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Designing Research to Improve Runoff and Erosion Control Practices: Example, Grass Hedges

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ABSTRACT

Soil and water conservation research often focuses on a better understanding of the principles, processes, and mathematics of the system but stops short of the important goal of developing improved control practices. Also, acquisition of accurate and pertinent data for improved models and relationships is often lacking. Studies to develop grass hedges as an erosion-control practice illustrate a productive research approach that provided both effective methodology and useful data. Experiences reported from scientists throughout the world provided a foundation from which to start. Indoor flume studies showed that grasses with tall, stiff stems were necessary to withstand concentrated flows. Tests were developed to evaluate plant stem strength. Sediment trapping effectiveness for different grasses of various hedge widths for different sediments at several flow rates was evaluated in a specially designed outdoor flume. Hedges were planted on standard erosion plots to test them under natural and simulated rainfall conditions. Stiff-grass hedges were then installed on a variety of cropland and critical area conditions to study their performance in field situations. Acquired data were used to improve erosion prediction relationships for conservation planning. The results were then incorporated into interim standards for stiff-grass hedges as an erosion-control practice to be used by action agencies. The effort to further improve this practice continues by researchers and scientists throughout the United States and many other parts of the world.

INTRODUCTION

Soil conservation research during the 20th century produced a great store of knowledge concerning erosion principles, processes, and prediction. It also produced erosion-control practices that are suitable for some land-use conditions, but more effective and practical methods are still needed for many conditions throughout the world. Therefore, a major emphasis for research deserves to be a focus on developing better runoff and erosion control practices for a wide range of land uses on sloping arable land for a wide range of crops, soils, climates, and topographies. "Control" research seems to have been underemphasized in recent years. This paper uses studies conducted to develop grass hedges as an erosion control practice to illustrate a successful research approach toward improved methods for management of erodible land.

RESEARCH GOALS

The research goals of much soil conservation research have focused on understanding the principles involved, the processes occurring, the prediction of runoff and erosion rates that result, and mathematically simulating these aspects. All are very important, but, too often, the research stops before the information obtained is integrated with the objectives and resources of farmers and other users into cost-effective practices for solving erosion problems. The ultimate purpose of developing greater knowledge concerning erosion should usually be improved erosion control. To be truly worthwhile, accumulated knowledge must be transformed into effective and practical solutions to current and future erosion problems. The principal aim of research must not just be more and more facts, but more facts of strategic value.

Another important goal for erosion research should be accurate and useable experimental data for defining, evaluating, and refining erosion relationships and models. Obtaining, assembling, and interpreting useful data are difficult, costly, and time consuming. Such work is not as exotic and enthralling as building models and theories. However, without good and ample data, the models and theories cannot be verified and can even be misleading and of negative value.

Sustainable productivity on sloping cropland and control of sediment movement on a wide range of land-use conditions requires effective and practical runoff and erosion control practices. Such practices must dissipate raindrop impact energy, reduce runoff rates, slow runoff velocities and/or trap detached sediment. Growing vegetation and vegetative residues are generally effective in all these ways, but many crops suffer major yield decreases when planted with other vegetation. One alternative is to use strips of close-growing grass and/or legume vegetation between cropped areas such as with strip-cropping or buffer strips, but these practices occupy significant portions of the cropland and may offer little resistance where concentrated runoff bends and flattens the vegetation. Close-growing, stiff-grass hedges provide a means to overcome these shortcomings. Research conducted to develop them as an erosion-control practice and procedures used to evaluate their usefulness illustrate important steps in formulating optimum designs for their use.

STEPS IN GRASS-HEDGE RESEARCH

Stiff-grass hedges (also called vegetative barriers and Puerto Rico terraces) are narrow, permanent, parallel strips of stiff, erect, dense, usually perennial grass (Fig. 1) that are

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planted nearly perpendicular to the flow of runoff (Kemper et al., 1992; Nat'l Research Council, 1993). They are useful both on agricultural land for erosion control and on construction sites or critical areas to control gully development and trap sediment. On cropland, they are most beneficial where major concentrations of flow occur, although they may be used throughout a field.

