Impact of Grass Hedges on Sediment Yield from a HEL Watershed

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Abstract

Stiff-stemmed grass hedges offer many opportunities to control erosion and other environmental contaminates leaving a field. The objective of this research was to evaluate the erosion-control effectiveness of narrow rows of grass hedges planted on 15.5-m spacings within a 6-ha watershed located in the deep loess hills region of western Iowa. Because only one watershed was planted in grass hedges, three different approaches were used to evaluate the erosion control effectiveness of the grass hedges as measured by sediment yield at the watershed outlet. The first approach was to compare measured surface runoff and sediment yields from the 1975-1991 period without hedges to the 1992-2002 period with hedges. The second approach was to develop a linear regression between annual sediment yield and surface runoff from data collected during the 1975-1991 non-hedge period and then estimate sediment yield without hedges for the 1992-2002 period from measured runoff values. The third approach was to use the WEPP Watershed model. The model was calibrated with data from the 1975-1991 period and then used to predict runoff and sediment yields without hedges for the 1992-1999 period using measured climatic and cropping and management inputs. Predicted sediment yields without hedges for the second and third approaches were compared with measured values with hedges. Stiff-stemmed grass hedges planted within the 6-ha watershed reduced sediment yield from 39 to 64% depending upon the approach used. Grass hedges had little to no impact on surface runoff losses, thus grass hedges acted as leaky dams temporarily ponding runoff, reducing sediment concentrations, and reducing sediment yield at the watershed outlet.

Keywords: erosion, erosion modeling, surface runoff, WEPP

Introduction

Stiff-stemmed grass hedges have been used in developing countries for many years as a natural way to trap sediment, bench the landscape, and reduce the inter-hedge slope (Alberts and Neibling 1994). The approach generally taken has been to select a native grass that has plant characteristics such as rigid stems, high stem density, rapid tillering, and tolerance to sediment deposition. While quantitative information on the mass of sediment deposition is relatively limited, observations indicated that sediment buildup behind grasses is quite high, often a meter or so every decade. Stem density is often so high that a temporary pond forms behind the grass hedge that does not drain completely until hours after a runoff event. The natural effectiveness of the hedge is also supplemented by pieces of residue and other organic debris that wash down to form an initial mat or barrier that the runoff must move through before being discharged. In the early 1990s, a Grass Hedge Workgroup was formed comprised of scientists, conservationists, and others interested in this technology and how it might be used in the U.S. as an alternative to expensive terrace construction (Kemper et al. 1992). Much of the research to investigate the erosion-control effectiveness of grass hedges has been conducted by the USDA-Agricultural Research Service in conjunction with personnel from the USDA-Natural Resources Conservation Service. Primary research sites were Holly Springs, MS (McGregor et al. 1999), Columbia, MO, and Treynor, IA (Kramer and Alberts 2000). For small plots where sheet-rill erosion dominates the erosion process, such

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as at Holly Springs and Columbia, research has shown that stiff-stemmed grass hedges reduce mean annual sediment losses by 60 to 80% compared to similar treatments without hedges. It is much more difficult to evaluate the influence of stiff-stemmed grass hedges on erosion control within a watershed with complex topography and steep slopes, and where much of the runoff within the watershed flows to ephemeral gully areas (channels) for movement out of the watershed. The objective of this research was to evaluate the erosion-control effectiveness of narrow rows of stiff-stemmed grass hedges planted on 15.5-m spacings within a 6-ha watershed in the deep loess hills region of western Iowa, an area comprised primarily of Highly Erodibile Land (HEL). The study spans a 28-year period (1975-2002), with 17 years of surface runoff and sediment yield measurements without grass hedges and 11 years of similar measurements with a network of established grass hedges.

Methods

Study area

The watershed is within Major Land Resource Area (MLRA) 107, the Iowa and Missouri Deep Loess Hills region, an area of 5.3 M ha. Corn and soybeans are the principal row crops.

