AGRICULTURAL SOIL EROSION RATES FOR THE LINGANORE CREEK WATERSHED IN THE PIEDMONT PHYSIOGRAPHIC PROVINCE OF THE CHESAPEAKE BAY WATERSHED

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Abstract The loss of soil from agricultural lands presents a substantial risk to the sustainability of arable fields and downstream water resources within the Chesapeake Bay. The ^{137}Cs (Cesium-137) technique was used to quantify soil loss for representative agricultural settings (pasture/hay and cultivated crop) of the upper Linganore Creek watershed (146 km^2) in the Piedmont Physiographic Province portion of the Chesapeake Bay watershed. The ^{137}Cs inventory for the reference site was 2,183 becquerels per square meter (Bq/m^2), and inventories for agricultural sampling points range from 467 to 2,623 Bq/m^2 with a median of 1,401 Bq/m^2 and mean of 1,399 Bq/m^2. Redistribution rate estimates for the 68 sampling points from all the sites, ranged from 48.8 megagrams per hectare per year (Mg/ha/yr) of erosion to 9.7 Mg/ha/yr of deposition, with a median and mean erosion rate of 13.5 and 15.5 Mg/ha/yr, respectively. The net erosion rates computed for sites ranged from 2.7 to 25.3 Mg/ha/yr with a mean of 15.3 Mg/ha/yr. The sediment delivery ratio is 100 percent for all sites except two pasture/hay sites with values of 85 and 89 percent. The mean erosion rates for these agricultural sites are greater than the overall sediment yield for watersheds in the Piedmont Physiographic Province, indicating that agriculture is an important source of sediment to the Chesapeake Bay. These findings indicate a capacity for further soil loss in agricultural areas and the potential delivery of this sediment to the Chesapeake Bay. Limitations of these data include the need to account for local variability of soil redistribution rates due to slope and profile curvature of hillslopes. The ^{137}Cs approach provides useful estimates of onsite and offsite soil loss for better management of agriculture and water resources and has the potential to assess the effectiveness of future conservation practices within the Chesapeake Bay Watershed.

INTRODUCTION

The loss of soil from agricultural land can have adverse effects on the soil productivity of arable fields. Soil loss occurs through the process of erosion by wind (aeolian) on near level fields (Sutherland, 1991), but most predominately by water (alluvial) on land with steeper slopes. Soil production benefits from fertilizer and manure only if a substantial amount of soil is available for root growth (Miller, 2001). Currently, global reserves of agricultural soil are being lost at a rate of 7 percent annually (Brown, 1984) with a cost of $27 billion per year in the United States (Pimentel and others, 1995). Soil that is lost from fields can contribute to impairments downstream (fig. 1). Rivers, lakes, and estuaries experience decreases in water quality because sediment transports contaminants and biota become stressed from loss of habitat and decreases in water clarity (Sutherland, 2008, U.S. Environmental Protection Agency, 2001). Reservoirs and navigation channels are adversely affected by reduced storage capacities and increased maintenance due to infilling from excess sedimentation. Water-treatment technology often has to be upgraded to provide safe drinking water. These downstream impairments from sediment are estimated to cost $17 billion per year in the United States

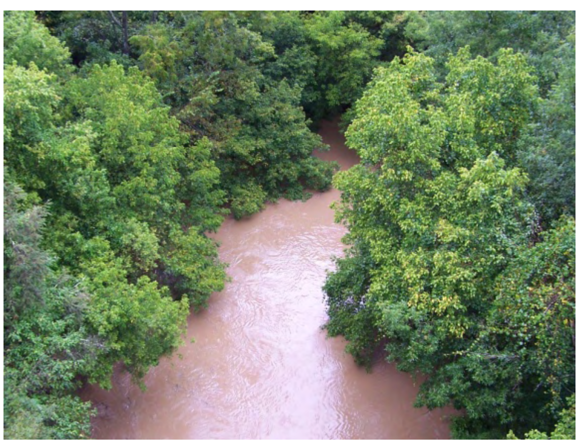

Figure 1 Stormflow carrying suspended sediment at Linganore Creek near Libertytown, MD, during Hurricane Hanna (September 2008)

(Pimentel and others, 1995). As a result of these impairments, there is an increased need to provide more detailed monitoring of soil loss for better management of agriculture and water resources.

