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Combining ^{137}Cs and topographic surveys for measuring soil erosion/deposition patterns in a rapidly accreting area[1]

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ABSTRACT

Narrow, stiff grass hedges are biological barriers designed to slow runoff and capture soils carried in runoff water. This study was designed to measure quantitatively the deposition of soil up slope of a narrow, stiff grass hedge using topographic and ^{137}Cs surveys. Topographic surveys made in 1991, 1995, and 1998 measured 1 to 2 cm yr^{-1} of recent sediment deposited up slope of the grass hedge. ^{137}Cs analyses of soil samples were used to determine the medium-term (45 years) soil redistribution patterns. Erosion rates and patterns determined using ^{137}Cs measured medium-term erosion near the hedge do not reflect the recent deposition patterns near the grass hedge measured by topographic surveys. Using the combination of topographic and ^{137}Cs surveys allows a better understanding of the role of grass hedges as barriers for capturing eroding soils and suggest that the recent deposition is associated with the grass hedge but that there is still a net loss of soil near the hedge position over the past 45 years.

Keywords: Erosion. Concentrated flow erosion. Cesium 137. Grass Hedges. Sustainable agriculture.

INTRODUCTION

Soil erosion is a major problem in many parts of the world (Morgan, 1995) leading to concern about the sustainability of agricultural systems to feed future generations. Soil erosion decreases organic matter, fine grained soil particles, water holding capacity, and rooting depth leading to loss of soil productivity, quality, and sustainability. The economic consequences of soil erosion on loss of productivity, land degradation, sustainability, and off-site, downstream damages on water quality are a major concern and have a high economic cost (Pimentel et al., 1995). Concentrated flow erosion occurring along narrow flow paths is a special concern. Grass filter strips (5 to 15 m wide) have been widely used for trapping eroding soils and chemicals (Daniels and Gilliam, 1996). However, the effectiveness of grass filter strips is reduced as flow rates increase, particularly, in areas of concentrated flow (Flanagan et al., 1989). Planting narrow stiff grass hedges on the contour across areas of concentrated flow is an alternative biological, low cost conservation practice for slowing

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Figure 1. Looking down slope toward the grass hedge at Site A after the soybean harvest and before corn harvest.

runoff and reducing erosion and soil loss (Kemper et al., 1992).

Grass hedges differ from other types of grass barriers (i.e., buffer strips, filter strips). They are narrow (< 50 cm) and designed to slow water movement and stimulate the formation of terraces from deposited materials. These dense stands of grass, planted on the contour in narrow strips across flow paths, reduce flow rates of the water allowing time for entrained soil particles to deposit. These deposited materials fill low places in the field so that water in future runoff events is even more broadly dispersed and less erosive.

The purpose of this study was to compare the erosion/deposition patterns up slope of a grass hedge using conventional topographic survey techniques to determine deposition rate since 1991 and using the redistribution of fallout ^{137}Cs to determine medium-term (45 years) deposition rates and patterns.

STUDY SITE

The study site is at the Beltsville Agricultural Research Center (BARC), United States Department of Agriculture (USDA), Agriculture Research Service (ARS) near Beltsville, Maryland, USA in a field where concentrated flow erosion channels had developed (Fig. 1). The field is row cropped on the contour with alternate years of corn [*Zea mays* L.] and soybeans [*Glycine max* (L.) Merrill]. Contour strips are 35 to 40 m wide with 10-15% slopes. In the last 10 years, corn has been no-till seeded into the soybean stubble while soybeans are planted after minimum tillage (surface discing <10 cm depth) to breakup the corn residue. Concentrated flow erosion channels had developed starting near the crest of the slope and crossed three cropping strips before joining near the base of the slope to exit from the field.

On April 17, 1991, miscanthus [Andress] was transplanted into four (4) hedges in the borders between strips of crops where concentrated flow channel development was evident. Transplants were made in the borders between strips of crops to minimize interference with farm operations and to reduce disturbance to hedges during the farm operations. In 1993, miscanthus was transplanted to fill gaps in the original hedges. In 1994, eastern gamagrass [*Tripsacum dactyloides* (L.) L.] was seeded to fill other gaps and to extend the length of the existing hedges.

The miscanthus hedge at Site A (Fig. 2) grew rapidly and expanded and was 1-2 m tall at the end of the first (1991) growing season. Beginning with 2-5 cm clumps planted 10-15 cm apart in 1991, the hedge at Site A had grown to a width of 20-30 cm and a height of 1.5-2.5 m by 1994 and has remained at approximately this size. Each spring, the hedge is trimmed to a height of approximately 30 cm. From a management view, no evidence of viable seed production by miscanthus has been seen so the spread of the hedge has been vegetative.