The topography is very rolling, with slopes of 2 to 4% on the ridges and valleys and 12 to 16% on the sides. The soils generally have a silt loam texture throughout their profile and are well drained and highly erodible. Principal soil series are the Typic Hapludolls, Typic Udorthents, and Cumulic Hapludolls.

Most of the precipitation occurs as rainfall. During the spring and early summer, intense rainstorms often occur on soil that has been tilled. Most of the soil water recharge occurs in the fall when slow-moving cold fronts create long-duration, low-intensity rainfall events.

1975-1991 period

The watershed was instrumented in 1974 with a broad crested V-notch weir, a water-stage recorder, and an automatic pumping sampler to collect sediment samples during a runoff event. During this 17-year period, the watershed was cropped to continuous corn. Typical tillage operations included two to three tandem diskings, anhydrous ammonia application, planting with a 4-row planter, rotary hoeing, one to two cultivations, and harvesting. The corn stalks were seldom chopped after harvesting. Lines for parallel, narrow rows of grass hedges were established on the general contour in April 1991. Because no guidelines were available on hedge establishment and spacing, a hedge spacing of 15.5 m was chosen to accommodate 16 rows of corn between each hedge (Figure 1). It was recognized early in the experiment that establishing and maintaining hedges that crossed ephemeral gullies would be a challenge. Clumps of Miscanthus were transplanted in areas where the hedges were to cross major ephemeral gully channels. Cave-in-Rock Switchgrass was drilled in May on the south side of the watershed.

Figure 1. Topography of 6-ha watershed showing

Switchgrass hedge width and interval.

Surface runoff and sediment yield at the watershed outlet were measured on an event basis during this 17-year period. Some snow-melt events in the early Spring were missed because the gauging site was out of operation.

1992-2002 period

On the north side of the watershed, Alamo Switchgrass was drilled in May 1992. Hedges were overseeded after initial drilling to establish a satisfactory stand with high stem densities. Clumps of Miscanthus and Switchgrass were transplanted in some of the ephemeral gully crossings in 1992. The transition from a non-hedge watershed to one of established hedges took several years, but 1992 starts the period of established grass hedges. Cropping and management operations continued through 1996 as they had since 1985, with continuous corn and heavy disking as the primary tillage operation. In 1997, 1998, and 1999; cropping changed to narrow-row soybeans planted with a no-till drill. A corn-soybean no-till rotation system was initiated in 2000.

In 1998, the highest surface runoff year of record (28 years) caused deep rills to form in most of the ephemeral gully channels. Considerable surveying was done in March and April of 1999 to characterize soil surface elevations. A bulldozer and small scraper were used to fill some of the deeper rills in April and May of 1999. The third highest runoff year of record occurred in 1999, which required tandem disking to fill in deep rills. In May of 2001, clumps of Switchgrass were transplanted in many ephemeral gully crossings to rebuild the hedges.

Because there was not an adjacent watershed that was managed similarly without grass hedges, three approaches were used to evaluate the effectiveness of stiff-stemmed grass hedges as an erosion- control practice.

Evaluation Approaches

Period

This approach will compare surface runoff and sediment yield differences between the 17-year period without grass hedges (1975-1991) to the 11-year period where grass hedges were established (1992-2002).

Statistical

Data collected during the 1975-1991 period were used to develop a linear relationship between measured sediment yield and measured runoff. The relationship was:

Sediment Yield (Mg/ha) = 0.3386* Runoff (mm)

with a regression coefficient (r^2) of 0.78. The equation was then used to predict annual sediment yields from runoff measured during the 1992-2002 period.

WEPP watershed model

The WEPP Watershed model (ver. 99.5) was used in the assessment (Ascough et al. 1997). The model predicts the effects of agricultural management practices and will accommodate spatial and temporal variations in topography, soil properties, and land use conditions within agricultural watersheds generally less than 260 ha in size. The model contains three primary components: hillslope, channel, and impoundment. The six input files required to run the WEPP Watershed model are described briefly.

