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Slope Length and Surface Residue Influences on Runoff and Erosion

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ABSTRACT

RUNOFF rate, runoff velocity, sediment concentration and soil loss rate of rills or overland flow channels were measured at selected downslope distances on plots with varying rates of sorghum and soybean residue. Runoff rate, runoff velocity and soil loss rate usually increased with downslope distance. In general, the presence of greater amounts of crop residue reduced sediment concentration and soil loss rate along the entire slope length. Substantial variations in runoff rate, runoff velocity, sediment concentration and soil loss rate were found with downslope distance on some residue treatments.

INTRODUCTION

Upland soil erosion is affected by many interrelated soil, crop, tillage and management factors. Identification of runoff rates and runoff velocities occurring in association with sediment concentration and soil loss rates could provide a more thorough description of the erosion process. This information would be especially useful in soil erosion models which evaluate fundamental erosion mechanisms.

Soil erosion components have been characterized in several studies. The morphologic characteristics of small rill systems and their influence on soil loss rates were examined by Mosley (1972). Young and Wiersma (1973) evaluated the relative importance of raindrop impact and flowing water to the erosion process. Field studies to measure rill erosion as affected by flow rate and canopy cover were conducted by Meyer et al. (1975). Laflen et al. (1978) determined the effect of slope length on soil loss for selected conservation tillage systems. Foster et al. (1982) identified erosion resulting from added discharge and simulated rainfall on untilled soil with various rates of cornstalk mulch. Soil loss rates for different slope lengths and tillage treatments on wheat fallow rotations were measured by Dickey et al. (1983).

Runoff rates of streams and rivers have been widely identified using dye dilution techniques. Fluorescent dyes, utilized in dye dilution procedures, are economical, easy to handle and can be measured quantitatively in very low concentrations. However, characterization of hydraulic parameters using fluorometric techniques has received only limited use on upland areas.

Information on fluorometric procedures for time-of-travel and discharge studies has been presented (Wright and Collings, 1964; Wilson, 1968; and Chase and Payne, 1970). Kilpatrick (1968) and Morgan et al. (1977) described validation of the dye-dilution technique for measurement of runoff rate. Dye requirements for slug injections into streams were also presented by Kilpatrick (1970). Smart and Laidlaw (1977) compared eight fluorescent dyes in laboratory and field experiments to assess their suitability in quantitative tracing work.

Total runoff and erosion were usually measured at a single discharge location in many of the previous erosion investigations. Limited information exists concerning variations in erosion and runoff rates with downslope distance. The objective of this study was to determine the effect of slope length and surface residue on runoff rate, runoff velocity, sediment concentration and soil loss rate.

PROCEDURE

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

Crop residues on the soil surface were first removed. The area was then plowed, disked and roto-tilled in depths of approximately 20, 13 and 8 cm, respectively. Following tillage, the plots were covered with plastic to maintain similarity in soil structure and water conditions. Plots were 3.7 m across the slope by 22.1 m long.

Prior to simulation testing, sorghum and soybean residue was returned to the plot surface in a random orientation at rates of 0.00, 0.84, 1.68, 3.36, and 6.73 t/ha. Each residue rate was used on two plots. These residue rates produced average sorghum surface cover of 0, 4, 17, 26, and 44% and soybean surface cover of 0, 17, 27, 36, and 56%, respectively. Surface cover was measured using the point quadrant method (Mannering and Meyer, 1963).

The residue rates were selected to represent the broad range of conditions found under various cropping systems. Small amounts of surface residue may produce substantial reductions in runoff and erosion as compared to bare soil conditions. Consequently, several treatments with comparatively low residue rates were chosen.

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 while the wet run was conducted

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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 runoff, which was measured using an HS flume with stage recorder.

Once steady state runoff conditions had become established during the wet simulation run, runoff samples for determining sediment concentration were obtained. Steady state runoff conditions were determined using a stage recorder and HS flume. Samples approximately 800 mL in size were collected in polyethylene bags at the point where each rill (flow area in which soil scouring had occurred) or overland flow channel (flow area in which soil scouring had not occurred) discharged into the collection trough.