Grass hedges have been used in various areas of the world for many years to stabilize sloping land. They involve less earthmoving and cost than common types of erosion control such as terraces. To answer the need for practical and economical erosion control practices internationally, John Greenfield (1987,1988) published, "Vetiver Grass, a Method of Vegetative Soil and Water Conservation" for distribution by the World Bank (World Bank, 1990). This booklet included numerous photographs showing the effectiveness of grass hedges of vetiver (Vetiveria zizanioides (L.) Nash), but little hard data was available to support their claims.

Figure l. Parallel stiff-grass hedges as used in a cropland field. Note deposition above hedge where concentrated flow occurred during rainstorms.

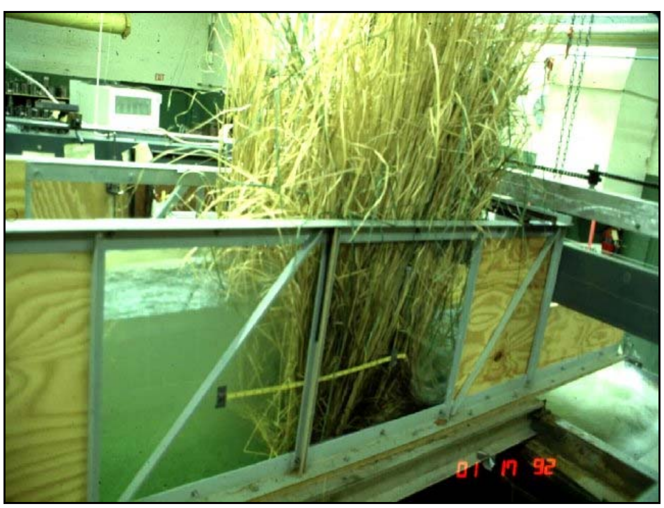

Figure 2. Vetiver hedge remained erect to create large, deep pool of backwater during tests with clear water in laboratory flume. Flow: left to right.

Because of the fervent testimony to the merits of vetiver by Greenfield and Richard Grimshaw, also of World Bank, the USDA Soil Conservation Service and Agricultural Research Service convened a workshop in 1989 to assess the effectiveness of grass hedges for erosion control. As a result, sources of vetiver in the United States were located, and it was planted at locations ranging from Texas to Iowa and Louisiana to Maryland. It grew rapidly during the first growing season, but was killed at locations where temperatures fell much below freezing during the following winter. Thus vetiver is viable only in the deep south of the US.

However, the potential of stiff grass hedges as a soil and water conservation practice motivated the workshop group to investigate this approach further. Line (1991) reported that very narrow grass strips were effective in trapping sediment, much of it in the water ponded above the grass. Kim McGintey and Gene Alberts (personal communications) noted that large volumes of sediment had deposited above fencelines in Iowa and Missouri. Other similar observations stimulated an effort to find stiff grasses with greater cold tolerance. A plan was formulated to locate, propagate, and test various types of grass. Along with the plant identification and propagation studies, characteristics of the different grasses were tested to determine their suitabilities as stiff-grass hedges, and related studies were made as a basis for using them as an erosion-control practice. Following are summaries of some of these.

Resistance to Flow

The capabilities of different grasses to withstand various rates of water flow were tested in an indoor tiltable flume as shown in Figures 2 and 3 (Dabney et al., 1996). Characteristics of interest were resistance to bending or breaking, ability to detain (pond) significant amounts water, and durability of the grasses during prolonged flows.

Vetiver and switchgrass (*Panicum virgatum* L.) had the greatest ability to withstand flows for backwater that reached depths up to nearly 0.4 m. Backwater depth was found to be nearly independent of flume slope. The increase in depth due to the hedges was related to a vegetation parameter that included stem diameter, stem density, and hedge width, existing grass leaf characteristics, and the flow Reynolds number. Another study (Meyer et al., 1995; Dabney, et al., 1995) using sediment that included some plant residues showed that backwater depth also increased as plant residues lodged in the hedges, increasing resistance to flow.

Both stem moment of inertia and modulus of elasticity were important characteristics resisting failure. Differences in modulus of elasticity among grass species were smaller than differences due to morphological age within a species. Generally, modulus of elasticity increased with stem age until maturity, becoming similar to that for wood. Regardless of species or age, a stem's elastic limit was reached when it deflected approximately 10% at a height of 150 mm.

