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Determining Soil Erosion with Varying Corn Stover Cover Factors

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DETERMINING SOIL EROSION WITH VARYING CORN STOVER COVER FACTORS

THESIS

A thesis submitted in partial fulfillment of the requirements
For the degree of Master of Science in Biosystems and Agricultural
Engineering in the College of Engineering at the University of Kentucky

By

Nicole K. Koeninger

Lexington, Kentucky

Director: Dr. Michael Montross, Professor of Biosystems & Agricultural Engineering

Lexington, Kentucky

2015

ABSTRACT OF THESIS

DETERMINING SOIL EROSION WITH VARYING CORN STOVER COVER FACTORS

Since the Dust Bowl, conservation agriculture has become a common practice globally. Because of the rising interest in the use of corn biomass as a feedstock for biofuel production, the effects of corn stover removal on soil erosion were explored. It was hypothesized that selective harvesting strategies would impact soil erosion differently across a variety of slopes. Soil erosion boxes were constructed, and a rainfall simulator with an intensity of 30 mm hr^{-1} for 46 minuntes was used to create runoff from slopes of 1, 5, and 10% and three cover factor treatments (no removal and two simulated corn stover removal strategies). Due to research time constraints, simulated corn roots were constructed to emulate actual corn roots in all experiments. The corn stover harvest strategies change the distribution of cobs, husks, leaves, and stalks in field; these changes were represented as the cover factor treatments. Changing the type of plant material on the soil surface impacted the predicted soil erosion from the Revised Universal Soil Loss Equation (RUSLE). Based on the results from this study, the effect of corn stover cover percentages had a significant impact on the predicted and observed soil loss.

KEYWORDS: Agricultural runoff, Biomass, Erosion control, Total suspended solids, Turbidity, RUSLE

__Nicole K. Koeninger__

_____January 28, 2015___

DETERMINING SOIL EROSION WITH VARYING CORN STOVER COVER FACTORS

By

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______ January 28, 2015 ______

To my parents Patti and Pete, I would not be here without your love and support. Thank you so much for instilling in me the confidence to pursue my education and the ability to handle any obstacle that is thrown my way.

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CHAPTER 1: INTRODUCTION

1.1 Introduction

For years, conservation agricultural practices such as no-till have allowed for crop residues to remain on the soil surface after harvest. No-till is used on 95 million hectares of land globally (Lal, Reicosky et al. 2007). This management style not only lessens the work for farmers, but also aids in the control of soil erosion. The additional residue remaining on the field reduces the impact from rain and wind, which in turn reduces soil erosion. This project focused on biomass removal and its effect on soil erosion due to water. Crop residues lower the erosivity of water flow because the shear stress is partially absorbed by the cover rather than the soil. In recent years, crop residues such as corn stover are becoming an emerging topic of discussion to be used in biofuel production. In the United States, the Energy Independence and Security Act (EISA) of 2007 mandates that the volume of renewable fuel used will increase from 34 billion liters in 2008 to 136 billion liters by 2022. Of these 136 billion liters, 61 billion liters must come from cellulosic biomass (switchgrass, corn stover, etc.). To be able to use corn stover for biofuels, it would have to be mechanically removed from the field, leaving the soil more susceptible to water erosion.

1.1.1 Tolerable Soil Loss Limit

Conservation agriculture came into existence after the Dust Bowl and was aimed towards protecting farm lands from wind and water erosion. In the 1930’s, estimates showed that 91 million ha of land were impacted by extreme soil erosion (Utz, Kellogg et al. 1938; Hobbs 2007). The possibility of large scale biomass removal causes major concerns of elevated soil erosion. To help combat excessive removal amounts, the Natural Resources Conservation Service (NRCS) has developed a tolerable soil loss limit (T-value) that is defined as the allowable amount of annual erosion that can occur from an area in Mg ha^{-1}. This value is taken as the maximum amount of soil loss that could occur while maintaining the same grain yield as the previous year’s harvest. This value was not intended to be used as a determination of the amount of soil loss that could impact water quality in nearby water systems, but rather the amount that can be lost without decreasing crop production (Mann, Tolbert et al. 2002).

1.1.2 Biomass Feedstocks

One cellulosic feedstock that has become a major research focus is corn stover. Corn stover is comprised of the stalks, husks, leaves, and cobs. Each fraction of the plant contains a different amount of usable sugar for biofuel production and contributes to soil health in a different manner. When left on the ground, the husks and leaves degrade quickly, leaving the stalks and cobs to help reduce impact erosion and return nutrients back to the soil (Garlock, Chundawat et al. 2009). A study conducted by Montross and Crofcheck (2004) showed that the lowest glucose yields in the corn stover fractions occurred in the stalks. Thus, it was proposed that the fractions with the highest glucose yield (leaves, husks, and cobs) should be used for biofuels production, while the stalks would remain on the soil to help control possible erosion. Corn residue has been considered as a desirable feedstock for biofuel production because of its availability, abundance, and low cost. According to the United States Department of Agriculture (USDA), delivered feedstock costs were $60 per dry metric ton for corn stover and $70 per dry metric ton for wheat straw (Pitcock 2013). However, to ensure the long term sustainability of using corn residue as a feedstock, residue production needs to be further evaluated. If the removal of corn residue leads to high production costs in the future, either though reduced crop yields or added nutrient requirements, then using corn residue would no longer be an economical feedstock (English, Tyner et al. 2013).

Corn stover is estimated to provide at least 221 million tons annually of the billion ton vision (U.S. Department of Energy 2011). To estimate the amount of available corn stover, the harvest index is used. According to Ertl (2013), the harvest index is the ratio of the above-ground plant material to the grain yield. For corn, the average harvest index ranges from 47 to 56 percent. This means that roughly half of the above-ground plant is grain while the other is corn biomass or stover. The higher the harvest index, the more plant residue will be available for biomass harvest as well as leaving enough in the field to combat possible soil erosion.

1.1.3 Biomass Harvesting Systems

To ensure sustainable stover collection, several types of land, cropping, and harvest management practices could be utilized. These land management practices include no-till, minimum-till, strip-till, and other tillage systems that are used in conjunction with various cropping practices (for example, continuous corn, corn-soybean rotation, winter cover crops, wheat and double crop soybeans). Within these management and cropping practices, an additional variable considered has been stover removal practices.

A mechanical combine harvester is used to separate the corn grain from the stover. Various corn stover removal strategies employ the combine during grain harvest to assist in stover harvest. Typically combines harvest 8, 12, or 16 rows with a row spacing of 0.76 m (30 in) resulting in a swath width of 6.1 to 12.2 m (20 to 40 ft.). Material other than grain (MOG) that passes through a combine is a function of the head design and settings. MOG is typically all of the cobs and a large percentage of husks and leaves. Under normal operating conditions with a traditional corn head, a small percentage of the stalks will also pass through the combine.

One potential corn stover collection method would involve modifying the head to cut the stalk and allow additional biomass above the cut location to pass through the combine (Shinners, Binersie et al. 2003). The stubble height left in the field directly affects the amount of biomass that remains standing and therefore impacts the amount of stover harvested (Karkee, McNaull et al. 2012). The optimal system for biomass removal would be one that has the highest grain recovery as well as leaving enough biomass on the field for erosion control and biofuel production. Hoskinson, Karlen et al. (2007) investigated a system that would cut all of the corn stover above a certain height on the stalk during grain harvest and conveyed the material into a wagon towed by the combine. They found the best harvesting system would be a scenario where the material above 40 cm from the bottom of the stalk was cut and collected. This allowed for the greatest ground speed and produced the best harvest efficiency.

Research has been conducted on single and double pass harvest systems of corn stover with conventional corn heads (Shinners, Bennett et al. 2012; Keene, Shinners et al. 2013). A conventional corn head does not cut the stalk but is designed to take in the ear (cob and grain) and a minimal amount of husks, leaves, and stalks. Conventional corn heads have been was designed to minimize the amount of MOG passing through the combine. However, settings can be adjusted to increase the quantity of leaves and husks that would be collected by the combine. The MOG from the combine can then be harvested in a single or double pass scenario.

With a single pass system all of the MOG that passes through the combine is collected by a baler towed by the combine (Figure 1-1). No additional passes over the field are required for baling and this strategy would leave an even amount of residue over the entire field (Figure 1-2). Keene, Shinners et al. (2013) attached a round baler to the back of the combine to preform single-pass baling. There are several advantages to single-pass baling, including; less trips across the field leading to less soil compaction and contamination from possible fuel spills, as well as, a reduced total harvesting cost of 26% as compared to a double-pass system (Shinners, Bennett et al. 2012). Another advantage is the soil biomass cover is more uniform across the field. Where the double-pass system has variability between windrows and the baled windrow, the single-pass system has an even distribution of biomass across the entire field (Figure 1-2).

Figure 1-1 Single pass combine and large square baler system

Figure 1-2 Ground cover after single pass baling

A common corn head used by farmers in Kentucky is a 12 row chopping head. With this type of head, knives are mounted underneath the head that chops the stalks into smaller pieces to aid in degradation. The chopped stalks are not brought through the combine but are left lying in the field (Figure 1-3).The chopping head does not change the amount of MOG passing through the combine, but would influence how the simulated biomass was applied to the soil surface in these experiments.

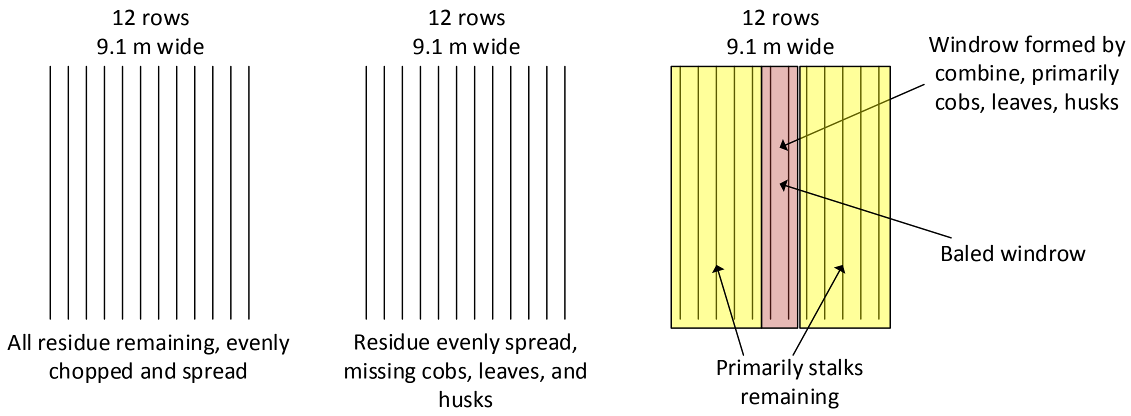
Figure 1-3 Corn stover residue after grain harvest with no biomass removal

When using a double pass system, the soil cover profile varies throughout the field. A windrow of MOG is produced from the combine and will be composed of primarily cobs, leaves, and husks. The second pass involves a tractor pulling a baler and collecting the windrow (Figure 1-4). A large quantity of the stalks directly underneath the windrow will be collected by the baler (Kepner, Bainer et al. 1980). This leaves most of the stalks, leaves, husks, and no cobs on the ground between the windrows. After baling, only a small percentage of leaves, husks, cobs, and stalks remain where the windrow had been (Figure 1-5).

Figure 1-4 Double pass baling of corn stover

Figure 1-5 Ground cover after double pass baling system

This thesis will examine the impact of corn stover removal in a single or double pass scenario compared to no corn stover removal when a chopping corn head is used. A single pass harvest system would leave an even amount of residue across the entire field. With the single pass system, almost all of the cobs will be removed and a large percentage of husks and leaves. In a double pass system, the material is windrowed by the combine and the resulting windrow is approximately 1.5 m (5 ft.) in width (Figure 1-6).



(a) (b) (c)

Figure 1-6 Distribution of corn stover biomass with no removal (a), single pass harvest (b), and double pass harvest (c)

1.2 Project objectives

To ensure sustainable corn stover removal for biofuels production, soil erosion must remain within tolerable limits. To accomplish that goal, acceptable removal rates must be established, and the influence of various stover removal strategies evaluated. Towards that end, this thesis focused on three specific objectives:

1. Create artificial roots and determine the effect of roots on soil erosion to facilitate the evaluation of varying cover and slope treatments;
2. Determine the effect of percent cover and slope on soil erosion resulting from corn stover residue removal strategies (single pass, double pass, and no removal); and
3. Evaluate the application of The Revised Universal Soil Loss Equation (RUSLE) on the single pass, double pass, and no removal of corn stover.

1.3 Organization of thesis

Chapter 1 provides an introduction to the thesis, including justification and background information as to the need for this research. This chapter also specifies the objectives for this thesis as well as the organization of the thesis. Chapter 2 provides a literature review of the information that pertains to soil erosion and biomass removal. Chapter 3 details the experimental design, data collection procedures, and data analysis. Chapter 4 presents the experimental results. Chapter 5 provides a summary of the conclusions. Chapter 6 illustrates the future work needed for this research topic. The appendices contain tables, graphs, and pictures not included in the body of the thesis.

CHAPTER 2:LITERATURE REVIEW

The purpose of this thesis was to determine the potential soil erosion caused by various corn stover residue removal strategies. In recent years, the idea of creating biofuels from agricultural residues has risen dramatically. One crop that has been a topic of interest is corn stover. Corn stover is a readily available crop residue that has a high sugar content that could potentially be used as a sugar source for biofuel production (U.S. Department of Energy 2011). Recent research studies have looked at the removal of corn stover for bioenergy production and potential environmental impacts, soil erosion being one of the major potential impacts (Haq and Easterly 2006; Johnson, Reicosky et al. 2006; Blanco-Canqui and Lal 2007; Garlock, Chundawat et al. 2009; Tan, Liu et al. 2012) .

Significant research has been conducted on the erosion rates for varying slopes, cover factors, soil types, and rainfall intensity. These will be reviewed briefly to provide a background for the research accomplished for this project. Models that have been used to examine water quality, soil erosion, and the importance of roots were also reviewed.

Noteworthy research has also been conducted on the environmental impacts of removal of cover factors and rooting systems. The research conducted on these topics will be selectively reviewed as it pertains to this study.

2.1 Soil erosion models

When evaluating erosion impacts, models are used to organize information and obtain logical predictions. There are several computer simulations that can help with time reduction by eliminating the need for in-field data collection and aiding in empirical analysis of data. These simulations can work through different scenarios, including cover factors, cropping systems, and rainfall intensities to help determine the most optimal field conditions for minimizing soil erosion (Thomas, Engel et al. 2009).

The Agricultural Production Systems Simulator (APSIM) (Keating, Carberry et al. 2003) displays the corn rooting system as it would be seen in the soil profile. The placement of the brace roots and the soil density play an important role in soil connectivity. Without the brace and micro roots holding the soil together, the potential for erosion to occur greatly increases. This program models the location and structure of the roots. With the model of the roots, it has the potential to be used in other soil erosion prediction models (Hammer, Dong et al. 2009).

There are several hydrology models that were developed to aid in the determination of soil erosion without collecting in-field data. The Soil and Water Assessment Tool (SWAT) (Arnold, Srinivasan et al. 1998) was created to simulate hydrologic processes in watersheds to estimate soil loss and streamflow. This model has been used to analyze the removal of sorghum residue from fields within a watershed to help determine the amount of soil erosion occurring. This simulation discovered that the larger rainfall events required more residues on the soil surface to help protect the land from soil erosion (Bumguardner 2013).