Additional samples were obtained at downslope distances of 3.8, 6.8, 9.9, 12.9, 16.0, and 19.0 m, along two of the largest rills or overland flow channels on each plot. An 800 mL runoff sample was obtained by placing a polyethylene bag across the channel cross section. A platform which extended across the entire plot width was used to prevent plot disturbance during sample collection.

At each of the points used to determine sediment content, samples for measuring runoff rate were also collected using dye dilution techniques. A known concentration of lissamine FF fluorescent dye was continuously injected into the channel at a constant rate (Replogle et al., 1966). Runoff samples containing the diluted dye were then obtained from the entire channel cross section. Dye concentration of the runoff samples was determined using a fluorometer. To minimize dye adsorption onto sediment, the runoff samples were filtered immediately after collection.

Some adsorption of dye onto soil materials was observed. Both an HS flume and the dye dilution technique were used to make total plot runoff rate measurements. To correct for dye adsorption onto soil materials, each of the concentrated flow runoff rate measurements was multiplied by the ratio of runoff rate identified using the HS flume to runoff rate determined using the dye dilution technique.

Mean flow velocity was also measured using a fluorometer (Hubbard et al., 1982). A slug of dye was injected into the channel and the length of time required for the concentration peak to pass a downstream point was determined. A time-concentration curve resulted from continuous pumping of a runoff sample from the channel through the fluorometer flow cell. Mean flow velocity was obtained by dividing travel distance by time of travel. No corrections to velocity measurements were required, since dye adsorption onto sediment materials did not affect travel time of the concentration peak.

Total runoff and erosion at the flume discharge locations were also measured by Gilley et al. (1986). Substantial reductions in total soil loss resulted from the presence of small amounts of crop residue. However, only data collected from individual rills or overland flow channels are reported below.

RESULTS

The area contributing to runoff becomes greater with increased downslope distance. Thus, larger discharge quantities may result at greater slope lengths. Soil detachment, deposition and sediment transport may be affected by variations in runoff rates and associated water depth and velocity. Runoff rate, runoff velocity, sediment concentration and soil loss rate at selected downslope distances will be described in the following discussion.

Runoff Rate

Runoff rates at various slope lengths for sorghum and soybean residue are shown in Figs. 1a and 2a, respectively. Average values from four rills or overland flow channels (two of the largest channels on each of two plots) are represented by each curve. For sorghum residue (Fig. 1a), the largest runoff rates were found on the 0.00 t/ha residue treatment while the 6.73 t/ha treatment produced the smallest runoff rates. Intermediate runoff rates were measured for the other sorghum residue plots.

Runoff rates did not vary consistently with residue rate on the soybean plots (Fig. 2a). On the 6.73 t/ha soybean residue treatment, runoff occurred principally as broad sheet flow. Runoff did not converge into channel networks as it moved over the plot surface. As a result, neither runoff rates nor soil loss measurements were made on this treatment.

In general, runoff rates for a given sorghum or soybean residue treatment increased with downslope distance. However, substantial differences in runoff rates occurred between residue treatments. Because of variations in flow pattern, the drainage area contributing runoff to a given channel could vary substantially with downslope distance. Convergence or divergence of flow into the rills or overland flow channels may also occur. The total quantity of water available for runoff at a given slope length may vary greatly between residue treatments because of differences in infiltration rates.

Runoff Velocity

Figs. 1b and 2b show runoff velocity at selected downslope distances for sorghum and soybean residue, respectively. Each curve represents average values from four measurements. In general, runoff velocities increased with downslope distance.

For both the sorghum and soybean residue treatments, the largest runoff velocities were usually recorded at the 0.00 and 0.84 t/ha residue rates. The 6.73 t/ha residue treatment produced the smallest runoff velocity, with intermediate values usually measured for the 1.68 and 3.36 t/ha residue treatments. As was true with runoff rates, substantial differences in runoff velocities were found between residue treatments.

Sediment Concentration

Sediment concentration at selected downslope distances for sorghum and soybean residue is shown in Figs. 1c and 2c, respectively. Average values from four rills or overland flow channels are represented by each curve. For a given slope length, sediment concentration usually decreased with residue rate.