A parameter using the product of stem density, stem modulus of elasticity, and stem moment of inertia was identified to predict hedge failure from inundation. Annual

Figure 3. Fescue hedge was bent by large flows and detained only small pool of backwater during flume tests.

Figure 4. Switchgrass hedge ponded and slowed sediment-laden flow, thereby allowing much of the sediment to deposit in the pool above the hedge. Flow: right to left in outdoor flume.

Figure 5. Deposition profile of trapped sediment that was typical after tests on switchgrass hedges in outdoor flume. Residue remaining on flume wall shows maximum water surface elevation in the ponded area.

mowing in late June increased stem density but decreased stem diameter, thus greatly reducing the value of this parameter and indicating less resistance to failure (Dabney et al., 1997).

Sediment Trapping Effectiveness

The capabilities of different grasses of various hedge widths to trap runoff-laden sediment were tested in a specially constructed outdoor flume (Fig. 4). Four sediment types ranging from a coarse sand to an agricultural silt loam, two sediment concentrations, and a wide range of flow rates typical of conditions where runoff concentrates were studied (Meyer et al., 1995; Dabney et al., 1995). Percentage of sediment trapped, profile of the deposited material, size distribution of the trapped sediment, and depth of ponding by the different grasses were measured.

For the grasses that withstood the flows well, greater than 90% of the sediment coarser than 125 µm was trapped at all flows tested but only about 20% of the sediment less than 32 µm was trapped. For sediment between these sizes, trapping percentage decreased rapidly with decreasing size and was affected greatly by flow rate.

The grasses that remained tall, stiff, and dense trapped sediment for several meters upslope of the hedge (Fig. 5). Generally, the greatest deposition occurred just downstream of a hydraulic jump that developed where faster flowing water abruptly slowed and deepened as it entered the ponded water. The thickness of the deposit then decreased toward the hedge, and nearly all sediment that reached the grass continued through the hedge with the runoff.

Switchgrass, vetiver, and miscanthus (*Miscanthus sinensis* Anderss.) grasses withstood the flows well, but fescue (*Festuca arundinacae* Schreb.) lacked the necessary stiffness or height and thus was much less effective in trapping sediment. The three better grasses ponded water up to depths of 0.4 meter. As ponded depth increased, the hydraulic jump moved upslope, which gave additional time for settling and created a greater ponded volume for the deposited sediment.

Erosion Plot Evaluations

Sediment losses from cotton with and without miscanthus hedges were evaluated for three years on 4% slope erosion plots under natural rainfall (Fig. 6) (McGregor et al., 1999). Residues from clipping the hedges were removed. The hedges reduced average annual soil loss on conventional tilled plots by 76% and on no-till plots by 58%. A small reduction in runoff was also found. Raffaelle et al. (1997) reported similar results based on simulated rainfall applied one week after corn planting on 10% slope plots with and without 0.6 m wide bermudagrass (Cynodon dactylon (L.) Pers.) strips. They found that the grass strips had no significant impact of runoff, but reduced sediment yield 90% for bare fallow, 75% for conventional tillage corn, and 55% for no-till corn.

These results showed that soil loss reduction by hedges is similar to that obtained using other less stiff grasses on relatively short slopes where runoff is not concentrated. Studies are continuing on the natural rainfall plots with the hedges being clipped and the resides left above and in the stubble, and other studies are underway on larger plots where tillage is parallel to hedges planted at a grade of 0.4% from the contour.

Field Evaluations on Cropland and Critical Areas

Stiff-grass hedges have been installed on a variety of cropland and critical area conditions for observation and evaluation. The topographic elevations of several sites have been evaluated periodically to determine the extent of soil movement on land with hedges. On other areas, observations and less detailed measurements have been taken.

Where hedges were planted in gullies and major concentrated flow channels, great quantities of sediment accumulated behind the hedges. The hedges continued to grow and roots grew from their nodes as the sediment deepened. The channels below the hedges continued to erode unless protected by backwater from a more downslope hedge or unless slope steepness was small below the last hedge. No undercutting of hedges has been observed.

Figure 6. Miscanthus hedge at lower end of erosion plot as used to measure soil loss and runoff from cotton during natural rainstorms.