The Water Erosion Prediction Project (WEPP) (Nearing, Foster et al. 1989) was developed to account for several variables within a field to predict soil erosion amounts. The variables that WEPP focuses on are vegetation canopy covers, infiltration, soil types, land management practices, slopes, and rainfall intensities. WEPP was developed to build on other soil erosion models, or even replace them, such as the Universal Soil Loss Equation (Wischmeier, Smith et al. 1978; Simanton, Weltz et al. 1991).

2.1.1 Revised Universal Soil Loss Equation (RUSLE)

The Universal Soil Loss Equation (USLE) (Wischmeier, Smith et al. 1978) and the Revised Universal Soil Loss Equation (RUSLE) (Renard, Foster et al. 1991) models were developed to predict average erosion rates under varying cropping systems and land management practices while incorporating specific soils, rainfall events, and topography. The RUSLE equation has five to six parameters, depending on how the slope length and steepness are calculated; sometimes these two parameters are found as one rather than separate variables. The RUSLE equation is shown in Equation 2-1.

$$A = RKLSCP \qquad \text{Equation 2-1}$$

Where;

A=soil erosion, Mg ha^{-1} yr^{-1}
R=rainfall and runoff erosivity, MJ mm ha^{-1} hr^{-1} yr^{-1}
K=soil erodibility factor, Mg ha^{-1} ha hr MJ^{-1} mm^{-1}
L=slope length factor
S=slope steepness factor
C=cover management factor
P=support practice factor

The RUSLE equation takes into account the major parameters that affect soil erosion. The rainfall and runoff erosivity (R-value) is shown in Figure 2-1. This represents the amount of energy it takes for the raindrops to dislodge the soil particles from the surface, the amount of rainfall, and the storm intensity (Schwab 1992).

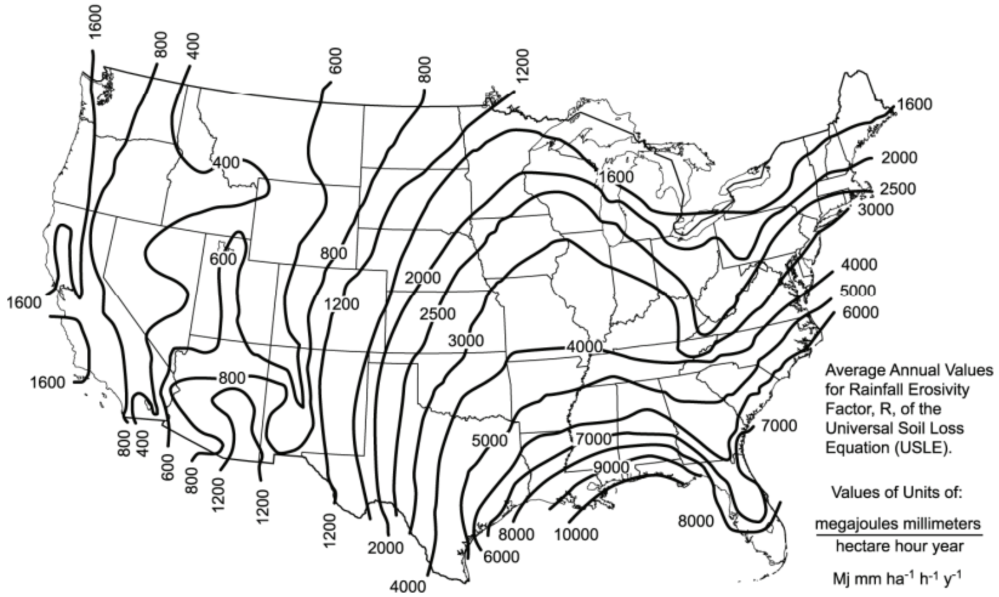


Figure 2-1 Rainfall and runoff erosivity R-factor by geographic location (adapted from Foster, McCool et al. (1981)) (Schwab 1992)(Schwab 1992)

The soil erodibility factor (K-value) takes into consideration the soil type and its properties. It is calculated using the percent sand, silt, clay, and organic matter; soil structure; and profile permeability class. The slope length (L) and slope steepness (S) values are topographic factors that are determined by the field slope angle and field length. The cover management factor (C-value) represents the amount of cover produced by soil biomass, canopy cover, soil roughness, soil moisture, and soil consolidation. The support practice factor (P-value) is the conservation practice factor and varies depending on contouring, tillage practices, and terracing (Schwab 1992). This model can be used to determine the amount of cover that needs to remain on the soil surface to protect against erosion (Spaeth, Pierson et al. 2003) because each variable within the equation is independent of the other, and they can be manipulated to try and find the optimal condition to control soil erosion.

2.1.1.1 Rainfall intensity effects on soil erosion

Rainfall intensities impact soil erosion based on the kinetic energy the rain drops induce on the soil surface (Richardson, Foster et al. 1983). Rainfall erosion (rill and sheet) occurs when rain drops directly hit the soil, dislodging the soil particles from the soil profile. Once the soil becomes saturated, the particles will be transported down slope (Nelson 2002). Critical shear stresses have been observed to quantify the effects corn stover residues have on soil erosion control. With the reduction of shear stress, residues reduce the detachments of soil particles when raindrops impact the soil surface. The cover absorbs the energy from the raindrop rather than the soil (Knapen, Poesen et al. 2008).

In a study conducted by de Carvalho, Durigon et al. (2014), they looked at varying rainfall erosivity (R) factors as well as cover factors over a 23 year time period. The cover factors they used were found by using 22 Landsat 5 satellite images. The R value was calculated using regression equations that were adjusted for the mean monthly rainfall, according to Renard, Foster et al. (1991).Within the 23 year study, four specific dates were compared at length. The four dates were compared to one another because they represented the dry and rainy season, and they had similar cover factors, for ease of comparison. The distributions of soil loss from each of the four dates are shown in Figure 2-2. From the figure, the four dates evaluated were October 1, 1994 (A), August 2, 2007 (B), May 20, 1986 (C), and May 10, 1994 (D). The mean cover factors were 0.235, 0.234, 0.090, and 0.090 for A, B, C, and D, respectively. For A, B, C, and D, the mean R values were 1,385.66, 9.50, 1,019.03, and 1,986.55 MJ mm ha^{-1} h^{-1}, respectively. Although the study dates had similar cover factors, the soil erosion amounts were different due to the variation in the rainfall erosivity value during the growing season. With this variation, the mean soil loss, for an individual rain event, ranged from 0.23-35.46 Mg ha^{-1}, an annual soil loss of 719.97 Mg ha^{-1}, and a mean loss of 109.45 Mg ha^{-1} for the four year study.

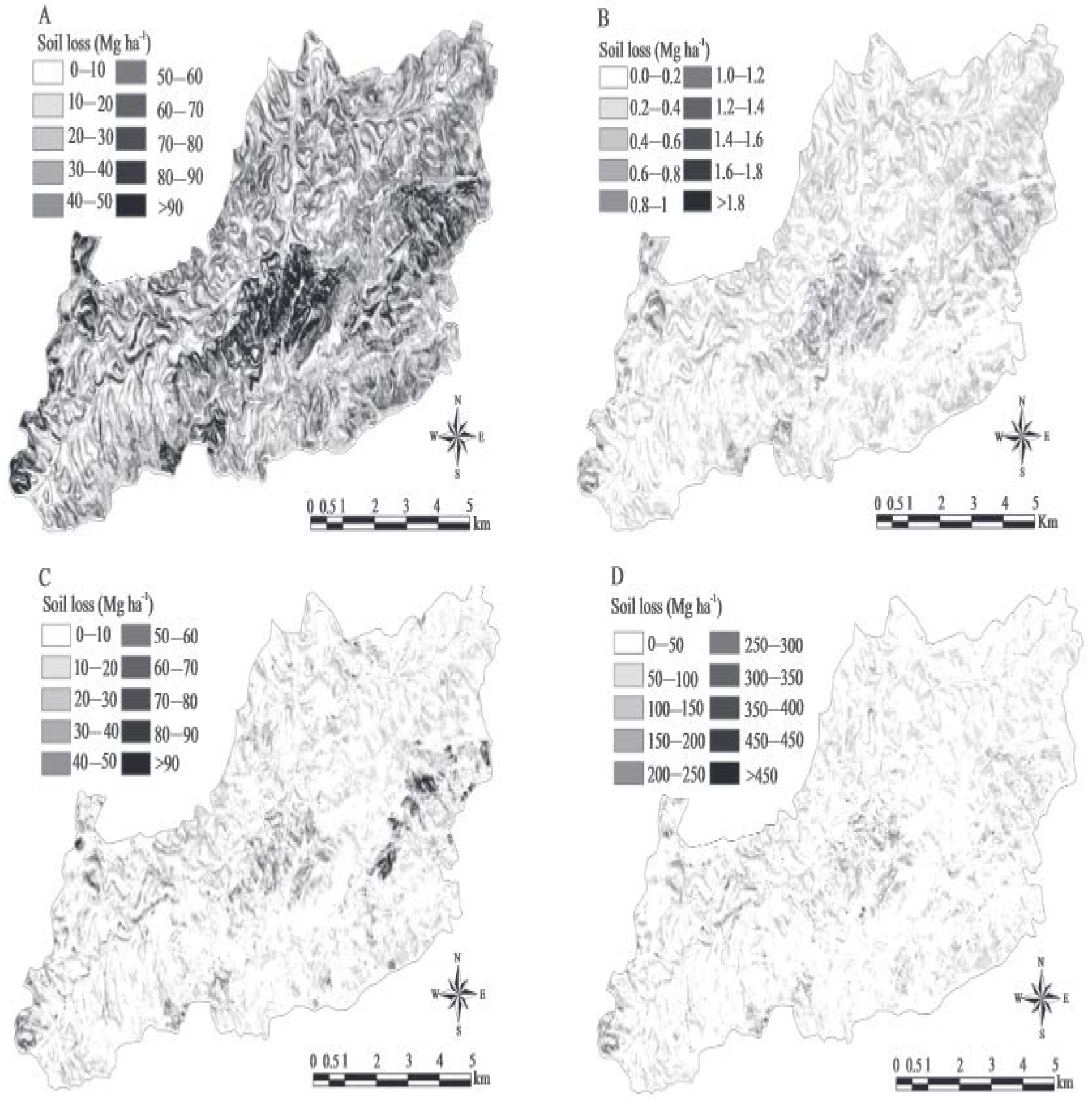


Figure 2-2 Soil loss based on the image acquired on October 1, 1994 (A), August 2, 2007 (B), May 20, 1986 (C) and May 10, 1994 (D), for the Palmares-Ribeirão do Saco watershed (de Carvalho, Durigon et al. 2014)

2.1.1.2 Soil effects on soil erosion

Soils behave differently when exposed to varied rainfall events, cover factors, and topography. A study conducted by Foster, Johnson et al. (1982) looked at critical slope lengths across a variety of soil types. Two of the soils were easily susceptible to rill erosion while the other two were not. Rill erosion is when water flows through small headcuts in the soil; while interrill erosion occurs when raindrops detach soil from the surface and the soil particles become loosened and more susceptible to sediment transport. The first was a Sidel silt loam that is susceptible to interrill erosion but not rill. The second soil type was a Russel silt loam, susceptible to rill erosion. The third a Miami silt loam only susceptible to rill erosion if it has been recently tilled and the forth a Miami silty clay, susceptible to rill erosion. The experiments conducted looked at the critical slope length regarding corn biomass cover, with the exception of the forth soil type looked at wheat straw. With the conclusions of this study, it was noticed that erosion rates increased by 3 to 15 times more after tillage than before tillage for a soil type that was not susceptible to rill erosion. It was concluded that critical slope lengths on untilled soil, for unsusceptible rill erosion soils were 45 to 200 m with mulch application rates of 0.2 to 0.9 kg m^{-2} on slopes of 7 to 9 percent. Also, critical slope lengths on untilled soil, for susceptible rill erosion soils were 40 to 150 m with mulch application rates of 0.6 to 1.3 kg m^{-2} on a 6 percent slope. When soils are susceptible to rill or interrill erosion, it is necessary for more cover to be present on the soil surface. When soil is tilled, it make the soil vulnerable to water erosion, and rills are more easily formed on tilled land, which in turn, makes the soil even more susceptible to erosion.

2.1.1.3 Slope effects on soil erosion

Slope length and steepness have a great impact on soil erosion and sediment-yield predictions. Foster and Meyer (1972) discovered that runoff transport capacity from uniform slopes during moderate rainstorm events is enough to transport available soil if the slope is greater than 2 or 3 percent and the soil is not permeable enough to reduce runoff. When looking at slope lengths and steepness, RUSLE only accounts for uniform slopes when land slopes can actually be convex, concave, or a series of convex, concave, and uniform sections. However, the effect of such irregularities on soil erosion is not accurately reflected by average slope steepness. In an effort to create new equations for determining soil erosion based on irregular slopes, Foster and Wischmei.W.H (1974) compared uniform slopes versus convex and concave scenarios. The evaluation of soil erosion was performed using RUSLE and assumed an R=200, K=0.49, C=0.25, and P=1 for all slopes, each averaging 7.5 percent. The soil loss that was calculated for the uniform, convex, and concave slopes were 99, 117, and 87 Mg ha^{-1}, respectively. What this indicated is that even with the same average slope percentage, the varied slope styles lead to differences in the soil loss.

2.2 Cover factors effect on soil erosion

There are several factors that influence the amount of soil erosion that occurs during a rain event. One major element that impacts the magnitude of erosion losses is soil cover. Removing residues from agricultural fields not only effects erosion but soil productivity and crop yields as well (Bumguardner 2013). Numerous studies have investigated the impact of removing biomass for biofuel production (Blanco-Canqui and Lal 2007; Hoskinson, Karlen et al. 2007; Tan, Liu et al. 2012; Miner, Hansen et al. 2013). Lindstrom (1986) determined the effect of different tillage management practices and levels of crop biomass harvesting on soil erosion. The experiments were conducted on two different study sites; a reduced tillage scenario on a Barnes loam with a 6% slope (1981 cropping season) and a no-till scenario with an Egan-Wentworth silty clay loam with a 5.8% slope (1984 cropping season). The residue levels were determined based off of USLE estimates to control the erosion amounts to the soil loss tolerance level of 11.2 tons ha^{-1} year^{-1}. The residue levels (Y) required, to be below the soil loss tolerance level, equated to 2,240 kg ha^{-1} for the Barnes and 1,680 kg ha^{-1} for the Egan-Wentworth soils. To simulate different harvesting scenarios, the residue was manipulated to represent a cover factor of 0.5Y, Y, and 2Y. During the 1981 cropping season, there were six notable storm events that produced runoff and soil erosion. The total amount of erosion for those six storms was 7,080, 11,830, 6,510, 1,750 kg ha^{-1} for the conventional tillage, and residue levels of 0.5Y, Y, 2Y and cover factor scenarios, respectively. For the 1984 cropping season, there were 10 storm events that produced water runoff and soil erosion.

The total amount of erosion that occurred was 32,790, 42,730, 10,400, and 5,470 kg ha^{-1} for the harvest scenarios of conventional and no-till with cover factors of 0.5Y, Y, and 2Y scenarios, respectively. It was concluded that soil erosion increased as the amount of residue harvested increased, for both planting systems.