Much larger sediment concentration occurred near the rill outlet locations on the 0.00 t/ha sorghum and soybean residue treatments. The largest variations in sediment concentration were found on the 0.00 t/ha residue plots. For both the 3.36 and 6.73 t/ha sorghum and soybean residue treatments, little change in

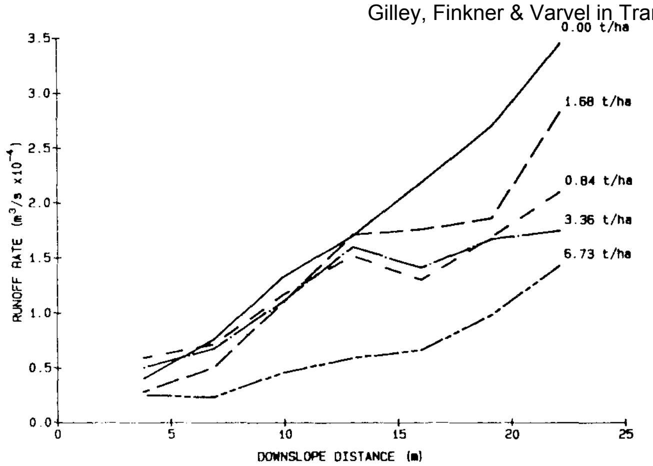

Fig. 1a—Runoff rate in rills or overland flow channels at selected downslope distances for five sorghum residue treatments.

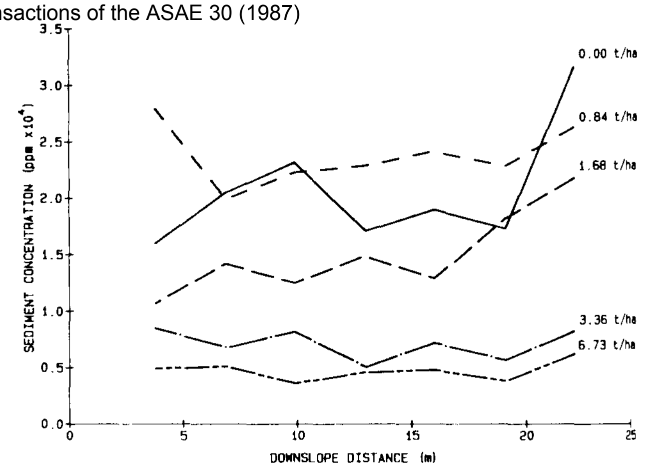

Fig. 1c—Sediment concentration in rills or overland flow channels at selected downslope distances for five sorghum residue treatments.

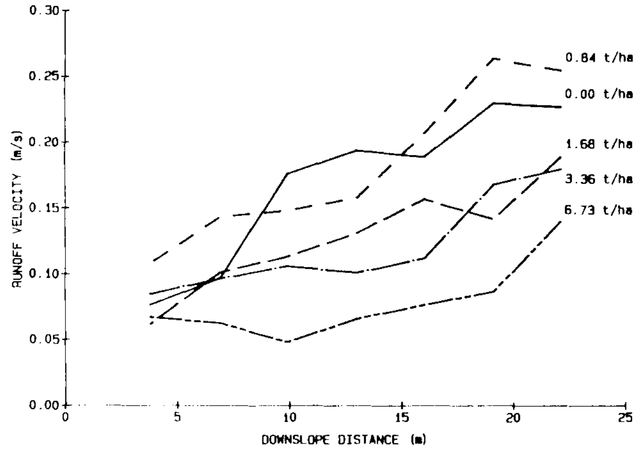

Fig. 1b—Runoff velocity in rills or overland flow channels at selected downslope distances for five sorghum residue treatments.

