate of 1.68 t/ha produced a significant reduction in total runoff. As was true with sorghum residue, a soybean residue rate of 13.45 t/ha prevented runoff for each of the simulation events.

A runoff mulch factor—surface cover relation was obtained by dividing total average runoff for each of the residue treatments by runoff for conditions without residue. The relationships between runoff mulch factors and sorghum and soybean surface cover are shown in Figs. 5 and 6, respectively. For sorghum surface cover given as a percentage, the following relation was obtained:

Sorghum runoff mulch factor

$$= e^{-0.031\ (\%\ \text{residue cover})} \quad \ldots\ldots\ldots\ldots\ldots [3]$$

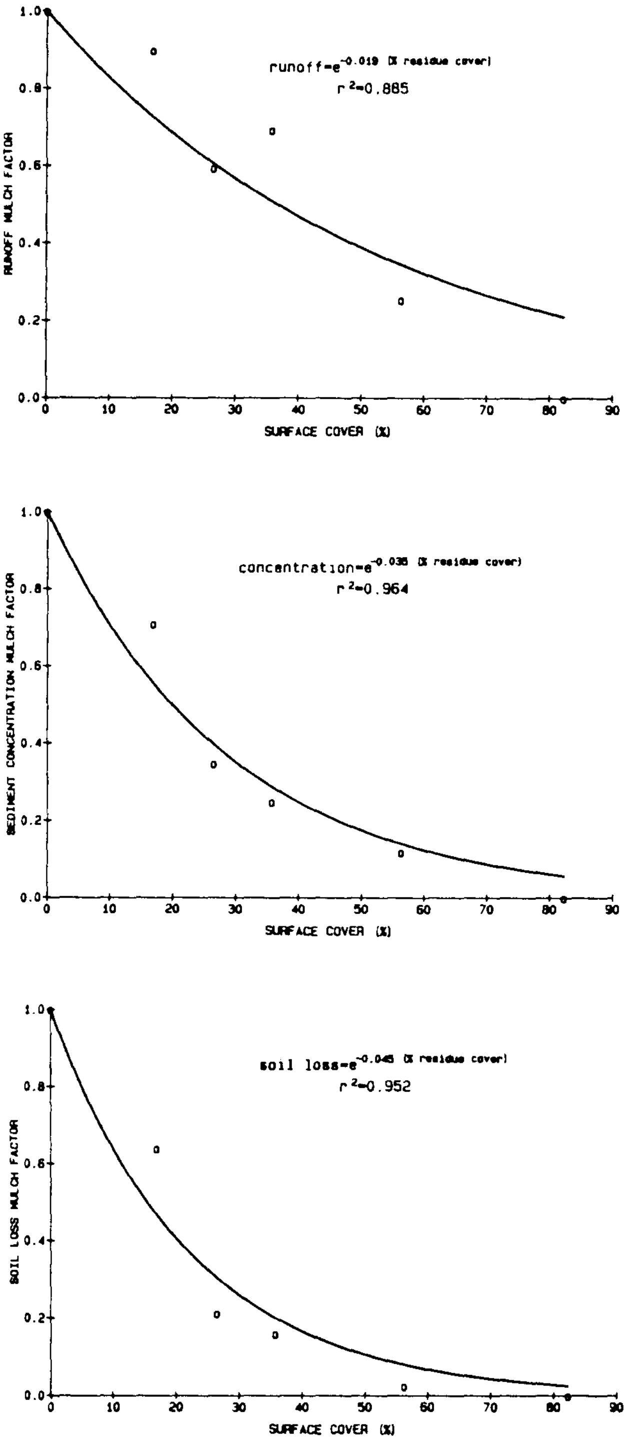

Fig. 6—The relationship between runoff, sediment concentration and soil loss mulch factor and soybean surface cover.

which has a coefficient of determination of 0.928.

The following equation was developed for soybean residue:

$$\text{Soybean runoff mulch factor} = e^{-0.019\,(\%\ \text{residue cover})} \quad \ldots\ldots\ldots\ldots\ldots [4]$$

The coefficient of determination of the above relation is 0.885. The reported runoff mulch factors are dependent upon study site characteristics, slope gradient and rainfall intensity and duration.