Climate input file

Measured daily precipitation, duration, time to peak, peak intensity, minimum temperature, maximum temperature, and wind velocity are required. Other daily input parameters, such as solar radiation and dew point temperature, were generated using WEPP's climate generator (CLIGEN).

Slope input file

Based on the direction of flow to the channels, the watershed was segmented into eight hillslopes and three channels. A DEM of the watershed was used to develop slope input parameters for both hillslopes and channels.

Cropping and management input file

Actual tillage dates and implements for each year of simulation were used. Two of the channels had similar management to the hillslopes. The main channel was a grassed waterway, which was represented in the input file.

Soil file

A soil file for the Monona soil (Typic Hapludoll) was used.

Channel input file

Channel input parameters include peak runoff calculation option, friction slope, channel erodibility, and critical shear stress. WEPP default estimated values were used for erodibility and critical shear stress.

Structure input file

This file provides water and sediment routing linkage. The file was created based upon topographic maps according to how the watershed was divided into hillslopes and channel elements and the direction of runoff between the elements.

Results

Period comparison approach

Nearly all the sediment yield from the watershed occurred during the months of March through September. Table 1 shows mean monthly precipitation and surface runoff values for the 1975-1991 non-hedge and 1992-2002 hedge periods for these seven months. Total March through September monthly precipitation and surface runoff for the 1992-2002 period were 5% and 55% higher than those measured for the 1975-1991 period, respectively. As already noted, precipitation and surface runoff values were unusually high in 1998 and 1999.

Table 1. Mean monthly precipitation and surface runoff.

Month	Precipitation		Surface Runoff	
	1975-1991	1992-2002	1975-1991	1992-2002
	-------------------------mm-------------------------			
Mar	61	43	1.6	4.2
Apr	78	92	2.0	2.0
May	121	121	14.4	7.4
Jun	115	145	8.7	23.1
Jul	91	114	2.4	12.5
Aug	108	110	5.1	12.9
Sep	88	71	6.6	1.2
Totals	662	696	40.8	63.3

As shown in Table 2, the impact of the grass hedges, including the changes in cropping and tillage practices that occurred in 1997, reduced sediment yield by 56% when mean annual monthly totals for the 1975-1991 and 1992-2002 periods are compared. Sediment yields from two years, 1998 and 1999, accounted for 82% of the total for the 11-year period.

Table 2. Mean monthly sediment yields.

Month	Sediment Yield		Change
	1975-1991	1992-2002	
	-----------Mg/ha------------		%
Mar	0.02	0.005	-75
Apr	0.97	0.39	-60
May	6.97	1.36	-80
Jun	8.54	4.18	-51
Jul	0.21	1.18	+462
Aug	0.17	0.33	+94
Sep	0.17	0.01	-94
Totals	17.05	7.46	-56

In 1998, failures from excessive concentrated flow breaching the hedges caused headcutting in the ephemeral gullies and undercutting of some of the hedge rows. Some previously deposited sediment was obviously lost from the watershed. Failures occurred again in 1999, although not as extensive as in 1998. Despite higher precipitation, higher runoff, entrainment of previously deposited sediment, and soil disturbance required to repair deep gullies, sediment yields during the grass hedge period were still 56% lower than for the non-grass hedge period.

Regression prediction approach

Measured surface runoff and sediment yields for the 1992-2002 period are shown in Table 3 with the estimated sediment yields from the relationship. Based on this simple analysis, the grass hedges and changes in cropping and tillage practices reduced sediment yield by 67%, from 22.4 to 7.5 Mg/ha. Even though the analysis is confounded by changes in cropping and tillage beginning in 1997, these changes probably had minimum effect on measured sediment yields in 1998 and 1999. Assuming that no-till reduced sediment yields by 75% for 2000, 2001, and 2002, the mean annual estimated sediment yield for the period would be reduced to about 24 Mg/ha. Based on these assumptions, the mean annual estimated sediment yield becomes 20.3 Mg/ha compared to the 7.5 Mg/ha measured value, a reduction of 64%. In 1998 and 1999, only a small portion of the sediment that had been trapped the previous 6 years is thought to have been transported out the watershed, primarily because the rills were deep, extending well below the tillage zone (~0.75 m), and narrow (~0.33-m wide).