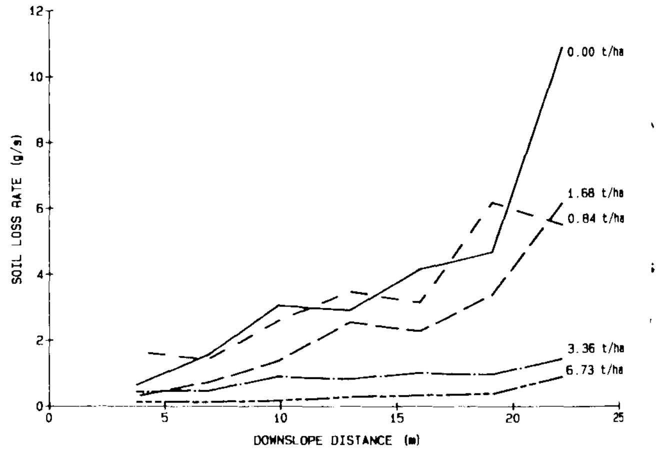

Fig. 1d—Soil loss rate in rills or overland flow channels at selected downslope distances for five sorghum residue treatments.

sediment concentration was found with downslope distance.

Soil Loss Rate

Figs. 1d and 2d show soil loss rate as affected by slope length for sorghum and soybean residue, respectively. Each curve represents average values from four rills or overland flow channels. In general, soil loss rate decreased with residue rate for a given slope length.

As was true with sediment concentration, substantial increases in soil loss occurred near the rill outlet location on the 0.00 t/ha sorghum and soybean residue plots. On the 3.36 and 6.73 t/ha sorghum residue treatments and 1.68 and 3.36 t/ha soybean residue plots, only small changes in soil loss occurred with downslope distance. The existence of sorghum or soybean residue, in general, produced substantial reductions in soil loss near the channel outlet locations.

DISCUSSION

For this experimental study, sorghum and soybean residue rates varied from 0.00 to 6.73 t/ha. The largest residue amount is greater than that expected on most soybean fields. The wide range in residue quantities was selected to provide experimental results applicable for a broad range of farming conditions. Identical amounts of sorghum and soybean residue were used to allow direct comparison in research results.

On those plots subject to substantial rilling, greater sediment concentration and soil loss rates usually occurred near the rill outlet locations. These large increases are attributed to greater rill soil detachment capability. The transport capacity of flow at the greater slope lengths was also large enough to remove much of the detached soil material.

In the experimental study, flow velocities were generally not great enough to move substantial amounts of crop residue. In addition, rill development did not occur beneath the crop residue. The experimental results for this investigation would probably not be applicable for areas on which substantial concentrated flow erosion is occurring. For greater slope lengths, larger residue amounts may be needed for protection from concentrated flow erosion.

On surfaces with little residue, movement of water and sediment from an area occurs principally by rill transport. It is difficult using existing technology to predict the quantity and location of rills or overland flow channels. Before information of the type presented in this paper can be fully utilized in computer modeling efforts, a reliable procedure for estimating rill density is needed.

This paper describes variations in runoff rate, runoff velocity, sediment concentration and soil loss rate at various slope lengths for selected types and rates of crop

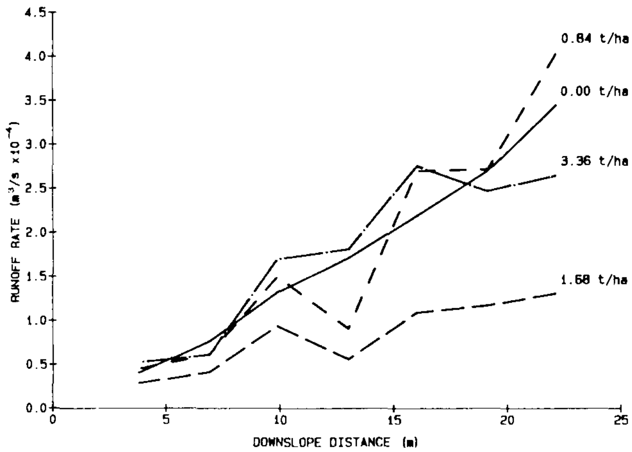

Fig. 2a—Runoff rate in rills or overland flow channels at selected downslope distances for four soybean residue treatments.