Eastern gamagrass also grew rapidly to form a hedge 10-15 cm wide and 30-60 cm tall by the end of the 1994 growing season. The eastern gamagrass hedge continues to grow and has developed into hedges of 20-30 cm wide and 1.0-1.5 m tall.

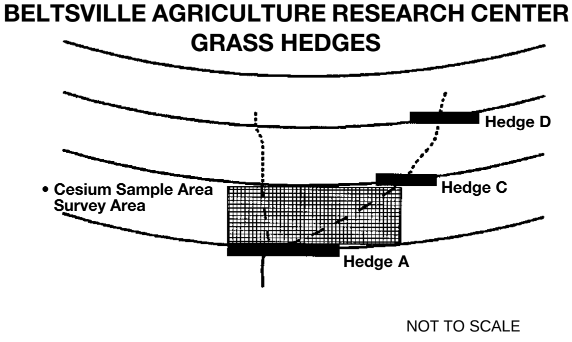

Figure 2. Diagram of grass hedges at the BARC study site. Letters and boxes indicate miscanthus and eastern gamagrass plantings from 1991 to 1994. Solid lines represent borders between contoured cropping strips and dotted lines represent concentrated flow areas. Soil samples for 137Cs analyses were collected in the contour up slope of hedge at Site A.

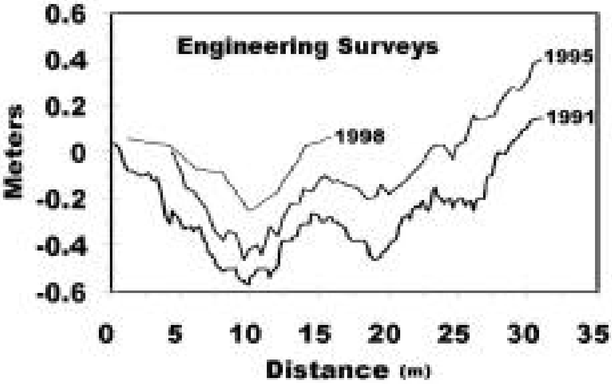

Figure 3. Topographic survey line 5 cm up slope of Site A, BARC South Farm.

METHODS

A topographic survey near the hedge at Site A was made using conventional surveying techniques with a level and rod on April 22, 1991. In August 1995 and April 1998, this topographic survey was repeated. Survey lines were made 5 cm down slope and 5 cm and 100 cm up slope of the hedge. The 1998 survey was expanded to made measurements at 1 m grid intervals for an area 100 x 36 m up slope of the hedge at Site A (Fig. 2).

Soil samples for ^{137}Cs analyses were collected in February 1998 at 1 m and 2 m up slope of the hedge at Site A and then at 2 m intervals up slope to the next field boundary and at 5 m intervals across the slope at Site A (Fig. 2). The total area sampled was 35 x 36 m. Profile soil samples were collected in 6 cm increments to a depth of 36 cm at 30 selected sites. Bulk samples of the 0-30 cm layer were collected at other sites. At random sites, soil samples were collected from 30-48 cm. Reference soil samples for ^{137}Cs analyses were collected in a grass and a grass-oak savanna area where BARC farm records showed no tillage activity since the 1940's. At 3 random sites in the grass and grass-oak savanna sites, soil samples were collected at 12 cm increments to 36 cm. At each reference site, bulk soil samples were also collected at 10 m intervals along a 100 m transect. These samples were collected to 30 cm depth.

Soil samples were dried at 90º C for 48 hours, weighed and were passed through a 2-mm screen. Materials (rocks etc.) greater than 2 mm were discarded. A 1-liter Marinelli beaker was filled with 1000 g of the sieved soil and sealed for gamma ray analyses. Gamma-ray analyses are made using the Canberra[2] Genie-2000 Spectroscopy System. This Windows™ based software/hardware package receives input into two (2) 8192 channel systems from two solid state crystals. One crystal is a Canberra Lithium-drifted Germanium crystal (Ge(Li) - 15% efficiency) and the other is a Canberra high purity coaxial Germanium crystal (HpC - 30% efficiency). The system is calibrated and efficiency determined using an Analytic2 mixed radionuclide standard (10 nuclides) whose calibration can be traced to U.S. National Institute of Standards and Technology. Estimates of radionuclide concentration of the soil samples are made using the Canberra Genie-2000 software. ^{137}Cesium is detected at 662 kev and count time for each sample is 30,000 seconds, providing a measurement precision of ± 4 to 6 % on most samples.