The Chesapeake Bay is the Nation's largest estuary and has been designated as an impaired water body because of excess sediment and nutrients (Phillips, 2002). The Piedmont Physiographic Province portion of the Chesapeake Bay watershed contributes the highest sediment yield within the basin (Gellis and others, 2009). The U.S. Geological Survey (USGS) SPARROW (SPAtially Referenced Regressions On Watershed attributes) model predictions of sediment load have identified agriculture as a important source of suspended sediment (John Brakebill, USGS, written commun., 2010) and the need has been identified to provide field estimates of soil erosion rates.

The purpose of this study was to quantify recent (approximately past 40 years) annual rates of soil loss for representative agricultural settings of pasture/hay and cultivated crops in the Piedmont Physiographic Province of the Chesapeake Bay using the ^{137}Cs (Cesium-137) field technique. This study was conducted by the USGS in cooperation with Frederick County, Maryland, and is part of a larger effort to better understand sediment processes for the entire Chesapeake Bay watershed (Gellis and others, 2009). This report presents the gross erosion rates, net erosion rates and sediment delivery ratios for nine sites. Soil samples were collected during 2009 from two types of agricultural land use.

CESIUM-137 TECHNIQUE

Traditional approaches for measuring soil erosion include direct field measurement and modeling. Field techniques to measure soil erosion include pins, field plots, and aerial photography. These methods are often costly and unreliable because of spatial and temporal variability (Collins and others, 2001). Model approaches such as the Universal Soil Loss Equation (Wischmeier and Smith, 1978) often lack adequate direct measurements for calibration and do not account for deposition (Sutherland, 1991, Collins and others, 2001).

The use of the ^{137}Cs (Cesium-137) technique provides an alternative to traditional methods used to measure soil erosion. ^{137}Cs is a by-product of nuclear fission and was released globally as fallout from the above-ground thermonuclear testing in the 1950s and 1970s (Cambray and others, 1985; Carter and Moghissi, 1977). Deposited primarily through precipitation, ^{137}Cs strongly adsorbed to soil, especially to fine particles (<2mm) (He and Walling, 1996). By comparing the amount of ^{137}Cs bound to soil in an uneroded (reference) area to that in an eroded or depositional (cultivated) area, the rate in which soil has been redistributed (erosion/deposition) can be estimated (Walling and He, 1997; Ritchie and McHenry, 1990). Some uncertainty exists in applying the technique in equatorial/arid areas, around areas of nuclear accidents, and in areas with localized variations in weather patterns and soil textures (Walling and Quine, 1995). Traditional methods often require extensive, long-term field work, and the key advantage to the ^{137}Cs technique is the ability to obtain estimates of onsite and offsite soil erosion and deposition from a plot of land during the past 40 years in a single visit (Walling and Quine, 1995). ^{137}Cs has been used successfully for estimating soil loss globally (Bernard and others, 1998; Ritchie and McHenry, 1990; Sutherland, 1989; Hasholt and Walling, 1992). In the Chesapeake Bay watershed, ^{137}Cs has been used to estimate agricultural erosion in selected subwatersheds in the Piedmont and Coastal Plain Physiographic Provinces of the Chesapeake Bay (Ritchie, 2005; Gellis and others, 2009).

STUDY AREA

The upper Linganore Creek watershed (146 km^2) is a tributary to the Monocacy River; which drains eventually to the Chesapeake Bay. The study area is located approximately 45 miles northwest of Baltimore (fig. 2). Approximately, 40.3 percent of the upper Linganore Creek watershed is composed of soils in the Ultisol taxonomic order (Soil Survey Staff, 2010). Land use is a mix of forest (19%), urban

(2%), agriculture (76%) and other (3%) settings. The agriculture acreage is comprised primarily of corn, wheat, barley, soybean, and pasture/hay (USDA, 2009). Cultivated crops are planted from April to May and harvested during August and September. The landscape within the Linganore Creek watershed consists of rolling hills with elevations that range from 110 to 250 meters. The local climate provides for a wet season of increased precipitation from April through June with a mean annual rainfall of 106.3 cm/yr (U.S. Department of Commerce, 2009).