In a study conducted by Gilley, Finkner et al. (1986), soil loss and sediment concentrations were observed with varying corn residue application rates. A random placement of residue rates of 0.00, 1.12, 3.36, 6.73, and 13.45 t ha^{-1} were applied to the simulation plots and were each replicated once. These application rates resulted in soil cover percentages of 0, 10, 31, 51, and 83%, respectively. They noticed with a residue rate of 13.45 t ha^{-1}, no runoff occurred for all rainfall application simulations. Soil losses were reported to be 4.26, 1.17, 0.46, and 0.03 t ha^{-1} for the 0.00, 1.12, 3.36, and 6.73 t ha^{-1} residue rates, respectively. They concluded that with, even a small amount of residue, there would be a reduction in soil loss. It was also concluded that with the 6.73 t ha^{-1} (51% soil cover) residue application rate, soil loss was essentially eliminated.

Smets, Poesen et al. (2008) examined the work conducted by 41 other studies and looked into the effect mulch cover has on soil erosion by water. They define the mulch factor (MF) to be the ratio of the soil loss rate from a covered soil surface to that of the uncovered bare soil. They separated the impacts of mulch cover into three different categories; soil properties, hydrology and runoff hydraulics, and soil erosion by water.

After reviewing the 41 case studies, it was concluded that mulch cover was effective in reducing soil loss from water erosion. It was shown that mulch covers have an effectiveness of b=0.038, in which b is a constant describing the effectiveness of mulch cover reducing soil loss (SL). Mulch cover can have a combination b-value (0.025-0.06) of rill and interrill erosion. The relationship of SL and b can be seen in Equation 2-2, where C is the mulch cover (%) and a and b are constants.

$$\mathrm{SL} = ae^{(-bC)} \qquad \text{Equation 2-2}$$

According to Woods (1989), residue can be quantified in three ways: percent cover, small grain equivalent (SGe), and pounds per acre (lbs/A). Corn residue is often estimated using one of the following methods: line-transect method, photo recognition method, and calculation method. The line-transect method frequently involves a 100 ft. measuring tape and residue counted on 100 marks that are directly over a piece of residue. The photo recognition method is conducted by making visual estimates of the cover and comparing those photos to the ones shown in Figure 2-3. The USDA has a protocol concerning cover factors being determined by photo recognition. With the calculation method, the percent cover is determined by multiplying the corn residue coefficient (60 lbs residue/ bushel grain) by the long-term yield. In a study conducted by Naudin, Scopel et al. (2012), the cover and mulch mass were determined by measuring the cover of the known plant residue mass. Photo recognition was also used to determine the percentage of cover in a given area. They specifically looked at the effects biomass removal has on soil cover. For a V. *villosa* field, 3 t ha^{-1} can be removed from three quarters of the field and 5.6 t ha^{-1} can be removed from the other quarter to maintain a 90% soil cover. Removal rates of 5.6 and 7.9 t ha^{-1} were required from three quarters and one quarter of the field to achieve a 30% soil cover, respectively.

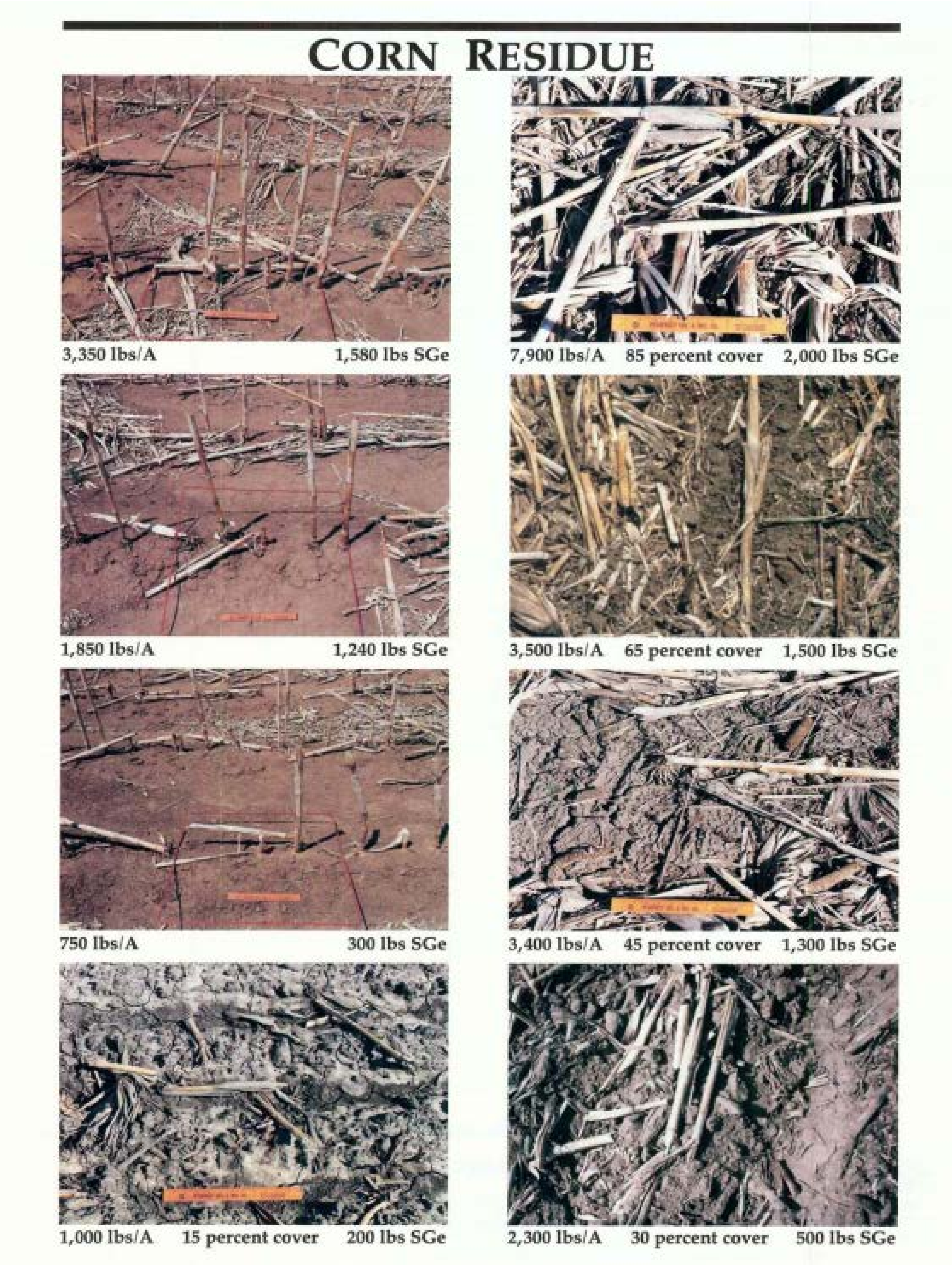


Figure 2-3 Corn residue photo recognition percentages and mass per area totals (Woods 1989)

Along with the USDA protocols, there are methods to calculate surface cover sub-factors based on residue weight. Figure 2-4 demonstrates the correlation between percent cover based on residue weight. An example of the using the graph would be, with 5000 lb ac^{-1} of corn residue at harvest equates to 82% soil cover and 2,500 lb ac^{-1} would represent 57% cover. With this relationship a 50% reduction in biomass does not change the cover factor by 50%. A 50% removal rate reduced the cover factor by 30% (Renard, Foster et al. 1997).

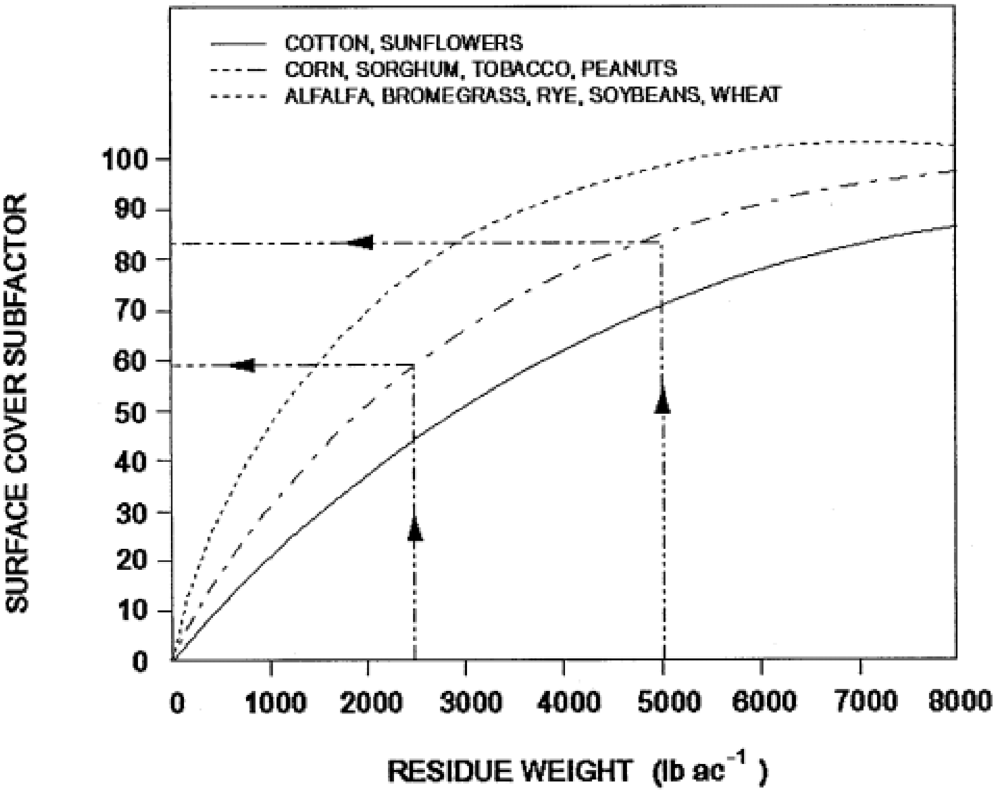


Figure 2-4 Relationship between residue weight and percent surface cover for various crops (Renard, Foster et al. 1997)

2.3 Total suspended solids (TSS) and turbidity

Total suspended solids (TSS) and turbidity are both indicators of water quality. The Environmental Protection Agency (EPA) defines turbidity, in units of nephelometric turbidity units (NTU), as the cloudiness of water. The higher the turbidity, the more likely the water is contaminated with disease or disease causing microorganisms. Most of the time, turbidity is caused by soil runoff (EPA 2014). TSS, on the other hand, is the total amount of solid material, organic or inorganic, present per volume of water. With this mass per volume measurement, sedimentation rates and sediment loads can be calculated (Environmental 2015). The two water quality characteristics are correlated to one another and both measurements are an indicator of reduced water quality.

There have been several studies conducted that looked specifically at lowering TSS and turbidity concentrations in runoff water (Outeiro, Ubeda et al. 2010; Bhuiyan, Rakib et al. 2011; Glendell and Brazier 2014). In a study conducted by Outeiro, Ubeda et al. (2010), agricultural runoff was compared to forest runoff for total suspended solids (TSS) and suspended sediment concentrations (SSC) on a sandy loam (Cambic Arenosol) soil. The TSS analysis considers all solids, including organic matter; while SSC only considers sediment particles in the runoff. The runoff concentrations were specifically analyzed during the September to October months because that is when the agricultural fields would have the most soil exposure due to low vegetation cover. Five intense rain events were studied and the SSC was reported for both the agricultural study site as well as the forest. However, only the agricultural runoff was analyzed for TSS concentrations. The mean SSC concentrations for the forest (133.8±2.3 mg l^{-1}) were significantly different than the agriculture concentrations (84.2±2.2 mg l^{-1}). Over the 5 storm events the TSS concentrations had a large range (0.36 to 18.31 mg l^{-1}). The conclusions of this study indicated that the forest runoff had significantly higher SSC concentrations than the agricultural study site, but those values may be influenced by human interactions and the spatial data layers used to compute the slopes and watershed areas.

Research conducted by Gilley, Finkner et al. (1986), looked at variations in sediment concentrations due to varying sorghum residue application rates. The sorghum residue was randomly placed on the erosion plots at rates of 0.00, 0.84, 1.68, 3.36, 6.73, and

13.45 t ha^{-1}. It was observed that the 13.45 t ha^{-1} application rate resulted in no runoff. Sediment concentrations were seen to be 31.5, 27.5, 12.8, 6.7, and 5.1 ppm x 10^3 for the 0.00, 0.84, 1.68, 3.36, and 6.73 t ha^{-1} residue rates, respectively. It was concluded that there was a significant reduction in total runoff for a residue rate of 3.36 t ha^{-1}. It was also summarized that there was significant reduction in sediment concentrations with a residue application rate of 1.68 t ha^{-1}. In general, an increase in sorghum residue helped reduce sediment concentrations in water runoff.

Kang, Amoozegar et al. (2014) looked at adding polyacrylamide (PAM) to the soil surface as an erosion reduction method. The experiments were conducted using constructed soil erosion boxes and a rainfall simulator. Four treatments ((i)no cover + no PAM, (ii) cover + PAM, (iii) cover + granular PAM (GPAM), (iv) and cover + dissolved PAM (DPAM)) were evaluated to see the effects the PAM cover had on TSS and turbidity concentrations in the runoff. The results showed that ground cover, alone, reduced turbidity and TSS concentrations by 60% as compared to bare soil. During the first rainfall event, the turbidity concentrations were 2315, 903, 78, and 60 NTU for treatments i, ii, iii, and iv, respectively. For the TSS, concentrations were 2670, 1039, 79, and 69 mg l^{-1}, for treatments i, ii, iii, and iv, respectively. Due to the decrease in TSS and turbidity concentrations with the application of PAM, it was suggested that PAM, applied in the dissolved form, would greatly reduce erosion under heavy rainfall events and would improve water quality in runoff.

CHAPTER 3: MATERIALS AND METHODS

3.1 Experimental setup

3.1.1 Soil erosion box design

This study was conducted in a laboratory located in the Charles E. Barnhart Building at the University of Kentucky. A rainfall simulator was used for all experiments; whose construction was described by Miller (1987). Soil erosion boxes were constructed using a 1.22 m X 1.22 m board (4 X 4 ft. sheet of plywood) as the base and 5.08 X 15.24 cm (standard 2 X 6 in) pieces of lumber as the sides. Under the box, a pallet was constructed for easy maneuverability with a forklift. This pallet was built using 5.08 X 10.16 cm (standard 2 X 4 in) boards with 45.7 cm spacing. The boxes are depicted in Figure 3-1. Another set of boxes were manufactured for the 2013 actual corn roots growing season. These soil erosion boxes were constructed using a 1.22 m X 2.44 m board (4 X 8 ft. sheet of plywood) as a base and 5.08 X 30.48 cm (standard 2 X 12 in) pieces of lumber as the sides. The rest of the box construction was the same as the small erosion box design.