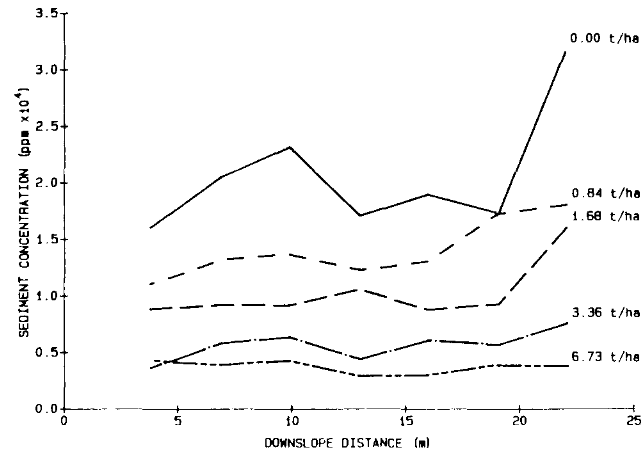

Fig. 2c—Sediment concentration in rills or overland flow channels at selected downslope distances for five soybean residue treatments.

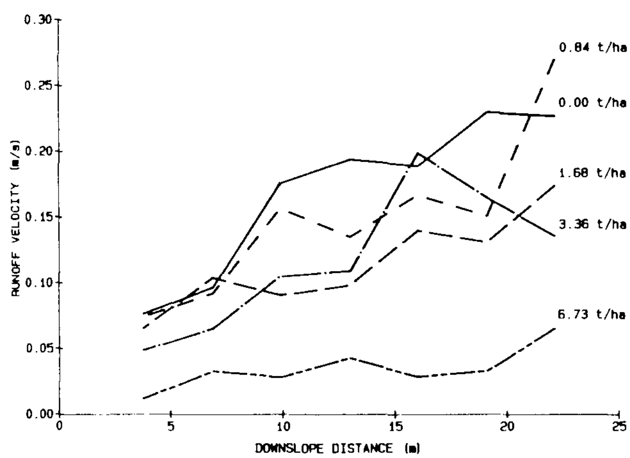

Fig. 2b—Runoff velocity in rills or overland flow channels at selected downslope distances for five soybean residue treatments.

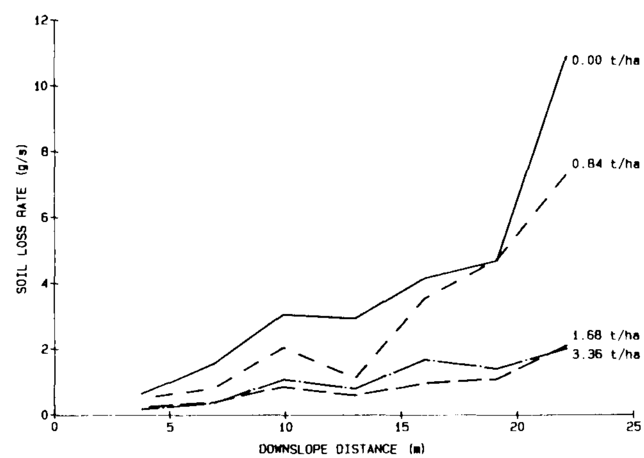

Fig. 2d—Soil loss rate in rills or overland flow channels at selected downslope distances for four soybean residue treatments.

residue. Runoff and soil loss variables may change greatly with downslope distance. The technology presently exists for accurately measuring runoff and soil loss variables on an eroding area. Information of this type could be utilized to develop and test mathematical models used for routing water and sediment along an eroding surface.

SUMMARY AND CONCLUSIONS

Runoff rate, runoff velocity, sediment concentration and soil loss rate were measured on plots with sorghum and soybean residue rates ranging from 0.00 to 6.73 t/ha. During simulated rainfall events, runoff rate and velocity of flow in rills or overland flow channels were determined at selected downslope distances using fluorescent dyes. Runoff samples for sediment concentration and soil loss measurements were collected from rills and overland flow channels at various slope lengths.

Increasing crop residue usually reduced sediment concentration and soil loss rate along the entire slope length. Runoff rate, runoff velocity and soil loss rate usually increased with downslope distance. For some residue treatments, substantial variations in runoff rate, runoff velocity, sediment concentration and soil loss rate occurred with slope length.

Detachment, deposition and sediment transport mechanisms occurring on upland areas are included in many erosion models. Runoff and soil loss variables must be predicted throughout the eroding area for the simulation models to function properly. Downslope routing of water and sediment may be possible if runoff rate, runoff velocity, sediment concentration and soil loss rate can be reliably estimated at a particular slope length.

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