METHODS

Sampling sites were selected on hillslopes on the basis of past farming practice information provided by the landowners. Selected sampling sites include one reference site and 9 agricultural sites (fig. 2). The reference site was chosen at the summit of an undisturbed (no erosion or deposition), fully vegetated, permanent pasture/hay area where ^{137}Cs would be concentrated near the surface (Collins and others, 2001; Walling and Quine, 1995). Land use at the reference site had been part of government conservation programs to minimize erosion. The agricultural sites included five pasture/hay and four cultivated crop settings located on hillslopes throughout the watershed. At each site, 6-12 composite samples were collected (table 1). A composite sample was taken from three locations about 15 meters apart along a contour (fig. 3). Soil was cored manually down to an estimated tillage depth (15-30 cm) with a 3.5-cm diameter stainless steel coring device. The tillage depth was determined on the basis of textural and color differences in the soil. Global Positioning System (GPS) coordinates, soil depths, and current land use were recorded along with a photograph of the site.

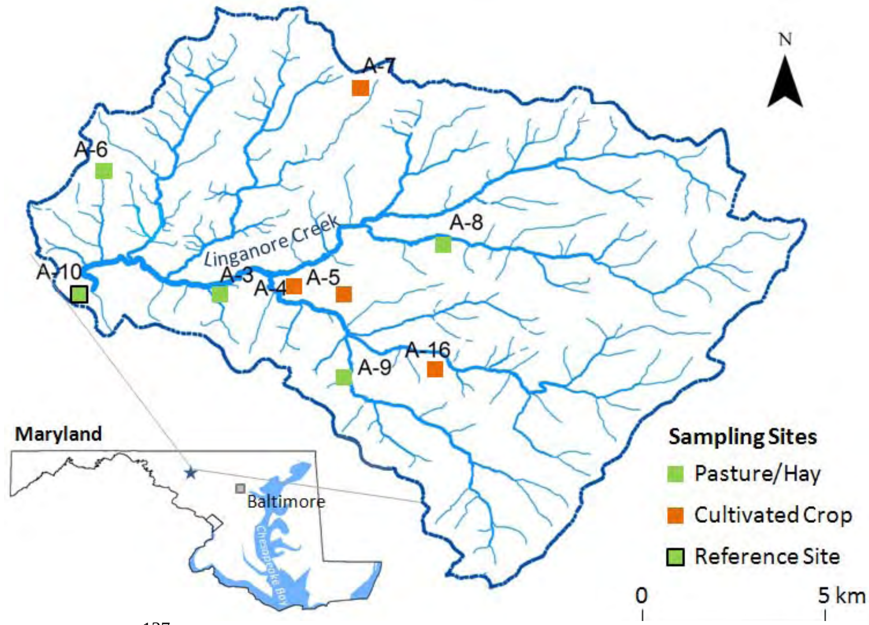

Figure 2 ^{137}Cs soil sampling sites in agricultural settings in the upper Linganore Creek watershed, Piedmont Physiographic Province, MD.

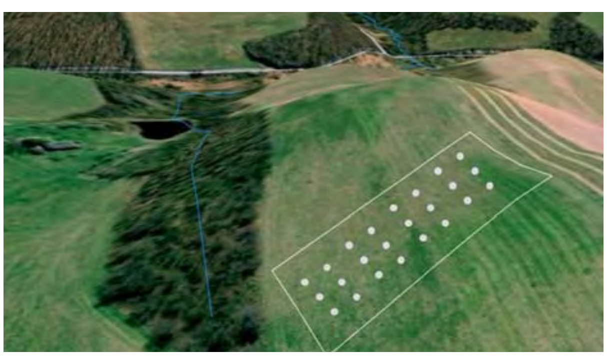

Figure 3 A composite sample was taken from three locations (represented by dots shown above) about 15 meters apart along a contour. At each site, 6-12 composite samples were collected; Upper Linganore Creek watershed, Maryland, 2009.

Soil samples were dried in an oven at 80°C for a minimum of 24 hours or until dry. Samples were ground using a mortar and pestal and mechanically sieved. All material passing through a 2-mm screen was retained for analysis (Ritchie and others, 2005). The soil fraction (<2 mm) was weighed and transported for analysis of ^{137}Cs activity to the U.S. Department of Agriculture – Agricultural Research Service (USDA-ARS) Hydrology & Remote Sensing Laboratory in Beltsville, Maryland. Analyses by USDA-ARS's for ^{137}Cs were made using gamma-ray procedures with a Canberra Genie-2000 Spectroscopy System that receives input from three Canberra high-purity coaxial germanium crystals (HpC >30 % efficiency) into 8192-channel analyzers. The system is calibrated and efficiency determined, using an analytic mixed radionuclide standard (10 nuclides) whose calibration can be traced to the U.S. National Institute of Standards and Technology. Measurement precision for ^{137}Cs is ± 4 to 6 percent and inventory is expressed in becquerels per kilogram (Bq/kg) or becquerels per square meter (Bq/m^2) (Ritchie, 2000, de Jong and others, 1982).