Using ^{137}Cs to estimate erosion and deposition rates is base on a comparison of ^{137}Cs concentration at a sample site with local fallout input of ^{137}Cs as measured at the reference sites where no loss of ^{137}Cs has occurred (Ritchie and McHenry, 1990). Sample sites with ^{137}Cs concentrations less that the reference sites are eroding while sample sites with concentrations greater than the reference sites are sites of soil deposition. Actual estimates of erosion and deposition rates based on ^{137}Cs con-

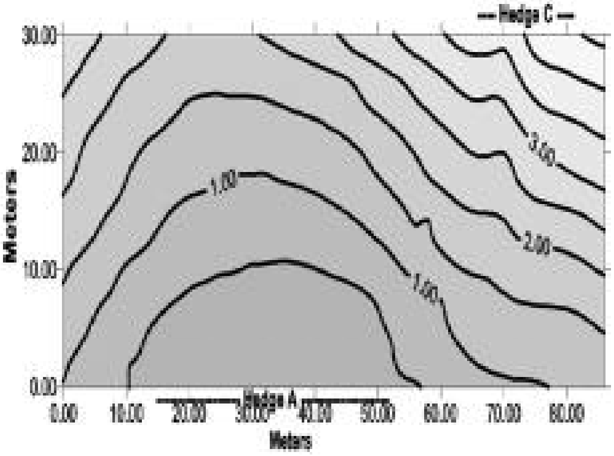

Figure 4. Digital Elevation Map of the surveyed area up slope of the hedge at Site A relative to an arbitrary datum. Note the evidence of a concentrated flow area between Site A and Site C.

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[2] *Trade names are included for the benefit of the reader and do not imply an endorsement of or a preference for the product listed by the U. S. Department of Agriculture.*

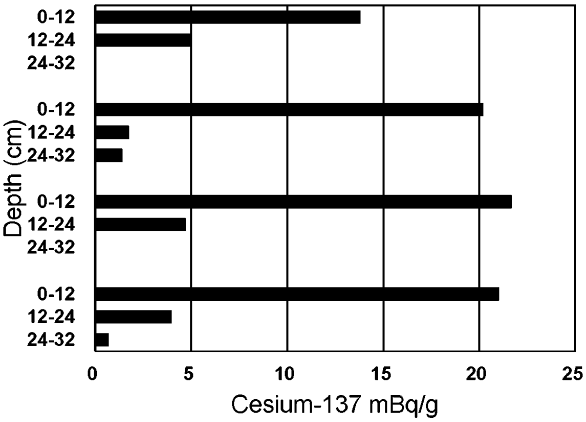

Figure 5. Average depth distribution of ^{137}Cs for six soil profiles from reference sites.

centrations are made using the models and software developed by Walling and He (1999).

RESULTS AND DISCUSSION

Topography surveys at the hedge at Site A made in April 1991, August 1995, and April 1998 5 cm up slope of the hedge (Fig. 2) show 2-12 cm of deposition between 1991 and 1998 (Fig. 3). Deposition is greatest (1-2 cm yr^{-1}) in areas where concentrated flow had eroded the deepest channels prior to the establishment of the hedge. There is a general leveling along the survey line by the time of the August 1995 survey that is especially evident in the 1998 survey. A Digital Elevation Model (DEM) created from the 1998 topographic survey up slope of the hedge at Site A shows the topography (Fig. 4). The concentrated flow channel up slope of Site A is still evident on the DEM. Field observations noted an extensive area of deposition approximately 5-15 m up slope and 40-50 m west of the center of the hedge at Site A. This leveling area is also evident on the topographic survey. Whether this deposition area is due to the hedge is not clear but it has developed since the hedge was established.

Based on deposition rates of 1 to 2 cm per year measured by the field survey and a bulk density of 1.2 g cm^{-3}, a deposition rate of 12 to 24 kg m^{-2} yr^{-1} is calculated for the area near the hedge at Site A. These data suggest that the hedge is acting as a filter to retain eroding soil in the field up slope of the hedge.

Reference samples collected from the grass and grass-savanna sited for 28 soil profiles had ^{137}Cs inventories ranging from 1786 to 4159 Bq m^{-2} with an average of 2896 ± 765 Bq m^{-2}. The distribution of ^{137}Cs in reference soil profiles (Fig. 5) is typical of an undisturbed soil profile with highest concentration in the surface soil layer. Total inventories in the reference profiles are consistent with measured fallout input for the northeastern United States.