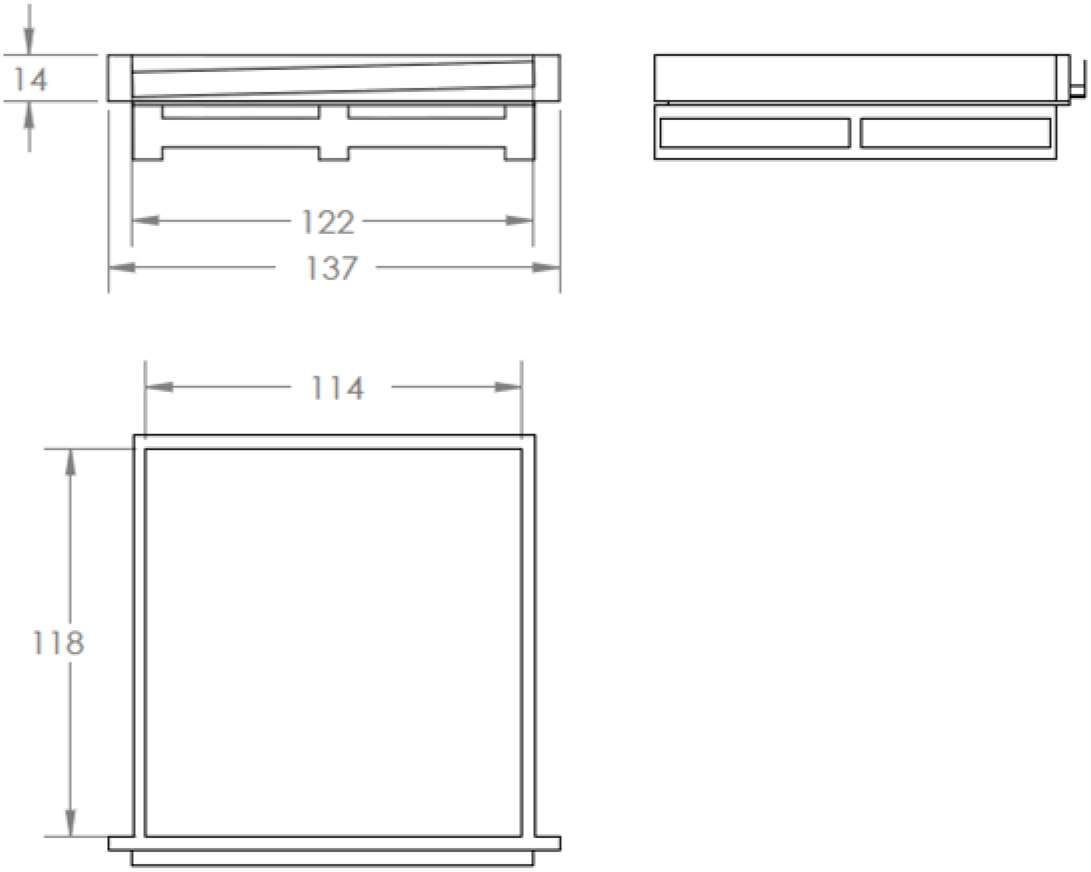


Figure 3-1: Soil erosion box dimensions (dimensions are in cm)

The boxes were lined with geotextile fabric to seal cracks around the wood framing. On the 114 cm end of the erosion box, a gutter was added to allow for sample collection. The gutters were made out of aluminum flashing with a 3% slope, to ensure all runoff would be directed to the sampling end. To ensure the runoff sample was not diluted by the rainfall, an aluminum flashing gutter shield was placed on top of the gutter to direct water away from the sampling end.

The target dry soil bulk density in the boxes was 1.12 g cm^{-3} (70 lb ft^{-3}) that was compacted following a method proposed by Romkens, Helming et al. (2002).This packing method consisted of a 41 kg steel weight being dropped six times from a height of 61 cm onto a 61 X 61 cm steel plate. The plate was positioned into the four quadrants and compacted each time. The soil was compacted in two different layers that had approximately 136 kg (300 lb) of soil at a nominal 15% w.b. moisture content and was leveled for each 8 cm lift. After compaction, the soil profile was screeded and limited amounts of soil added as needed to ensure a level, even surface for the experiments.

3.1.2 Soil classification

The soil used was taken from the University of Kentucky's Maine Chance Research Farm (Latitude: 38.1164°N; Longitude: 84.4903W). The soil was dug vertically down, and consisted mostly of the A profile and some of the B layer. The soil samples were taken to the University of Kentucky's Regulatory Services to determine soil type and composition. The soil was determined to be a Maury silt loam (fine, mixed, mesic Typic Paleufalf) composed of 13% sand, 72% silt, and 15% clay.

3.2 Objective 1: Determine the effect of roots on soil erosion and create artificial roots to facilitate the evaluation of varying cover and slope treatments

The goal of this objective was to determine the influence of the corn root system related to soil erosion. Growing corn for each cover and slope treatment was not practical due to time constraints, therefore simulated roots were constructed. These simulated roots could then be used in further analysis, rather than actual corn roots. This objective was completed by growing corn in soil erosion boxes and using a rainfall simulator. When conducting each of these experiments a 5% slope with only the roots as soil cover was compared to bare soil and simulated roots. The treatments for this objective were bare soil (no roots), actual corn roots (no cover), and simulated corn roots (no cover). There was a minimum of three replicates preformed for each treatment and the runoff volume, total suspended solids (TSS), and turbidity were measured.

3.2.1 Corn growth process

The actual corn roots used in this experiment were grown in soil erosion boxes. The corn (Pioneer Hi-Bred 6626RR) was planted on May 14, 2014 with a row spacing of 0.38 m (15 in), which allowed for 12 plants to be grown in each erosion box that would correspond to a plant population of 88,900/ha (36,000/ac) (Figure 3-2). A second set of actual corn roots were grown from May 19, 2013 until October 20, 2013. The same type of corn was grown with row spacing of 0.76 m (30 in) and inter-row spacing of 0.18 m (7 in), which allowed for 15 plants to be grown in each erosion box that would correspond to a plant population of 50,500/ha (20,400/ac). The seed planting was the same for the 2013 and 2014 growing season.

Figure 3-2 Illustration of soil erosion box with planted corn

Each seed was planted 4 cm deep, 21 cm from the box sides, and 28 cm apart (inter-row). The planting schematic is shown in Figure 3-3 . After planting, 227 g of ammonium nitrate was applied to the soil surface to promote plant growth as well as being watered every other day for the 105 day growth period. The corn stalks were hand cut approximately 31 cm above the roots, similar to the height remaining after harvest using a chopping corn head, on August 27, 2014.

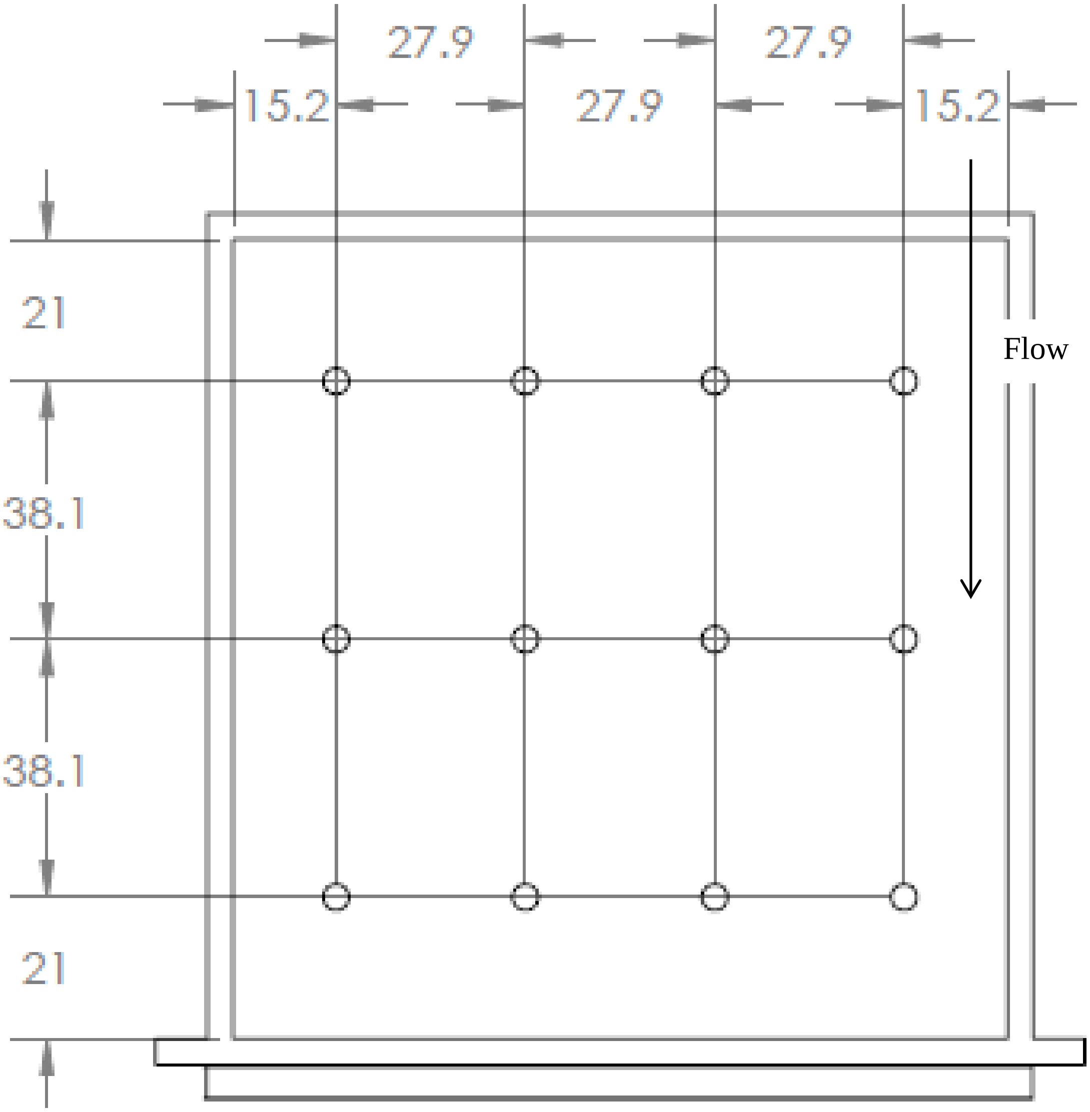


Figure 3-3: Position of corn plants in soil erosion boxes (dimensions in cm)

3.2.2 *Simulated roots*

Corn roots are an essential part to erosion control; however, corn takes 90-120 days to reach full maturity and using actual corn roots for the cover factor experiments was not feasible. Because of time constraints, simulated roots were created to allow the rooting system to be present in all experiments without being dependent on corn growth. These roots were modeled after a corn root that had grown in an erosion box and were manufactured out of welded steel. The simulated roots are shown in Figure 3-4. Each root had a stalk made out of 3.2 cm steel conduit piping and had approximately 28 simulated brace roots. The brace roots were made from 0.62 cm diameter steel rods that were welded to the stalk. There were two concentric rings of brace roots. The inner ring had a diameter of approximately 8.25 cm and the outer ring of roots had a diameter of 12.7 cm. The tips of the brace root pieces were ground and filed to a sharp point to facilitate insertion into the compacted soil.

Figure 3-4 Simulated corn roots driven into soil prior to placement in rainfall simulator

3.2.3 Slope

The slope used for the comparison of the different root type experiments was 5%. To achieve the desired slope, lumber was used as a lift. To reach a 5% slope, the box needed to have a 6.1 cm lift placed at the back end of the box, opposite of the gutter system.

3.2.4 Rainfall

If required, simulated roots were installed into the soil erosion boxes. The erosion boxes were saturated at a 0% slope in order to preserve the soil and not create runoff. Once water began to pool on the soil surface, rainfall was stopped and the lifts for the desired slope were put into place. The simulated rainfall began with an application rate of 30 mm hr^{-1} and continued for 46 minutes after runoff began. This storm event was the one year, one hour storm intensity for Lexington, Kentucky. This intensity was chosen because it would be strong enough to produce runoff, but is still commonly seen throughout a years' time. The calibration curve for the rainfall simulator used in these experiments can be found in Appendix A.

3.2.5 Runoff sample collection

Runoff samples were collected in 1 L washed polyethylene bottles at time intervals of 2, 4, 8, 14, 22, 30, 38, and 46 minutes after runoff began. A stopwatch was used to record the time it took to collect the runoff sample (Edwards, Moore et al. 1999). Using the bottle fill time and the mass of each runoff sample, the mass flow rate was computed for each time interval. After collection, the samples were stored at 2.8°C (37°F) at the University of Kentucky Biosystems and Agricultural Engineering Department until being analyzed (Enlow 2014).

3.2.6 Laboratory analysis

Runoff samples were analyzed for total suspended solids (TSS) and turbidity. The analysis of the samples was conducted at the University of Kentucky Biosystems and Agricultural Engineering Department using a LaMotte 2020 turbidimeter (Chestertown, Maryland) for turbidity analysis and a Sequoia Scientific LISST-Portable|XR (Bellevue, Washington) for the TSS analysis. For all dilutions, the standard procedure was conducted according to the LISST-Portable XR manual (Sequoia 2011).

3.2.7 *Density determination*

After testing, three soil cores were taken to determine the dry bulk density. The schematic of the coring probe is shown in Figure 3-5. The two pieces of aluminum fit together and a piece of wood was placed on the top. Using a hammer, the probe was driven into the soil surface until the bottom piece was completely submerged. The soil was then excavated from around the probe and the upper portion of the probe was removed. Excess soil was cut level from the bottom and top section to allow for a consistent sample volume. The soil was then oven dried at 100°C for 24 hours and weighed to calculate the dry bulk density.

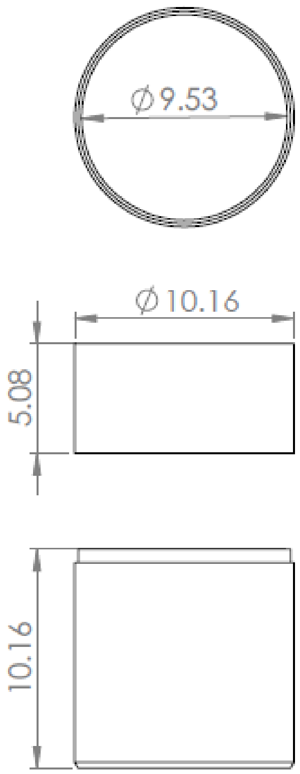


Figure 3-5 Density probe design (dimensions in cm)

3.2.8 *Data analysis*

After analysis, the runoff samples were normalized by the volumetric flow rate and transformed using the natural logarithm. This was to normalize all data because the flow rates were not consistent between experiments. The flow rate was calculated using the bottle fill time divided by the mass of the runoff sample. This mass flow rate was then converted into a volumetric flow rate with units of L s^{-1}. All statistical analysis was performed using the PROC GLM (general linear models) model and the Tukey range test (MEANS) in SAS 9.4. Changes over time were evaluated as repeated measures, with time being the repeated measure. A significance level of $\alpha=0.05$ was used for all analysis.

3.3 Objective 2: Determine the effect of percent cover and slope on soil erosion resulting from corn stover residue removal strategies (single pass, double pass, and no removal)

The overall goal for objective 2 was to determine the effect of three cover factor scenarios on the rate of soil erosion from three slopes. This objective was completed by using soil erosion boxes, a rainfall simulator, and varying types and amounts of corn stover cover fractions.