The ^{137}Cs activity levels was converted to inventory levels, which represents the total radionuclide content of the soil profile per unit area. The ^{137}Cs inventory levels were used to estimate medium-term (approximately past 40 years) soil redistribution rates using the Mass Balance Model II described in Walling and He (1997). This theoretical mass balance model integrates ^{137}Cs inventory fluxes on the basis of the reference site inventory to predict overall erosion and deposition for a hillslope. Model II accounts for the total ^{137}Cs deposited at a site and any initial loss, decay and erosion or deposition that occurs. ^{137}Cs inventories greater than the reference site are depositional and lesser inventory values are considered erosional. Slopes for each site were derived from 10-meter digital elevation models.

RESULTS AND DISCUSSION

<u>^{137}Cs Inventories and Redistribution Rates of Samples</u> The ^{137}Cs reference inventory for the study area was 2,183 becquerels per square meter (Bq/m^2). Patterns of ^{137}Cs fallout in temperate latitudes for reference areas have been found to range from 2,000 to 4,000 Bq/m^2 (Collins and others, 2001). Gellis and others (2009) report an average ^{137}Cs inventory from three reference sites in the Pocomoke River watershed, Delaware and Maryland, and one reference site in the Little Conestoga watershed, Pennsylvania, of 2,729 Bq/m^2 and 2,432 Bq/m^2, respectively. The reference value is also similar to the ^{137}Cs inventory in 75 samples from reference sites in Canada that have a mean of 2,150 ± 100 Bq/m^2 (Sutherland, 1991).

The ^{137}Cs inventories for the agricultural samples collected in this study range from 467 to 2,623 Bq/m^2 with a median of 1,401 Bq/m^2 and a mean of 1,399 Bq/m^2. For comparison, studies completed in the Piedmont Physiographic Province by Gellis and others (2009) determined a range of 907 to 2,453 Bq/m^2 in the Little Conestoga Creek watershed (Gellis and others, 2009).

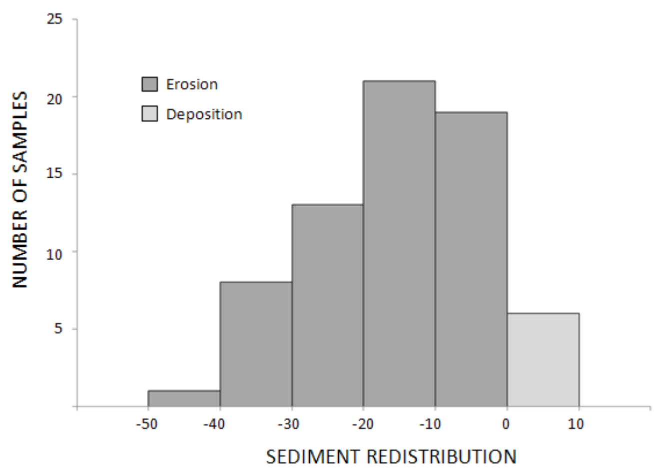

Figure 4 Sediment redistribution for 68 samples collected in agricultural settings in the Linganore Creek watershed, Maryland. Negative values for sediment redistribution represent erosion.

The redistribution rate is the mass change over time of soil movement by erosion or deposition along a field. The distribution of soil redistribution rates (erosion/deposition) estimated for all 68 samples from the 9 sites are shown in the histogram in figure 4. For all the individual samples, 91.2 percent showed erosion, and 8.8 percent had deposition. Redistribution rates for the individual samples ranged from 48.8 megagrams per hectare per year (Mg/ha/yr) of erosion to 9.7 Mg/ha/yr of deposition, with a median and mean erosion rate of 13.5 and 15.5 Mg/ha/yr, respectively.