Table 3. Measured surface runoff and sediment yields. Estimated sediment yields represent those losses expected if grass hedges had not been planted.

Year	Runoff	Sediment Yield	
		Measured	Estimated
	mm	-------------Mg/ha------------	
1992	4.3	0.02	1.4
1993	156.3	3.8	52.9
1994	22.5	0.2	7.6
1995	3.2	0.1	1.1
1996	78.0	4.4	26.4
1997	18.1	1.4	6.1
1998	193.5	41.4	65.5
1999	158.1	25.8	53.5
2000	64.4	4.6	21.8
2001	2.7	0.07	0.9
2002	28.4	0.21	9.62
Totals	729.5	82.0	246.8
Mean	66.3	7.5	22.4

WEPP prediction approach

Predicted annual runoff and sediment yield values from the calibrated model compared to those measured at the watershed outlet for the 1975 – 1991 period are shown in Figure 2.

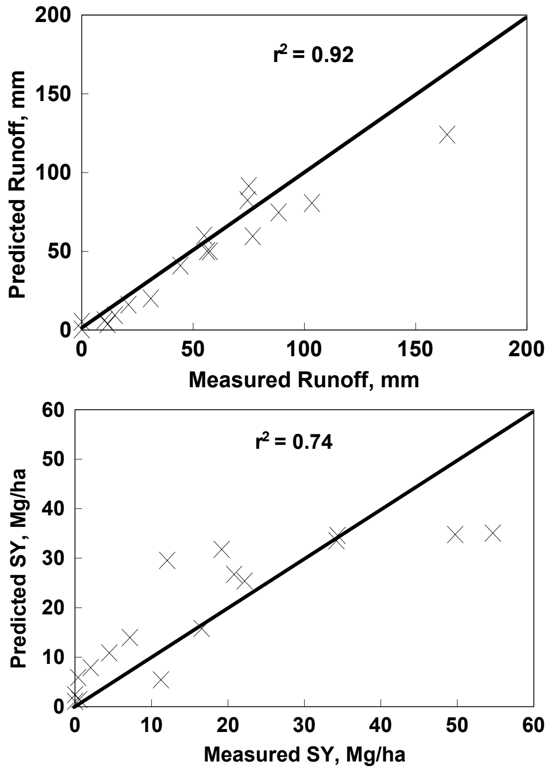

Figure 2. Relationships between predicted runoff and sediment yields (SY) from the WEPP Watershed model and measured values for a 17-year period (1975-1991).

Mean annual predicted and measured surface runoff losses were 45.6 and 55.0 mm, respectively, with a correlation coefficient of 0.96. Initially, the model was over predicting runoff, so the soil hydraulic conductivity value (Ksat) in the Soil input file was adjusted. Mean annual predicted and measured sediment yields were 18.6 and 17.0 Mg/ha, respectively, with a correlation coefficient of 0.86.

Table 4 shows some additional descriptive statistics that are useful in evaluating the performance of the model for predicting sediment yield. The calibrated model is over predicting all the statistic parameters in Table 4. The relative difference in the mean statistic is the smallest because the model under predicted a 49.7 Mg/ha sediment yield by 43% in 1977 and a 54.6 Mg/ha sediment yield by 56% in 1984.

Table 4. Statistical parameters for measured and predicted sediment yields (1975-1991).

Statistic	**Sediment Yield**		**Relative**
	Measured	**Predicted**	**Difference**
	----------**Mg/ha**---------		**%**
Mean	17.0	18.6	9.2
50% Percentile[1/]	12.0	15.8	31.0
75% Percentile	22.2	31.8	43.3
25% Percentile	2.0	5.9	189.7

[1/] Median value.