3.3.1 Rainfall

The soil erosion boxes with bare soil (no roots or cover) were saturated at a 0% slope until pooling began. Rainfall was stopped and the simulated roots and associated cover factors were placed on the soil surface. Rainfall began again until the biomass was completely saturated and pools began to form on the soil surface; rainfall was stopped and the box was lifted to the desired slope. The simulated rainfall began with an intensity of 30 mm hr^{-1} and continued for 46 minutes after runoff began. Appendix A. has the calibration curve for the rainfall simulator.

3.3.2 Slope

The effect of slope was examined using three levels (1, 5, and 10%).These factors were chosen to represent the range of slopes typically encountered on crop fields in Western Kentucky. To achieve a slope of 1, 5, and 10%, lumber was used to raise the rear of the soil boxes by 1.2, 6.1, and 12.2 cm respectively. This lift was placed at the back end of the box, opposite from the gutter system.

3.3.3 Cover factors

Corn stover was obtained from the C. Oran Little Research Farm in Versailles, Kentucky (latitude: 38.0837°N; longitude: 84.722W). The crop was hand harvested at the end of the 2013 growing season. The crop was separated into cobs, husks, leaves, stalks, and grain on campus. This material was then stored in cold storage at the University of Kentucky Biosystems and Agricultural Engineering Department until the experiments were conducted.

Three different cover factors were taken into consideration: no removal after harvest (NR), what stover remains after a windrow was baled (BW), and in-between windrows with biomass removal (IBW). The NR cover factor represents a no-till scenario where the cover remains in the field after harvest and is not disturbed until the next year's crops are planted. This cover treatment consists of all the leaves, stalks, cobs, and husks that would remain in the field after grain harvest. The BW cover factor was simulated by the amount of residue that would remain in a windrow after baling. In a field, this cover would only be seen on two rows out of every twelve rows harvested. The other ten rows would be the amount of biomass seen in the IBW cover treatment. The IBW cover factor represented the amount of stover that would be located in between the windrows. Figure 1-6 illustrates the different cover factors that could occur across a field. Weighting the representative areas with treatments IBW and BW would allow for the evaluation of double pass baling. IBW would correspond to single pass collection of corn stover.

To accurately determine the amount of biomass remaining on the soil surface for each scenario, unpublished data from Montross and Turner was utilized. An unpublished study (Koeninger, Montross et al. 2013) utilizing subsurface drip irrigation allowed for the estimation of corn stalks, cobs, leaves, and husks as a function of grain yield. These amounts were calculated using the regression equations from Table 3-1. All grain and biomass yields were calculated using a zero percent moisture basis. To be consistent with this study, the stalks above and below the ear were combined to find the total mass of stalks remaining on the ground. The regression equations were used to determine the mass of each component that would need to be on the soil erosion boxes when looking at the NR cover scenario. A grain yield of 3.82 t ha^{-1} (180 bu ac^{-1}) was used to estimate the amount of stover on the surface. This corresponded to an average yield for Kentucky (NASS 2014) and matched the yield shown in the field scale corn stover harvest pictures (Appendix B.).

Turner, Montross et al. (2012) provided the distribution of corn stover fractions in double pass large square bales. This, along with data from Montross (2003) was used to determine the mass of each fraction that would be on the ground in-between baled windrows (IBW) and what would remain after baling had occurred (BW). To calculate the amount of stalks that would be within a baled windrow, only two out of the 12 rows, or 16% of the harvested area, were taken into consideration. Stalks from the other 10 rows would not be collected due to the design of the combine. These stalks are chopped during harvest and the biomass remained near the roots. In a double pass harvest system the baler only picks up two rows of stalks for each 12 rows harvested.

Turner, Montross et al. (2012) indicated that the average biomass collected in a double pass scenario was 1.87 Mg ha^{-1}. The bale composition on a mass basis was 21, 19, 9, and 49% for leaves, husks, stalks, and cobs, respectively. To determine the amount remaining on the ground after the baler was operated, the baled biomass was subtracted from the total amount. To calculate the biomass left in-between the windrows, the baled biomass and the stover remaining after baling was subtracted from the total biomass. Table 3-2 shows the amount of each component that was randomly placed on the soil erosion boxes for each treatment. The corn stalks were cut into 10 cm pieces with a table saw and placed on the soil surface. This would also approximate the conditions seen in the field with a chopping corn header.

Table 3-1: Regression equations for biomass yield (dry t ha^{-1}) as a function of grain yield (g) (Koeninger, Montross et al. 2013)

Components	**Equation**	**r^2**
Leaves	0.2482g + 1.0103	0.88
Husks	0.1011g + 0.2683	0.54
Stalks above ear	0.0332g + 0.7796	0.08
Stalks below ear	0.4263g + 0.5194	0.63
Cobs	0.132g + 0.6309	0.87
Total biomass	0.9409g + 3.2085	0.91

Table 3-2 Cover factor mass (g m^{-2}) applied to soil erosion boxes

Components	**NR**	**IBW**	**BW**
Leaves	381	290	52
Husks	141	95	11
Stalks	649	527	106
Cobs	212	0	121

3.3.4 Runoff sample collection

The runoff samples were collected following the procedure described in section 3.2.5.

3.3.5 Laboratory analysis

TSS and turbidity analysis was performed as described in section 3.2.6 and the soil density measured as described in section 3.2.7

3.3.6 Data Analysis

These experiments were analyzed as a 3x3 factorial with repeated measurements. The slope and cover factor were the factors considered and the samples taken at each time interval were treated as repeated measures. All statistical analysis was conducted using the PROC GLM (general linear models) function and Tukey range test (MEANS) in SAS 9.4. A significance level of $\alpha=0.05$ was used for all data analysis.

3.4 Objective 3: Evaluate the application of The Revised Universal Soil Loss Equation (RUSLE) on the single pass, double pass, and no removal of corn stover

The overall goal of objective 3 was to evaluate the suitability of RUSLE to estimate soil erosion from varying cover types and slopes. This was completed by transforming the TSS concentrations found in objective 2 into soil lost for the modelled storm event. A comparison was then made between the measured soil loss and the computed RUSLE values. Potential soil erosion from the alternative corn stover harvest strategies were then compared to the no residue removal option.

3.4.1 Revised Universal Soil Loss Equation (RUSLE)

The Revised Universal Soil Loss Equation (RUSLE) was used to model the amount of erosion that would occur with varying cover factors and slopes. RUSLE was previously discussed in section 2.1.1.

Following USDA (2013) guidelines, the coefficients for RUSLE were determined using the following procedure. The rainfall and runoff erosivity factor (R-value) was found using a specific storm event of 30 mm hr^{-1} which is the one hour, one year storm event for Lexington, KY (NOAA, Commerce et al. 2014). This storm event was chosen because it was intense enough to produce runoff in all experiments, but was still an event that would be typically seen at least once a year. The R-value found using the specific storm event modeled in this thesis was calculated using Equation 3-1 (USDA 2003; Pitt 2004).

$$\mathrm{R} = \sum_{j=1}^{J} (EI_{30})_j \qquad \text{Equation 3-1}$$

Where;

E=erosivity of individual storm, MJ ha^{-1}

I=rainfall intensity, mm hr^{-1}

j=index for each storm

J=number or storms per year

The erosivity of the individual storm (E) is calculated using Equation 3-2.

$$\mathrm{E} = \sum_{k=1}^{M} e_k \Delta V_k \qquad \text{Equation 3-2}$$

Where;

e=unit energy, MJ ha^{-1} mm^{-1}

ΔV=rainfall amount for the kth period

k=an index for periods during a rain storm where intensity can be considered to be a constant

M=number of periods

The unit energy is calculated using Equation 3-3.

$$e = 0.29[1 - 0.72\exp(-0.082i)] \qquad \text{Equation 3-3}$$

Where;

i=rainfall intensity, mm hr^{-1}

The soil erodibility factor (K-value) was found using Equation 3-4 (Schwab 1992) and the soil properties listed in Table 4-5.

$$K = 2.8 * 10^{-7} M^{1.14}(12 - a) + 4.3 * 10^{-3}(b - 2) + 3.3 * 10^{-3}\,(c - 3) \qquad \text{Equation 3-4}$$

Where;

M=particle size parameter (% silt + % very fine sand) X (100 - % clay)

a=percent organic matter

b=soil structure code (very fine granular, 1; fine granular, 2; medium or coarse granular, 3; blocky, platy, or massive, 4)

c=profile permeability class (rapid, 1; moderate to rapid, 2; moderate, 3; slow to moderate, 4; slow, 5; very slow, 6)

The slope length (L-value) was found using Equation 3-5 (Schwab 1992). According to USDA (2013) the slope length (l) used in Equation 3-5 would be considered 4.52 m rather than the box length of 1.22 m because of the relationship between the overland flow path distance and the rill-interrill steepness.

$$L = \left(\frac{l}{22}\right)^m \qquad \text{Equation 3-5}$$

Where;

l=slope length, m

m=dimensionless exponent

Where m is expressed by Equation 3-6 and θ is found using Equation 3-7.

$$m = \frac{\sin(\theta)}{\sin(\theta) + 0.269\sin(\theta)^{.8} + 0.05} \qquad \text{Equation 3-6}$$

Where;

Θ=field slope steepness in degrees

$$\theta = tan^{-1}\left(\frac{s}{100}\right) \qquad \text{Equation 3-7}$$

Where;

s=field slope in percent

The slope steepness factor (S-value) was found using Equation 3-8 for slopes less than 9 percent and Equation 3-9 for slopes greater than 9 percent, both specifically calibrated for field lengths less than 4 m (USDA 2013).

$$S = 10.8 sin(\theta) + 0.03 \qquad \text{Equation 3-8}$$

$$S = 16.8 sin(\theta) - 0.50 \qquad \text{Equation 3-9}$$

The cover management factor (C-value) was determined for each of the three treatments; NR, BW, and IBW using photographs. The cover factor percentage used in RUSLE is the percent of the soil surface exposed, rather than the percentage of biomass covering the ground. The C-values for the three biomass harvesting strategies were determined using photo recognition. On a field in Western Kentucky, after the 2013 corn harvest, a 1 X 1m square was made out of 5 cm PVC pipe and placed on the ground, in and outside of baled windrows. Several pictures were taken at random locations throughout the field to get an accurate representation of the cover conditions. Photos were then taken of the biomass on the soil erosion boxes to compare to actual field conditions (Woods 1989). The support practice factor (P-value) was 1 for all calculations because there was no strip cropping, contouring, or terracing in any experiments.

3.4.2 Data analysis

The predicted soil loss from RUSLE was compared to the laboratory experiments. To calibrate RUSLE, the cover factors were adjusted to match the experimental data. A comparison of corn stover removal strategies and their impact on potential soil erosion was also performed.

CHAPTER 4:RESULTS AND DISCUSSION

4.1 Objective 1: Determine the importance of roots concerning soil erosion and create artificial roots to facilitate the evaluation of varying corn and slope treatments

4.1.1 Overview

The application of artificial roots for the evaluation of soil erosion with varying cover factors are presented in this section. The TSS concentrations and turbidity measurements were determined from bare soil, actual corn roots, and simulated roots at a slope of 5%. The flow rate, TSS concentration, and turbidity concentrations were compared between the three soil conditions (bare soil, actual corn roots, and simulated roots). The results demonstrated the potential similarity between the actual corn and simulated roots for the use in laboratory soil erosion studies.

4.1.2 Flow rate determination

The volumetric flow rate calculated for each runoff sample was used to normalize the turbidity and TSS concentrations. The flow rate, as a function of time since runoff, and the standard deviation for the three soil conditions at a slope of 5% are shown in Table 4-1.

Table 4-1 Actual corn, simulated roots, and bare soil average volumetric flow rates and standard deviations at a slope of 5%

	Actual Corn		**Simulated Roots**		**Bare Soil**	
Time Since Runoff (min)	**Average (L s^{-1})**	**Stdv.**	**Average (L s^{-1})**	**Stdv.**	**Average (L s^{-1})**	**Stdv.**
2	0.016	0.008	0.014	0.004	0.011	0.002
4	0.016	0.007	0.015	0.004	0.013	0.003
8	0.017	0.008	0.016	0.005	0.015	0.004
14	0.021	0.005	0.018	0.006	0.019	0.003
22	0.022	0.003	0.019	0.007	0.019	0.003
30	0.023	0.004	0.018	0.007	0.019	0.002
38	0.022	0.004	0.019	0.007	0.020	0.002
46	0.023	0.005	0.019	0.007	0.021	0.003

4.1.3 Turbidity

The turbidity for each treatment was measured and shown in Figure 4-1. All of the treatments trended the same way, with the first flush occurring during the 2 to 4 minute sample times and decreased turbidity as runoff continued. As expected, the turbidity concentrations from the simulated roots were lower than the bare soil, but not significantly different. Unexpectedly, the turbidity measured from the actual corn roots was higher than both the bare soil and simulated roots. At the 8 minute sampling time, there was a significant difference between the actual corn roots and simulated roots. However, after 8 minutes until the end of the rain event, there was no significant difference between the bare soil, actual corn roots, and simulated roots.

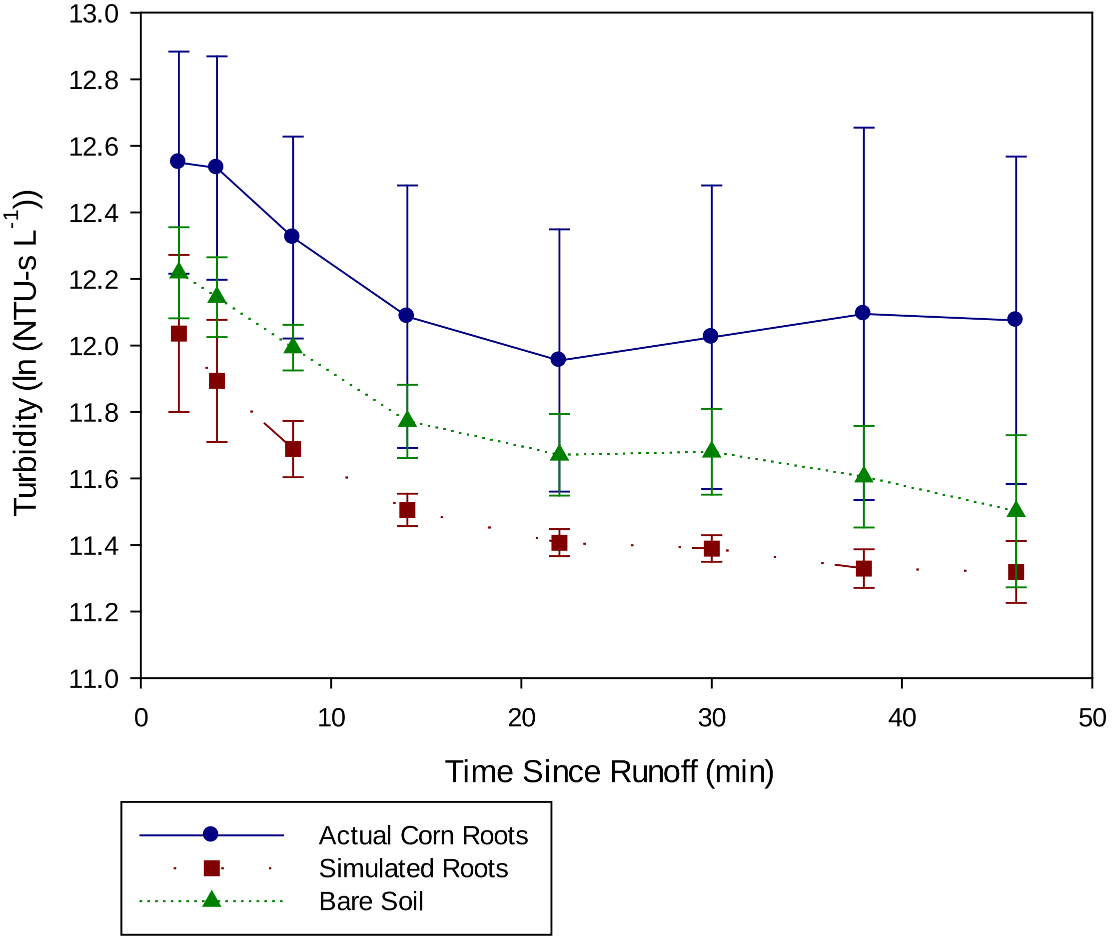


Figure 4-1 Average turbidity concentration and standard deviation (3 replications) adjusted for normalized flow (natural logarithm) at 5 % slope versus time since runoff (actual corn roots, simulated roots, and bare soil)

The hypothesis was that corn roots and simulated roots would be statistically not different in terms of runoff volume and turbidity concentration. In addition, it was hypothesized that the bare soil would have a higher runoff and turbidity concentration compared to the corn and simulated roots. Neither hypothesis was correct. The runoff volumes from all three conditions were statistically not different (p-value=0.7164). This is not that surprising since the roots provide limited soil cover that would influence the runoff volume. Surprisingly, the turbidity concentrations between the three soil conditions were statistically not different. This was primarily due to the high variation seen with the corn roots.