Redistribution Rates of Sites All agricultural sites for both pasture/hay and cultivated cropland showed some level of gross and net erosion (table 1). Gross erosion represents the total amount of soil eroded at the site. Gross erosion rates for the sites ranged from 3.1 to 25.3 Mg/ha/yr with mean of 15.5 Mg/ha/yr. At each site, some of eroded soil may be redeposited further down slope, but the soil eroded off the site (downstream) represents the net erosion. Net erosion rates ranged from 2.7 to 25.3 Mg/ha/yr with a mean of 15.3 Mg/ha/yr. The sediment delivery ratio expresses the soil movement offsite (net erosion) as a percentage to the total soil loss onsite (gross erosion). This ratio is 100 percent for all sites, except two pasture/hay sites with values of 85 and 89 percent. In a comparison of similar studies in agricultural settings in the region, Gellis and others (2009) found erosion rates ranged from 14.0 Mg/ha/yr to 28.1 Mg/ha/yr for the nine sites in the Pocomoke River watershed. Bernard and Laverdiere (2001) estimated values in the Appalachian Piedmont for gross and net erosion to be 3.2 Mg/ha/yr and 3.0 Mg/ha/ yr, respectively, with a sediment delivery ratio of 94 percent. Erosion rates from these studies are similar to erosion rates reported for Linganore Creek watershed.

These levels of erosion rates and sediment delivery ratios have several possible contributing factors including land use, slope, and floodplain processes. The type of agricultural land use and conservation practices has an important role in soil redistribution. Rates and patterns of erosion and deposition have been shown to depend on profile curvature, plan curvature, and slope gradient (Penncock and de Jong, 1987). Slopes for all sites range from 3 to 13 percent on predominately convex hillslopes (fig. 5). Lastly, floodplain alluvial processes at the bottom of hillslopes have been shown to be a contributing factor in estimating soil erosion rates (Ritchie and others, 2005).

Agriculture may be an important source of sediment because erosion rates in the upper Linganore Creek watershed (2.7 to 25.3 Mg/ha/yr) are higher than the overall sediment yield of 1.03 Mg/ha/yr for the entire physiographic province in the Chesapeake Bay (Gellis and others, 2009). Sediment that is eroding off of cropland may be deposited in the channels and floodplains before it reaches the Chesapeake Bay. Additional studies in the upper Linganore Creek watershed are identifying the relative sediment contribution from streambank erosion in comparison with the agricultural erosion presented in this study. Streambank erosion has been shown to be an important source of sediment in other areas especially during increased discharge (Lawler and others, 1997). These field estimates of potential sources of soil loss will provide a comparison with existing model predictions.

A potential useful application of the ^{137}Cs technique in the Chesapeake Bay is the ability to monitor the effectiveness of conservation practices. Schuller (2007) used the ^{137}Cs technique to compare soil distribution rates for conventional tillage versus no-till. Conventional tillage showed net erosion rates of 11 to 2.0 Mg/ha/yr with a 100-percent sediment delivery ratio offsite and downstream. No-till showed reduced erosion rates of 1.4 to 2.0 Mg/ha/yr with a sediment delivery ratio of 19 percent. Similar monitoring in the Chesapeake Bay watershed could further aid conservation efforts and benefit both agriculture and downstream management of water resources.

CONCLUSIONS

The ^{137}Cs technique was used to obtain soil loss estimates for nine agricultural sites in Linganore Creek watershed within the Piedmont Physiographic Province portion of the Chesapeake Bay. ^{137}Cs inventories documented for reference and agricultural sites were comparable to values found at site in temperate latitudes and in similar studies. Redistribution rates were predominately erosional, and 100 percent of sediment delivery was offsite (downstream) for all but two sites. The range of erosion rates was greater than the average sediment yield reported for the Piedmont Physiographic Province, indicating that agriculture is an important source of sediment. More data are needed to confirm the results of this study and to better explain the variability that may be present as a result of slope and profile curvature of the hillslopes. However, the current findings indicate a high potential for further soil loss in agricultural areas and the possibility that this sediment could be delivered to the Chesapeake Bay. The ^{137}Cs approach provides useful onsite and offsite estimates of soil loss that are needed for better management of agriculture and water resources and that have the potential to be used to assess the effectiveness of conservation practices.

Table 1. Results of ^{137}Cs soil redistribution technique for selected agricultural (current) land use sites in the upper Linganore Creek watershed, Piedmont Physiographic Province of Maryland, 2009.
[-, no data; Bq, becquerels; kg, kilograms; m^2, square meters; Mg/ha/yr, megagram per hectare per year; %, percent; ID, indentifier; N, number]