On cropland, the land slope between hedges flattened appreciably due to benching. In the concentrated flow areas, this benching was largely due to sediment loss immediately below the upslope hedge and deposition above the downslope hedges (Fig. 1). However, benching also occurred on the remainder of the cultivated area where soil movement by erosion was minor, due to major soil translocation by tillage (Dabney et al, 1997; Dabney et al., 1999).

On-farm field trials identified several potential limitations of stiff-grass hedges including: (1) yield loss in adjacent crop rows if tall grass hedges are not mowed and (2) the need for subsurface drainage where tillage creates small berms across swale areas. Farm workers also need to be educated to distinguish hedge grasses from weeds such as Johnsongrass.

Applications for Erosion-Prediction Models

Data and observations obtained from laboratory and field experiments on grass hedges are being incorporated into modifications of the Revised Universal Soil Loss Equation (RUSLE) and the Water Erosion Prediction Project (WEPP) erosion models. As previously used, these models did not consider changes in slope steepness over time and so could not predict long-term conservation benefits. They also did not account for tillage translocation. Since hedges bench the land between successive hedges and the hedges plus the associated parallel tillage also redirect runoff flow, these effects need to be incorporated into models so they will accurately describe hedge impacts on soil loss.

In RUSLE, erosion control credit is given by modifying the conservation practice (P) and length-steepness of slope (LS) factors. When first established, hedges serve as guides to contour cultivation and receive credit in P for contouring and strip cropping. Once well established, their ability to pond backwater and promote sediment deposition is credited by using the effective width of the hedge rather than their actual width. The latest recommendation is to use whichever is wider: the actual hedge width or the “effective width” calculated as a fraction of the slope length (Toy and Foster, 1998). This effective width is 0.12 for slope steepnesses less than 5%, 0.08 for 5% to 10%, and 0.04 for 10% to 15%. At slopes steeper than 15%, backwater distances will be minor and no additional effective width is calculated. However, effective widths should be based on slope steepness in the vicinity of the hedges, which is generally reduced over time, so effective widths may gradually increase.

Changes in the land surface profile between hedges were simulated using WEPP (Zhu et al., 1999). The steepness at the lower edge of the hedges increased markedly, but it decreased for the rest of the cropped interval and was only 1% to 2% just upslope of the hedges. Incorporating this change had little effect on predicted runoff but a showed major decrease in predicted soil loss.

The resulting model modifications and predictions have broadened the applicability of the experimental findings. They have also helped clarify the strengths and weaknesses of this technology, and have identified further research that is needed.

MORE EFFECTIVE EROSION CONTROL FROM BETTER PRACTICES

The research studies outlined above were conducted by researchers at the National Sedimentation Laboratory, Oxford MS. They have provided a better knowledge of the effects of stiff-grass hedges on runoff and erosion, have produced pertinent data for quantifying and validating this practice, and have identified strengths and weaknesses when applied on a wide range of land-use conditions. However, this research is only part of a much broader international cooperative effort among other researchers (too numerous to reference), educators, action-agency professionals, and farmers, who have joined together to improve this practice. This combination of research knowledge plus experience that is being gained from field tests by countless action agency personnel has provided much information that is essential for optimum progress. Within the United States, this ongoing group effort has led to increasing recognition and the development of technical guidelines and standards for this practice (Dabney et al., 1993). (Contact the authors for information on personnel and activities of this group.) Some state offices of the NRCS have developed interim practice standards (eg. Mississippi Code 205-1, Vegetative Barriers) and made the practice eligible under federal cost-sharing conservation programs. Vegetative barriers are now recognized as one of ten conservation buffer types in CORE4 (NRCS, 1999).

Even the most effective erosion-control practices are of little benefit unless they are applied extensively by farmers and other land managers. Thus, dissemination of available technology by widespread "technology transfer" using popular publications, public meetings, computerized information networks, and expert systems must not be overlooked. The following Internet worldwide web locations provide additional information about grass hedges, also sometimes called vegetative barriers: http://www.sedlab.olemiss.edu/uep_unit/projects/Dab_veg/index.htm; http://www.ftw.nrcs.usda.gov/nhcp_2.html; and http://www.vetiver.org.

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