One potential reason for the highly variable turbidity concentrations with the actual corn roots was due to environmental conditions while the corn was grown. Twelve soil erosion boxes were placed outside from May 14 to August 26, 2014. Four of the boxes had corn planted and eight were bare soil to be used for the bare soil control and the simulated root treatments. Unfortunately, towards the end of the growth period, excessive rainfall occurred that resulted in highly saturated soils. The boxes did not have drainage and there was not sufficient evaporation and transpiration to prevent extended periods of soil saturation. Because of this excess water, algae growth to varying degrees on all of the soil surfaces was evident based on a green tint.

The algal growth was severe on the bare soil and simulated root treatments. When the boxes were placed under the rainfall simulator, very small amounts of soil were in the runoff samples. The algae had formed a protective layer on the soil surface and prevented erosion. The boxes for the simulated roots and bare soil were emptied and re-packed. After the boxes were re-packed, the bare soil and simulated root treatments produced data that was expected. Although not statistically different, the simulated corn roots had a slightly lower turbidity concentration and runoff volume relative to the bare soil. A comparison between the actual corn roots and the simulated roots was not possible, likely due to interference from algae on the corn boxes. It was believed that the algae cells on the soil surface and potentially organic contamination from the corn growth and weeds were in the runoff and artificially increased the turbidity concentrations from the corn boxes. This likely skewed the turbidity of the runoff from the corn boxes. There was a large variation in the turbidity from the four replications; it is unknown what the exact cause of the large variation in turbidity was with the actual corn.

However, experiments were conducted during the 2013 growing season, to determine if actual corn roots and simulated roots behaved similarly to one another (Figure 4-2). The results showed that there was no significant difference between the actual corn roots and simulated roots (p-value=0.433). Also, the bare soil was significantly different than the simulated and actual corn roots turbidity concentrations (p-value<0.001). Unfortunately, the soil density was not taken for the actual corn root boxes; therefore, this data can only be treated as preliminary data and a basis for the hypothesis of the simulated roots emulating the actual corn root functions.

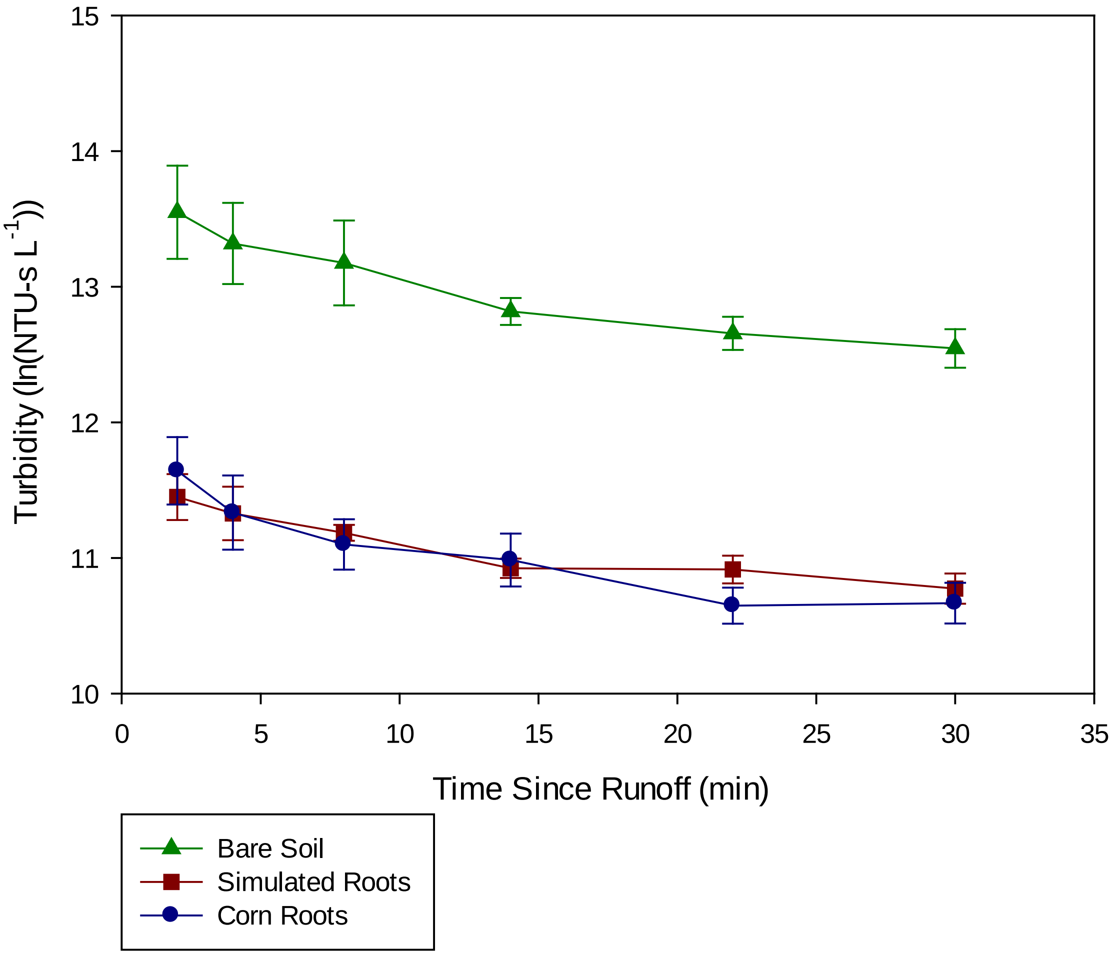


Figure 4-2 Average turbidity concentration and standard deviation (3 replications) adjusted for normalized flow (natural logarithm) at 5 % slope versus time since runoff for the 2013 growing season (actual corn roots, simulated roots, and bare soil)

4.1.4 Total Suspended Solids

The total suspended solids (TSS) concentrations were analyzed and are shown in Figure 4-3. Similar to the turbidity concentrations, the simulated roots had a TSS concentration that trended lower than the bare soil treatment. Conversely, the actual corn roots treatment had a higher TSS concentration than the bare soil and simulated root treatments. The largest difference between each treatment was at the 2 minute sample time with concentrations of 2122, 2615, and 3875 mg l^{-1} for the simulated roots, bare soil, and actual corn roots, respectively. However, the actual corn roots, simulated roots, and bare soil were not significantly different (p-value=0.1717). The elevated TSS concentrations measured in the actual corn roots runoff was most likely due to elevated organic matter in the sample, including potential algal cells.

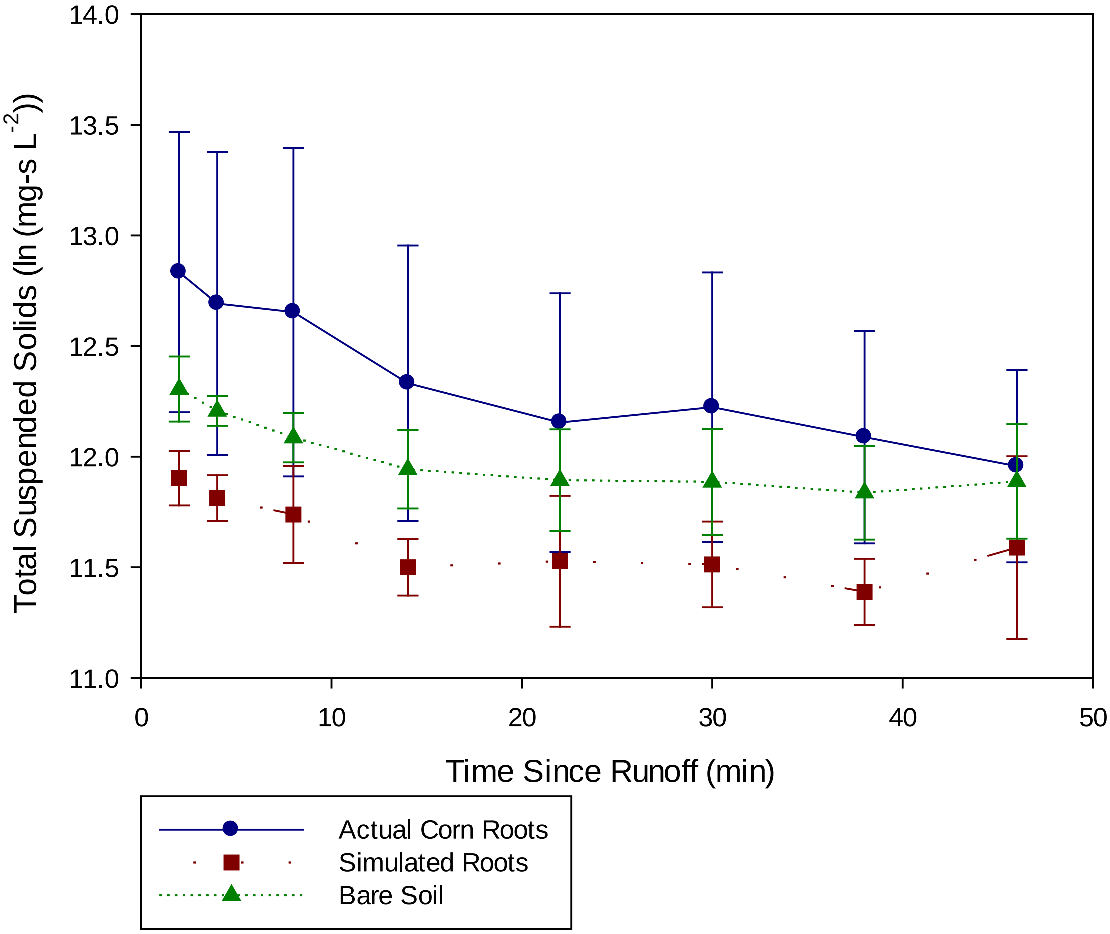


Figure 4-3 Average TSS concentration and standard deviation (3 replications) adjusted for normalized flow (natural logarithm) at 5 % slope versus time since runoff (actual corn roots, simulated roots, and bare soil)

The hypothesis was that the bare soil would have a higher TSS concentration in the runoff and the simulated and actual corn roots would be the same. Statistically there was no significant difference between the TSS concentrations in the runoff. This was likely due to the large variations in the TSS concentration from the actual corn roots. Interestingly, there were two replications of the corn roots that had a similar TSS concentration to the simulated roots (Figure 4-4). The other two replications were significantly higher (p-value <0.0001). If only two of the replications for the actual corn roots were considered, the simulated and actual corn roots followed a similar trend and were statistically not different.

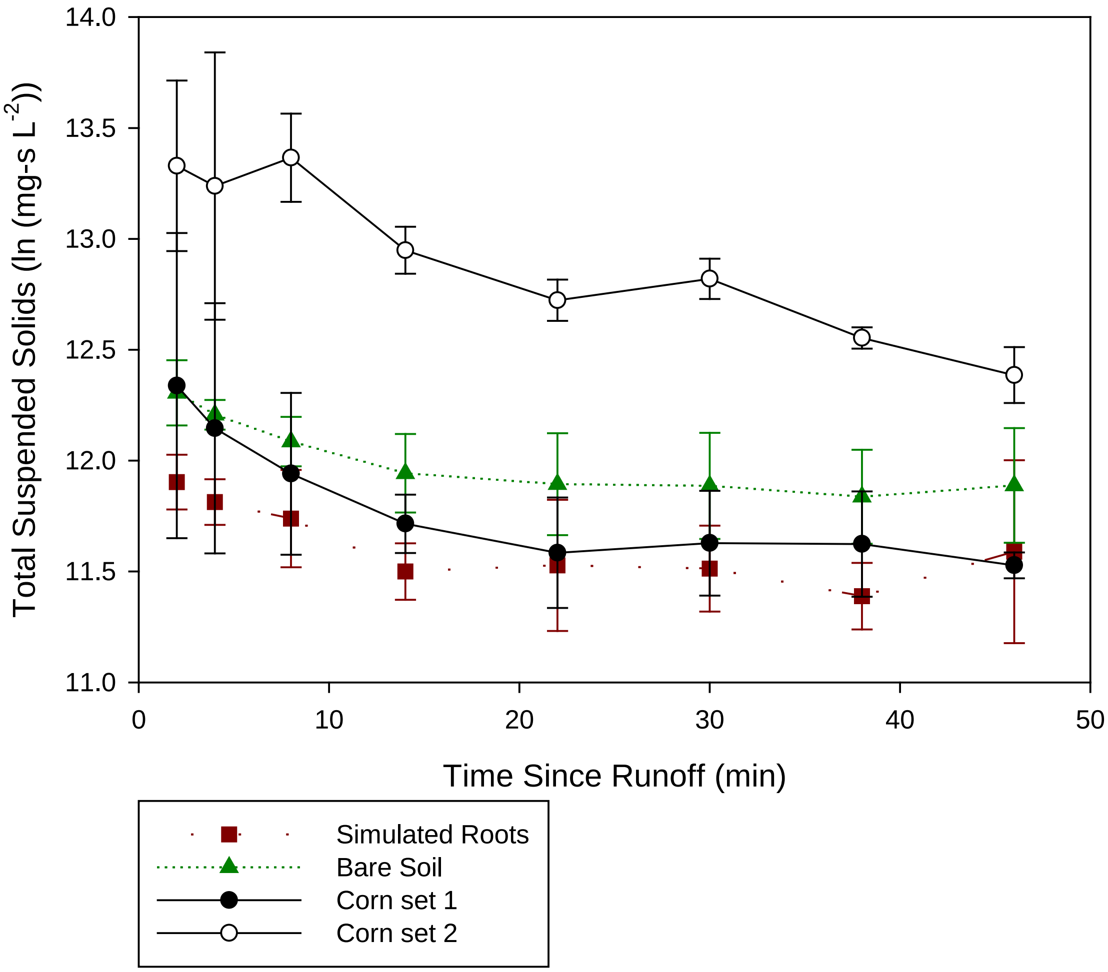


Figure 4-4 Average TSS concentration and standard deviation (3 replications) adjusted for normalized flow (natural logarithm) at 5 % slope versus time since runoff (for actual corn roots split into two groups, simulated roots, and bare soil)

Similarly to the turbidity concentrations, TSS concentration analysis was performed on actual corn roots versus simulated roots during the 2013 growing season. The same problems arose with the soil density not being taken for the actual corn root boxes. However, the simulated roots and the actual corn roots were statistically not different from one another after the 8 minute sample time; which has led to this data being preliminary data and strengthening the reason behind assuming the simulated roots would behave similar enough to actual corn roots.