Sediment Concentration

Sediment concentration of runoff versus cumulative rainfall for the various sorghum residue treatments is shown in Fig. 3. Sediment concentration was found to be similar for the 0.00 and 0.84 t/ha residue treatments. Average sediment concentration for each of the simulation runs on the sorghum plot is reported in Table 1.

Fig. 4 shows the effects of cumulative rainfall on sediment content for each of the soybean residue treatments. In general, reductions in sediment concentration resulted from increased application of residue. Table 2 presents average sediment concentration for the soybean plots. An application rate of 1.68 t/ha produced significant reductions in average sediment concentration for both sorghum and soybean residue.

Sediment concentration for each of the residue treatments was divided by sediment concentration for conditions without residue to obtain sediment concentration mulch factors. Fig. 5 contains sediment concentration mulch factors used to develop the following equation for sorghum residue:

$$\text{Sorghum sediment concentration mulch factor} = e^{-0.050\,(\%\ \text{residue cover})} \quad \ldots\ldots\ldots\ldots\ldots [5]$$

where surface cover is given as a percentage. The coefficient of determination for the above equation is 0.987.

Information presented in Fig. 6 was used to develop a sediment concentration mulch factor for soybean residue. For surface cover given as a percentage, the following relation was obtained:

$$\text{Soybean sediment concentration mulch factor} = e^{-0.035\,(\%\ \text{residue cover})} \quad \ldots\ldots\ldots\ldots\ldots [6]$$

which has a coefficient of determination of 0.964. Figs. 5 and 6 demonstrate the relative effectiveness of surface residue in reducing sediment content of runoff for the given experimental conditions.

Soil Loss

Cumulative soil loss versus cumulative rainfall for the sorghum residue treatments is also given in Fig. 3. Reduced soil loss rates resulted from both increased infiltration and reduced sediment content of runoff. Total soil loss and soil loss rate during the final five minutes of each simulation run on the sorghum plots are given in Table 1. A sorghum residue rate of 1.68 t/ha produced a significant reduction in total soil loss.

Fig. 4 shows cumulative soil loss for each of the soybean treatments. Consistent reductions in soil loss can be seen to have resulted from increased application of residue. Table 2 shows total soil loss and soil loss rate during the final five minutes of each simulation run on the soybean treatments. A significant reduction in total soil loss occurred for a soybean residue rate of 0.84 t/ha.

A soil loss mulch factor was obtained by dividing total soil loss for each of the residue treatments by soil loss for conditions without residue. The relationship between soil loss mulch factor and surface cover for sorghum residue is presented in Fig. 5. For surface cover given as a percentage, the following relation was obtained:

Sorghum soil loss mulch factor

$$= e^{-0.073\ (\%\ \text{residue cover})} \quad \ldots\ldots\ldots\ldots\ldots [7]$$

which has a coefficient of determination of 0.997.

For soybean residue, the following equation, shown in Fig. 6, was developed:

Soybean soil loss mulch factor

$$= e^{-0.045\ (\%\ \text{residue cover})} \quad \ldots\ldots\ldots\ldots\ldots [8]$$

The coefficient of determination of the above relation is 0.952. The relative effectiveness of surface residue in reducing erosion for the given experimental conditions is shown in Figs. 5 and 6.

SUMMARY AND CONCLUSIONS

A rainfall simulator was used to measure runoff and erosion from plots on which sorghum and soybean residue was added at rates ranging from 0.00 to 13.45 t/ha. In general, increased rates of unanchored sorghum and soybean residue resulted in reduced runoff, sediment concentration and soil loss. No runoff occurred on the plots with 13.45 t/ha of sorghum or soybean residue for the given soil and rainfall conditions.

Regression equations were developed that related surface cover to residue mass. Runoff, sediment concentration and soil loss mulch factors were determined by dividing the parameter values measured for a particular surface cover by corresponding values obtained for conditions without residue. Regression equations were identified that related runoff, sediment concentration and soil loss mulch factors to surface cover. Each of the mulch factors were found to be highly correlated to surface cover. Experimental results indicate that for a given rainfall rate, soil condition, and slope gradient, a separate mulch factor can be used to relate surface cover to runoff, sediment concentration and soil loss.

Sorghum and soybean residue were both shown to be beneficial in reducing runoff, sediment concentration and soil loss for uniform soil conditions. The effectiveness of a particular conservation tillage system is influenced by the amount of crop residue maintained on the soil surface. Maintenance of adequate surface cover can serve to protect valuable soil and water resources.

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