It is assumed that the positive bias in the calibrated model will be represented in the predictions for the 1992-1999 period. Until further calibration can be accomplished, it will be assumed that model predictions of sediment yield, particularly for years with low sediment yield values, will have no bias and when compared to measured values, differences will represent the influence of the grass hedges on sediment yield. Mean annual predicted and measured surface runoff losses were 85 and 79.2 mm, respectively (see Table 5). Mean annual predicted and measured sediment yields were 15.8 and 9.6 Mg/ha. Assuming the difference in these values are due to the impact of grass hedges in trapping sediment on the hillslopes and in the channels, the hedges reduced sediment yield by 39% over the 8-year period. As previously discussed, many of the grass hedges crossing ephemeral gully channels were breached and undercut from excessive runoff in 1998 and 1999. Measured sediment yields in those years include some sediment that had been trapped prior to 1998.

In 1998, the measured sediment yield was 41.4 Mg/ha, the third highest on record. Predicted sediment yield was 31.0 Mg/ha. When major rilling occurs on these soils as in 1998 and 1999, the depth of the rill is usually greater than the width because the rill erodibility value does not change with depth. Rill depth became so great in some concentrated flow areas that a bulldozer and small scraper were required to fill in the rill cut. In general, the breaches and cuts through the hedges were narrow relative to the width of the sediment deposition area, implying that only a fraction of the previously trapped sediment was lost from the watershed. Much of the measured sediment yield in 1998 and 1999 came from ephemeral gullies that developed deep rills in the inter-hedge areas.

Table 5. Measured and predicted surface runoff and sediment yields from the WEPP Watershed model (1992-1999 only). Predicted values represent those losses expected if grass hedges had not been planted.

Year	**Runoff**		**Sediment Yield**	
	Measured	**Predicted**	**Measured**	**Predicted**
	------- mm--------		**--------Mg/ha-------**	
1992	4.3	27.3	0.02	1.5
1993	156.3	157.0	3.8	35.9
1994	22.5	21.4	0.2	18.4
1995	3.2	17.6	0.1	0.9
1996	78.0	47.7	4.4	25.6
1997	18.1	24.0	1.4	0.1
1998	193.5	190.0	41.4	31.0
1999	158.1	195.0	25.8	13.0
Totals	634.0	680.0	77.1	126.4
Means	79.2	85.0	9.6	15.8

Conclusions

Surface runoff and sediment yields were measured from a 6-ha watershed located in the deep loess hills region of western Iowa from 1975 through 2002. Beginning in 1991, narrow rows of stiff-stemmed grass hedges were planted on 15.5-m spacings on the approximate contour throughout the watershed. The 28-year period was separated into a 17-year period without grass hedges and a 11-year period with established grass hedges. Three different approaches were used to estimate the impact of the grass hedges on sediment yield. Small plot research conducted in Holly Springs, MS and Columbia, MO indicates that grass hedges trap from 60 to 80% of sheet-rill erosion from <0.01-ha plots. From a watershed with ephemeral gullies and concentrated flow channels, the overall sediment trapping efficiency would be expected to be less than from small plots. A paired watershed in time approach comparing the 1975-1991 and 1992-2002 sediment yields indicated that the grass hedges reduced sediment yield by 56%. A regression approach where a linear relationship between sediment yield and measured runoff was developed for the 1975-1991 non-hedge period and used to estimate sediment yields from the hedge period indicated that grass hedges reduced sediment yield by 64%. For the third approach, the WEPP Watershed model was calibrated with data collected from 1975-1991. Runoff and sediment yields were predicted using measured climate data and dates of actual tillage operations (1992-1999 only). Data from the model indicated that grass hedges reduced sediment yield by 39%. Data will be collected from this watershed for several more years to better quantify the erosion control effectiveness of grass hedges and their impact on reducing sediment yield leaving the field. It is clear, however, that grass hedges on these steep slopes will work best in combination with soil conservation practices, such as, to minimize soil detachment and transport.

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