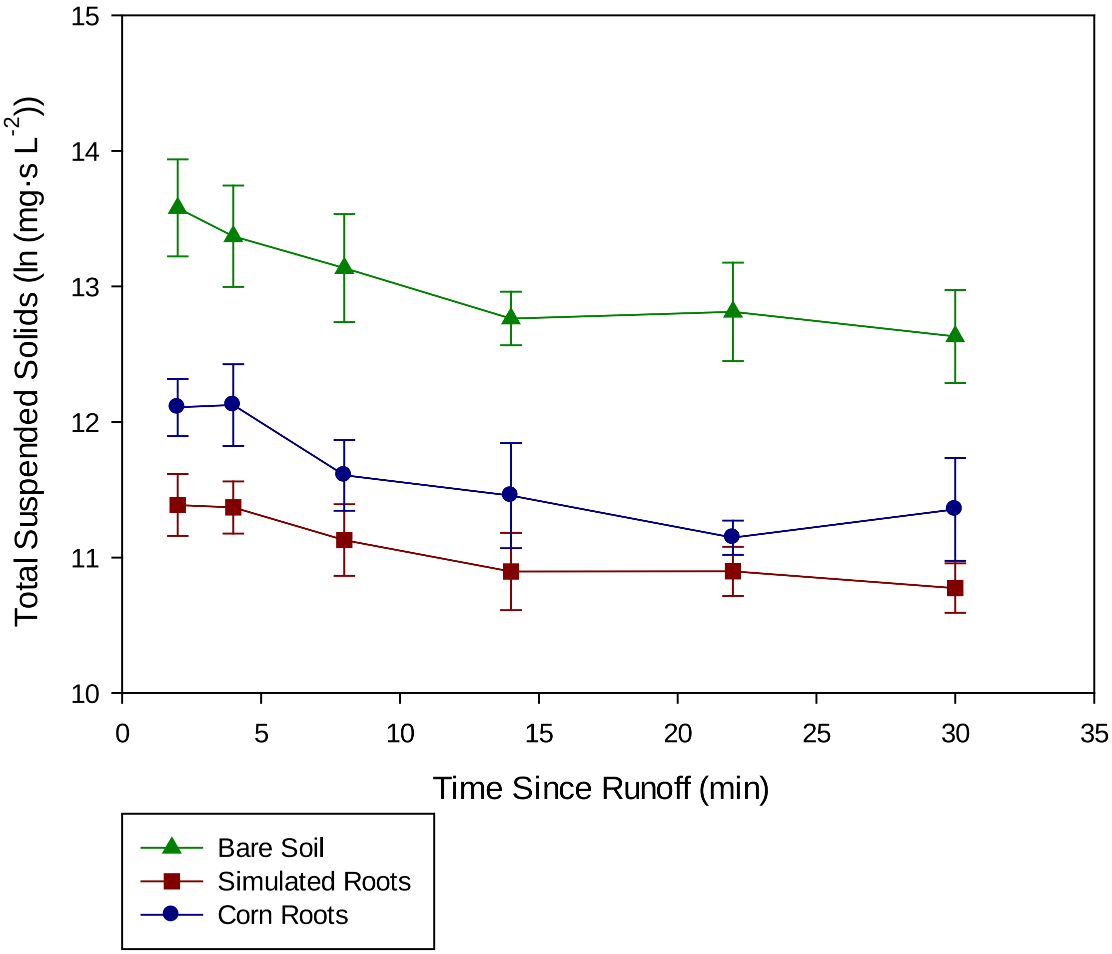


Figure 4-5 Average TSS concentration and standard deviation (3 replications) adjusted for normalized flow (natural logarithm) at 5 % slope versus time since runoff for the 2013 growing season (actual corn roots, simulated roots, and bare soil)

The simulated roots were believed to adequately represent the actual corn roots. Although, not statistically different, the bare soil and the simulated root treatments behaved as expected. It was believed that the simulated roots would function similar enough to the real corn roots to be used in objective 2. This study did not explicitly consider the corn roots since they would be present for all cover factors. Small differences between simulated and actual corn roots would not change any conclusions based on cover factors. Also, with the 2013 corn roots experiments demonstrating that the simulated roots were not statistically different than the actual corn roots, it was assumed the simulated roots would represent the corn roots. As described in Foster, Johnson et al. (1982), unanchored biomass failed at a range of discharge rates and the cornstalks washed away one piece at a time. Therefore, the corn roots are likely responsible for holding the biomass on the surface during rainfall events

4.2 Objective 2: Determine the effect of cover factor and slope on soil erosion resulting from corn stover residue removal

4.2.1 Overview

The goal of this objective was to determine the effect varying cover factors had on soil erosion. The turbidity and TSS concentrations were evaluated at three slopes and three types of cover factor treatments. The results are summarized below.

4.2.2 Flow rate determination

The volumetric flow rate was determined for the runoff samples at each sample time that was used to normalize the TSS and turbidity values. The flow rates and associated standard deviations for each slope and corresponding cover factors are shown in Table 4-2, Table 4-3, and Table 4-4. It was observed that the runoff flow rates were fairly consistent, with a slight upward trend, between sample times in each experiment. However, the flow rates significantly varied between slopes (p-value=0.0002) and cover factor treatments (p-value <0.0001). The flow rates associated with the varied cover factor treatments were not significantly different on the 1% slope (p-value=0.154). On the 5% slope, the flow rates had no significant difference between the cover factor treatments (p-value=0.1584). At the 10% slope, the BW treatment had a flow rate approximately 51% greater than the NR and IBW treatments; and a significant difference between the BW treatment and the NR and IBW treatments was seen (p-value=0.0069).

An explanation for such variation would be that the water did not have enough force or momentum at the more shallow slopes to move the biomass, specifically for the NR treatment. In the case of the 10% slope, the runoff water would have been forceful enough to shift the biomass out of the way or flow underneath it, causing the biomass to float on the water surface (Foster, Johnson et al. 1982). For the 1% slope, the water may have been pooled behind pieces of the biomass, leading to a slower flow rate (Gilley, Finkner et al. 1986).

Table 4-2 Volumetric flow rates and standard deviations (3 replications) for the 1% slope and corresponding cover factors of NR=no removal, IBW=in-between windrows, and BW=baled windrow

	NR		**IBW**		**BW**	
Time Since Runoff (min)	**Average (L s^{-1})**	**Stdv.**	**Average (L s^{-1})**	**Stdv.**	**Average (L s^{-1})**	**Stdv.**
2	0.004	0.001	0.004	0.001	0.009	0.003
4	0.004	0.001	0.004	0.002	0.010	0.002
8	0.005	0.001	0.005	0.002	0.010	0.003
14	0.005	0.002	0.005	0.003	0.011	0.003
22	0.006	0.002	0.005	0.003	0.011	0.003
30	0.005	0.001	0.006	0.003	0.011	0.003
38	0.006	0.002	0.006	0.003	0.011	0.003
46	0.007	0.003	0.005	0.002	0.011	0.003

Table 4-3 Volumetric flow rates and standard deviations for the 5% slope and corresponding cover factors of NR=no removal, IBW=in-between windrows, and BW=baled windrow

	NR		**IBW**		**BW**	
Time Since Runoff (min)	**Average (L s^{-1})**	**Stdv.**	**Average (L s^{-1})**	**Stdv.**	**Average (L s^{-1})**	**Stdv.**
2	0.005	0.001	0.009	0.001	0.010	0.003
4	0.005	0.001	0.009	0.001	0.010	0.003
8	0.006	0.001	0.010	0.001	0.012	0.003
14	0.007	0.001	0.010	0.001	0.013	0.004
22	0.007	0.000	0.010	0.001	0.012	0.004
30	0.008	0.001	0.010	0.001	0.013	0.004
38	0.009	0.001	0.011	0.001	0.014	0.004
46	0.011	0.002	0.009	0.002	0.014	0.004

Table 4-4 Volumetric flow rates and standard deviations for the 10% slope and corresponding cover factors of NR=no removal, IBW=in-between windrows, and BW=baled windrow

	NR		**IBW**		**BW**	
Time Since Runoff (min)	**Average (L s^{-1})**	**Stdv.**	**Average (L s^{-1})**	**Stdv.**	**Average (L s^{-1})**	**Stdv.**
2	0.006	0.003	0.010	0.000	0.019	0.002
4	0.007	0.003	0.010	0.001	0.018	0.001
8	0.007	0.003	0.011	0.001	0.020	0.001
14	0.008	0.004	0.012	0.001	0.021	0.001
22	0.010	0.004	0.013	0.001	0.022	0.002
30	0.011	0.004	0.013	0.001	0.021	0.002
38	0.011	0.005	0.013	0.001	0.021	0.002
46	0.012	0.004	0.013	0.001	0.022	0.003

4.2.3 Turbidity

The turbidity was analyzed for all permutations of varying cover factors and slopes. The turbidity of the NR treatment (Figure 4-6), the IBW treatment (Figure 4-7), and the BW treatment (Figure 4-8) are shown for all three slopes. The NR treatment had the lowest turbidity concentration of approximately 81 to 110 NTU irrespective of the slope. The IBW treatment had a slightly higher turbidity concentration that varied between 221 and 742 NTU after the first flush occurred. The highest turbidity was measured for the BW treatment that varied between 660 and 1510 NTU. For each cover factor treatment, the slope did not significantly affect the turbidity (p-value=0.2599).

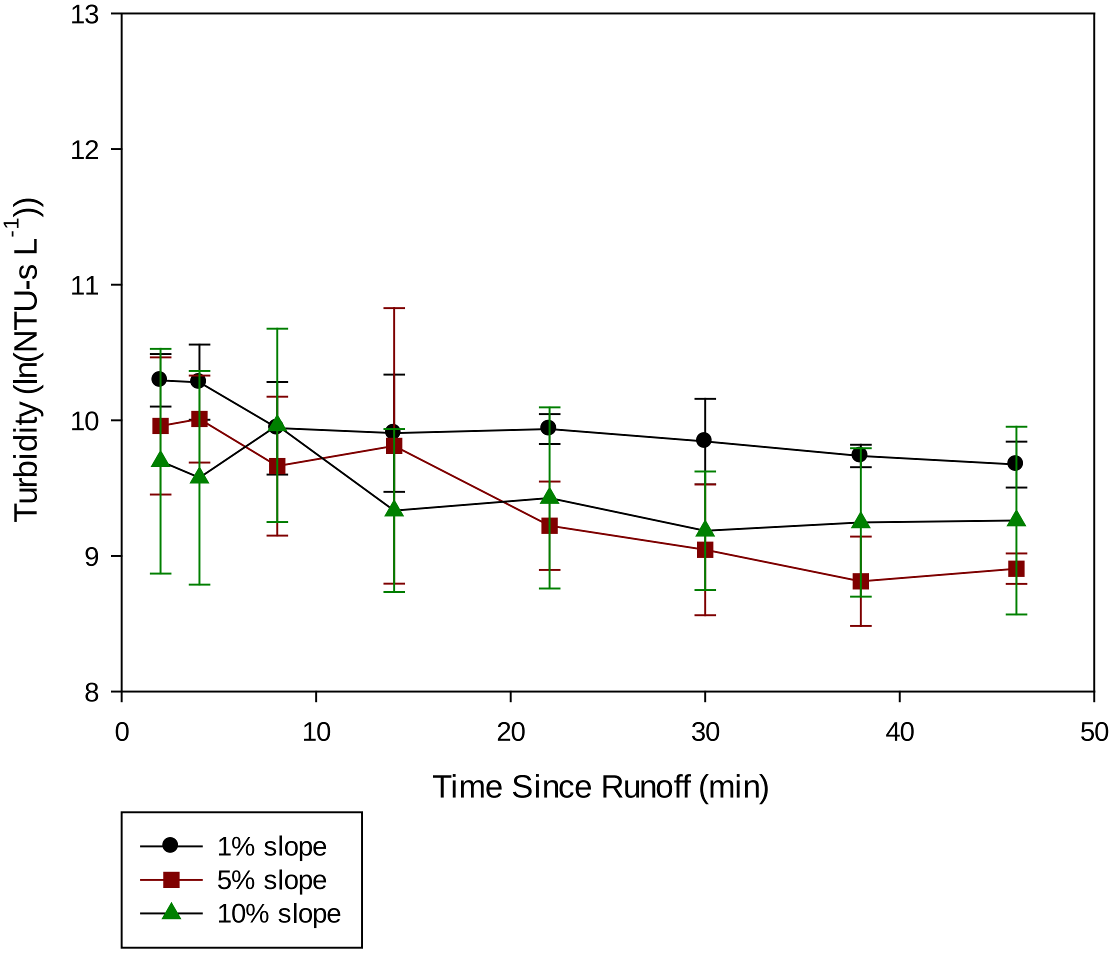


Figure 4-6 Average turbidity concentration and standard deviation (3 replications) adjusted for normalized flow (natural logarithm) for the NR cover treatment versus time since runoff (1% slope, 5% slope, and 10% slope)