The distribution of ^{137}Cs up slope of the hedge at Site A, in general, is typical of tilled soils (Fig. 6). The average ^{137}Cs distribution of 25 soil profiles (Fig. 6) shows inventories decreasing with depth. There were no significant differences in ^{137}Cs between the 0-6 and 6-12 cm layers, the layers tilled in the last 12 years, but deeper layers had significantly lower ^{137}Cs than the 0-12 cm layers and also differed from each other. Less than 50% of the profiles had ^{137}Cs below 30 cm and no ^{137}Cs was found below 36 cm at any of sites. There are exceptions to the average profile (Fig. 6) where distributions are more like untilled soils. The highest concentrations in surface layer and the minimum depth distribution are 16-32 m up slope of the hedge. In general the minimum concentrations by layer and greatest depth distribution were found nearest the hedge where the concentrated flow was greatest before the hedge was planted and the location where we measured 2-12 cm deposition since 1991 with the topographic surveys. ^{137}Cs inventories for all the sample sites (n=152) averaged 3249 ± 642 Bq m^{-2} which are higher than the reference sites (2896 ± 765 Bq m^{-2}) indicating a net movement of ^{137}Cs into the sample area.

Average ^{137}Cs inventory per square meter was lowest near the hedge and became more uniform at greater distances from the hedge. The first two intervals (1 and 2 m up slope of the hedge) were the area where the maximum

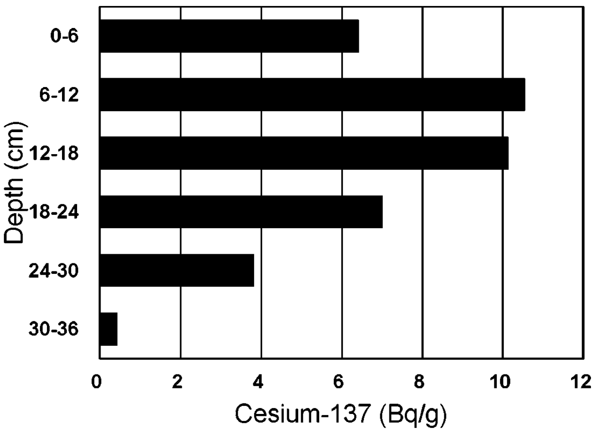

Figure 6. Average depth distribution of ^{137}Cs for 25 soil samples near the grass hedge at Site A.