Site ID	Land Use	N[1]	Slope %	^{137}Cs Activity (Bq/kg)	^{137}Cs Activity (Bq/m^2)	Gross Erosion Rate[2] (Mg/ha/yr)	Net Erosion Rate[2] (Mg/ha/yr)	Sediment Delivery Ratio %
Reference	Pasture/Hay	1	-	9.09	2185	-	-	-
Agricultural Sites								
A-3	Pasture/Hay	8	3	5.86	1,596	14.0	12.5	89
A-4	Cultivated Crop	8	3	7.04	1,192	18.7	18.7	100
A-5	Cultivated Crop	8	4	5.01	1,137	25.3	25.3	100
A-6	Not Determined	6	12	3.87	1,571	12.5	12.5	100
A-7	Cultivated Crop	12	3	5.17	1,185	20.4	20.4	100
A-8	Pasture/Hay	7	3	7.48	1,303	15.0	15.0	100
A-9	Pasture/Hay	9	13	9.49	1,587	9.0	9.0	100
A-10	Pasture/Hay	7	13	8.01	1,996	3.1	2.7	85
A-16	Cultivated Crop	8	12	7.26	983	21.7	21.7	100
				Mean values	=	15.5	15.3	

[1]N is the number of composite samples collected at each hillslope or reference plot.
[2]Relaxation mass depth for Model II is 4.0 (He and Walling, 1997), proportional parameter is 0.5 (Ritchie and McCarty, 2003).

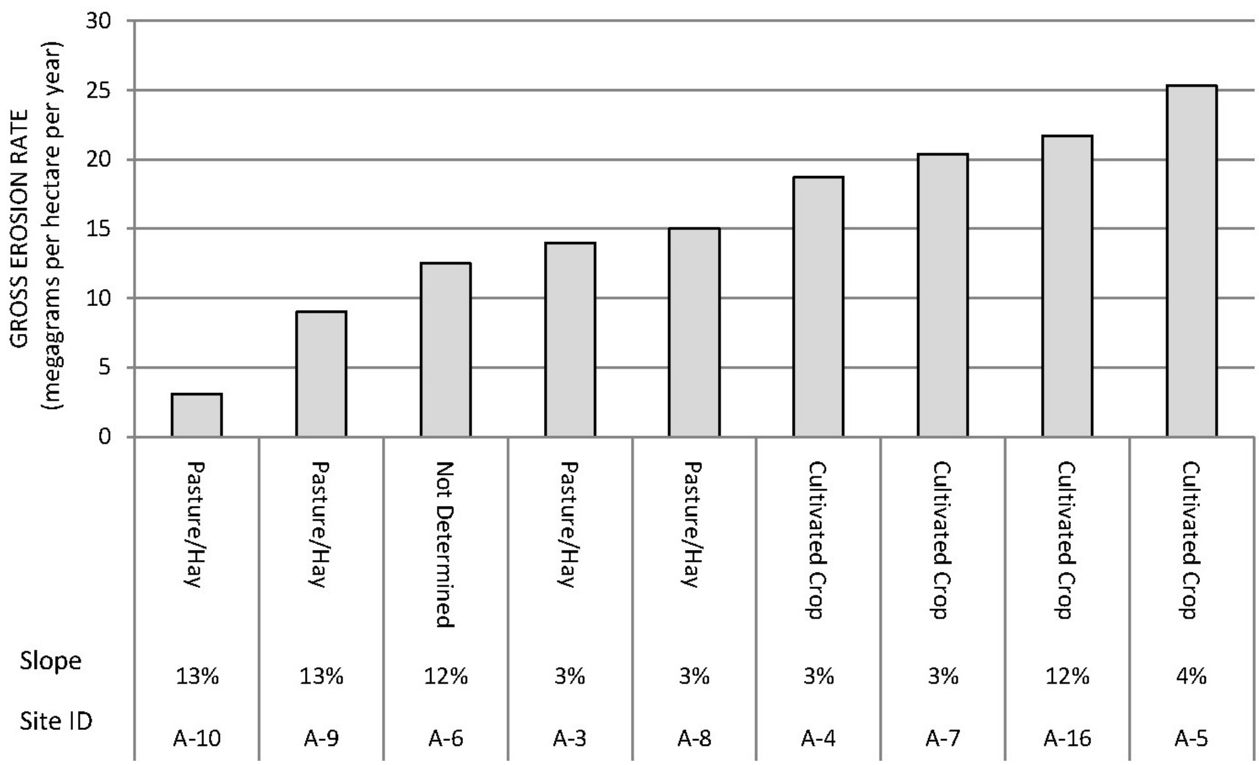

Figure 5. Gross erosion rates, land use and slope for selected agricultural (current) land-use sites in the upper Linganore Creek watershed, Piedmont Physiographic Province of Maryland, 2009.

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