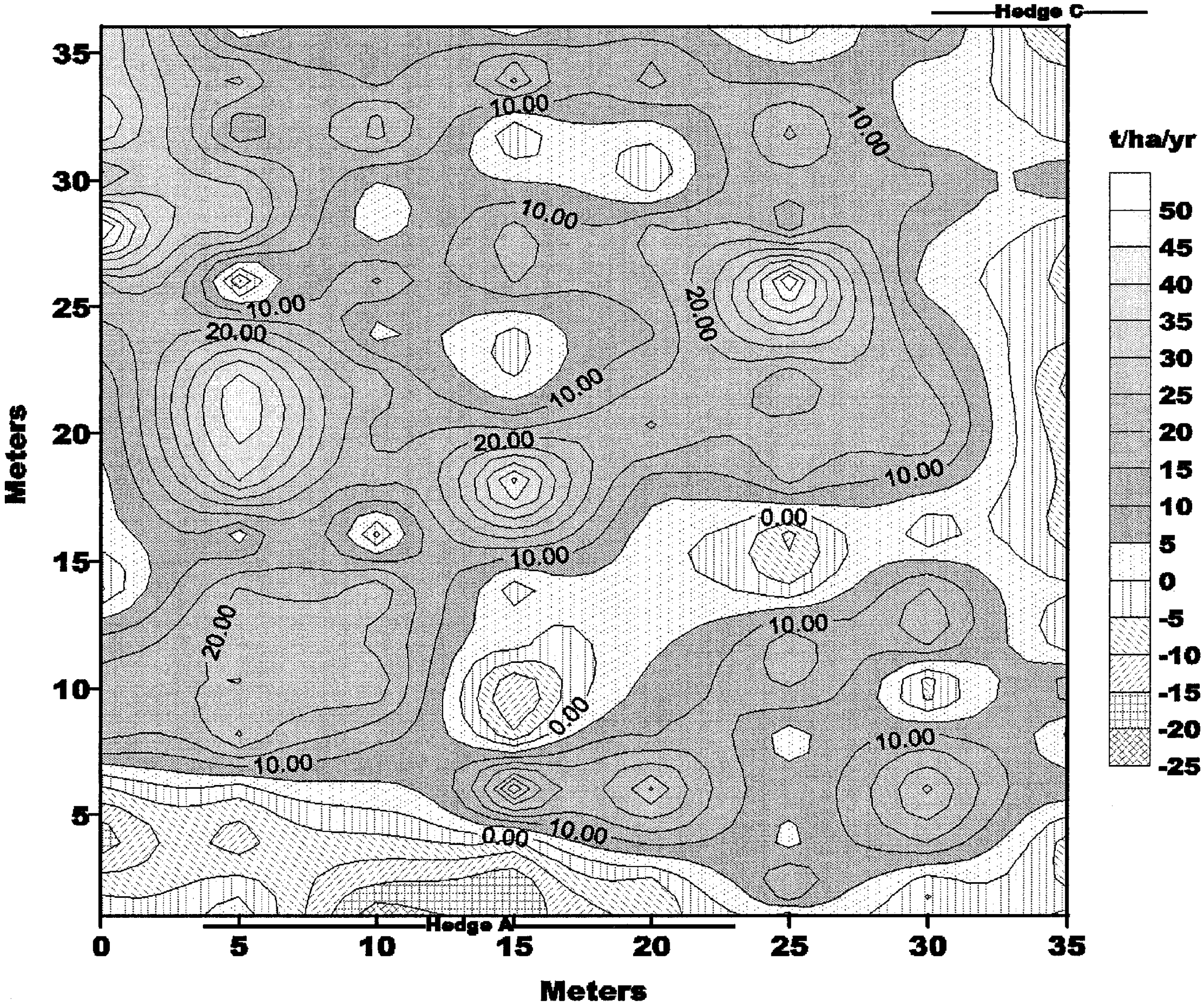

Figure 7. Spatial distribution of erosion and soil deposition determined from ^{137}Cs measurements and a proportional model (Walling and He, 1999).

development of the concentrated flow erosion channels had occurred prior hedge establishment. This concentrated flow had eroded much of the surface soil. While field surveys show significant deposition in the area since 1991, it is evident that over the longer time period (45 years) measured by the ^{137}Cs technique there is still a net loss of soil near the grass hedge where the most severe concentrated flow erosion was occurring. ^{137}Cs data is reflecting the medium-term erosion pattern (45 years) and not just the conditions that have occurred since the grass hedge was established in 1991.

Based on the ^{137}Cs data, soil redistribution rates up slope of the hedge at Site A were calculated using the Proportional Model of Walling and He (1999). Particle size analyses of samples showed no significant differences in particle size distribution at eroding and depositing sites. The pattern of medium-term soil redistribution calculated from ^{137}Cs (Fig. 7) reflects the areas of concentrated flow erosion evident in the field (Fig. 4) when the grass hedge was established. The pattern of deposition in the field probably represents the effects of the contour farming practices that has been in place in the field for the past 30 years.

The area of erosion along the grass hedge estimated from ^{137}Cs (Fig. 7) is the location of the concentrated flow erosion which was evident in the field when the decision was made to establish grass hedges to control the concentrated flow channels developing in the field. While topographic surveys show net deposition in this area since 1991, the ^{137}Cs data indicate a medium-term net loss of soil in this part of the field. The other areas of erosion in the middle of the area and along the 35 m area (Fig. 7) are in the region where the concentrated flow erosion channels had developed between Site A and Site C. The areas of deposition near the concentrated flow channels represent low places and eddy areas along water flow paths across the field. The management strategy of using contour strips has resulted in the net accumulation of soil since 1954 over much of the area that was sampled. While concentrated flow areas were occurring that were becoming a critical management concern in this field, in general the net effect of the contour farming had been positive in controlling soil loss from the total area.

CONCLUSIONS

This study shows the importance of understanding the history and management of a study area as we interpret soil redistribution patterns using ^{137}Cs or topographic surveys. Topographic surveys show significant recent (since 1991) deposition rates near grass hedges while ^{137}Cs data show a medium-term (45 years) net erosion in the same area. This study reinforces the basic concepts that ^{137}Cs provides estimates of medium-term (45 years) erosion rates not short-terms erosion rates. Using the combination of topographic and ^{137}Cs surveys of an area provides better insights into the history and pattern of erosion of the area. The data also show that the hedges are acting to capture soil particles entrained in the concentrated flow. One interesting possibility from this study site is that with the current rapid rate of deposition near the grass hedges we may be able to return to this site in a couple years and with another set of ^{137}Cs redistribution rates make an estimate of recent deposition rates.

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