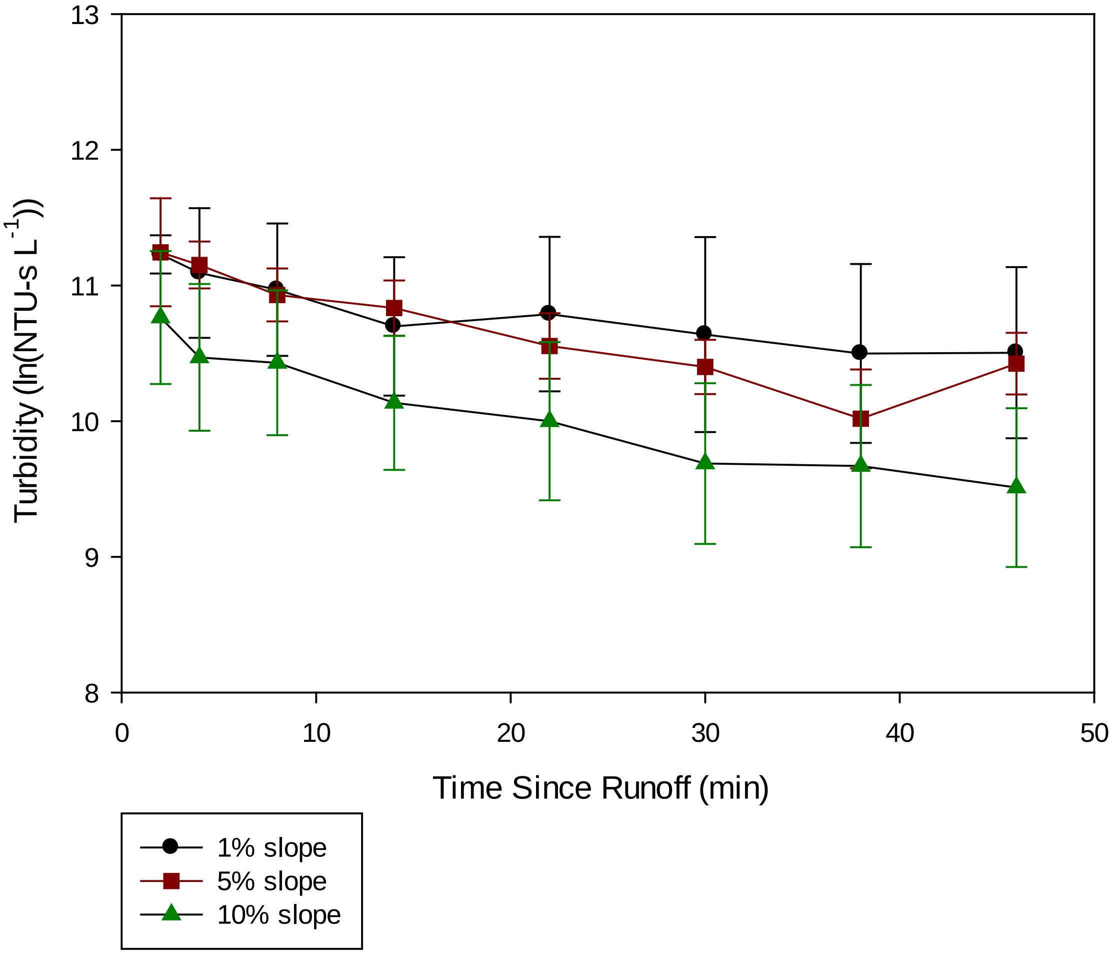


Figure 4-7 Average turbidity concentration and standard deviation (3 replications) adjusted for normalized flow (natural logarithm) for the IBW cover treatment versus time since runoff (1% slope, 5% slope, and 10% slope)

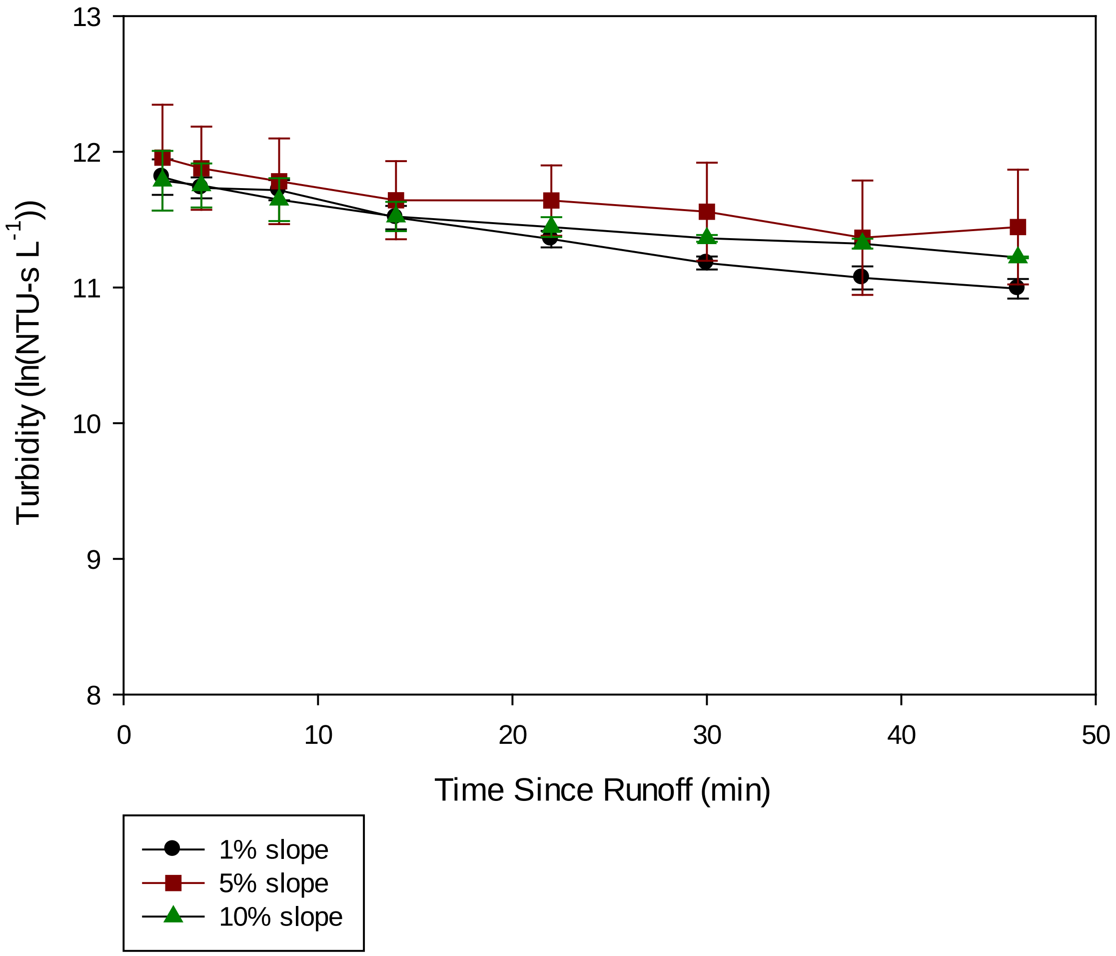


Figure 4-8 Average turbidity concentration and standard deviation (3 replications) adjusted for normalized flow (natural logarithm) for the BW cover treatment versus time since runoff (1% slope, 5% slope, and 10% slope)

The turbidity concentrations were compared to one another based on the sample time, to determine the effectiveness of each cover treatment throughout the rain event. Looking specifically at the 1% slope (Figure 4-9), there was a significant difference between the cover factor treatments (p-value=0.0105). At the 2 minute sample time, all of the cover factors were significantly different. This difference could be accounted for due to the first flush event. This is where the soil particle fines are more easily transported down the slope and are captured in the runoff sample. This would increase the turbidity concentrations for the beginning sample times, and eventually the concentrations decrease due to a lack of particle fines transport. As the rain event progressed, the NR (104±11 NTU) and BW (953±220 NTU) turbidity concentrations were the only concentrations significantly different from each other until the end of the rain event, except for the 30 minute sample time; where all three turbidity concentrations were not statistically different.

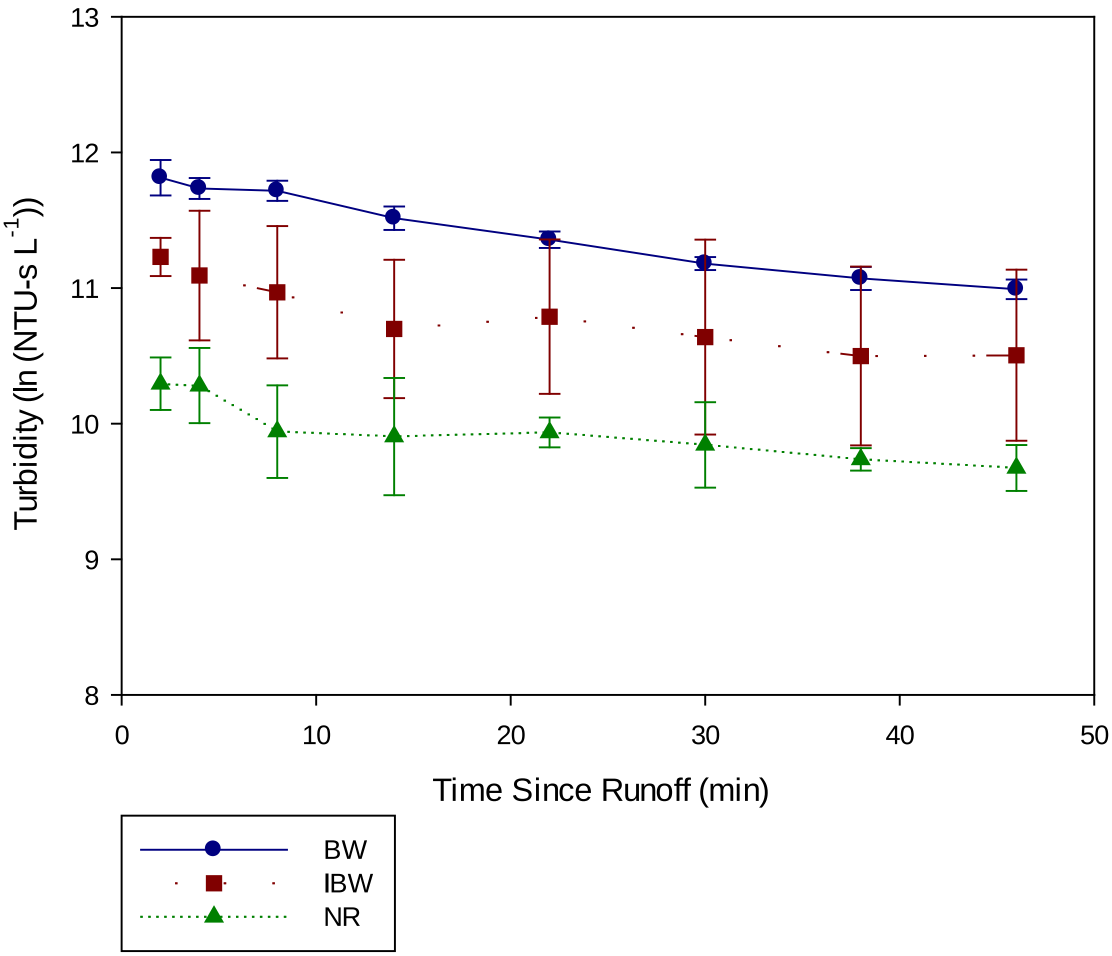


Figure 4-9 Average turbidity concentration and standard deviation (3 replications) adjusted for normalized flow (natural logarithm) at 1 % slope versus time since runoff (BW=baled windrow, IBW=in-between windrows, and NR=no removal)

For the 5% slope (Figure 4-10), there was an overall significant difference between the turbidity concentrations for all three cover treatments (p-value=0.0017). The turbidity concentrations at the 2 minute sample time showed that only the NR and BW treatments were statistically different from one another. The NR and IBW, as well as, the IBW and BW treatments were not statistically different from one another. During the 4 minute and 8 minute sampling times, the NR treatments had turbidity concentrations that were significantly different from the BW and IBW concentrations. At the 14 minute sampling time, there was no significant difference between any of the cover treatments. For the 22 minute sampling time, until the end of the rain event, there was a significant difference between all of the cover treatments in terms of turbidity concentration.

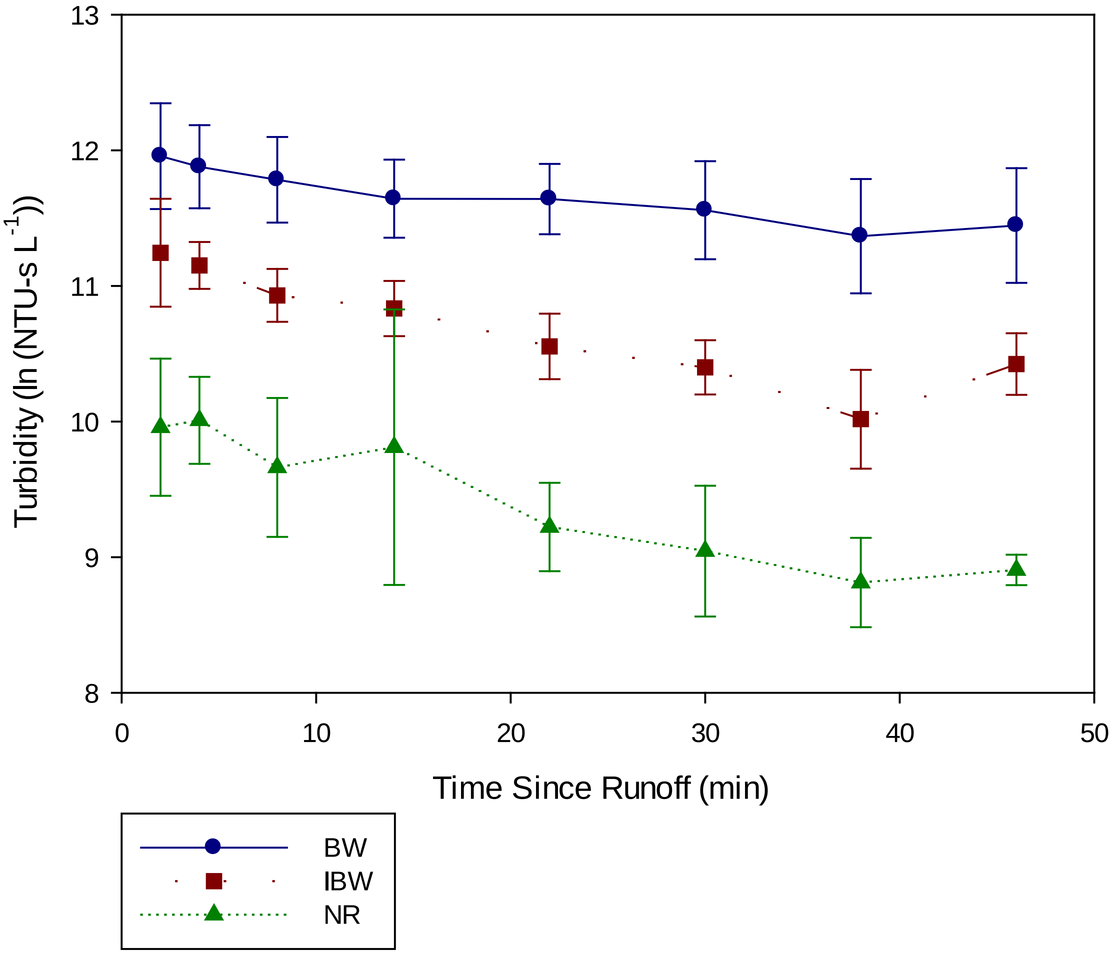


Figure 4-10 Average turbidity concentration and standard deviation (3 replications) adjusted for normalized flow (natural logarithm) at 5 % slope versus time since runoff (BW=baled windrow, IBW=in-between windrows, and NR=no removal)

The turbidity concentrations at the 10% slope (Figure 4-11) for the varied cover factors had an overall significant difference (p-value=0.0137). During the 2 to 22 minute sample times the NR and BW treatments were statistically different from one another. Conversely, the NR and IBW and the IBW and BW turbidity concentrations were not significantly different from one another. From the 30 minute sample time until the end of the rain event, the average concentrations were 1752±89, 245±17, and 111±12 NTU for the IBW, BW, and NR cover treatments, respectively. After the 30 minute sample time, the BW turbidity concentrations were significantly different from the IBW and NR cover factor treatments. The NR and IBW cover treatments turbidity concentrations varied the most over the 10% slope which may be due to the water having to force some of the biomass out of its flow path. Conversely, the BW treatment had minimal cover; therefore the water would have an easier and more consistent time flowing down the slope profile.

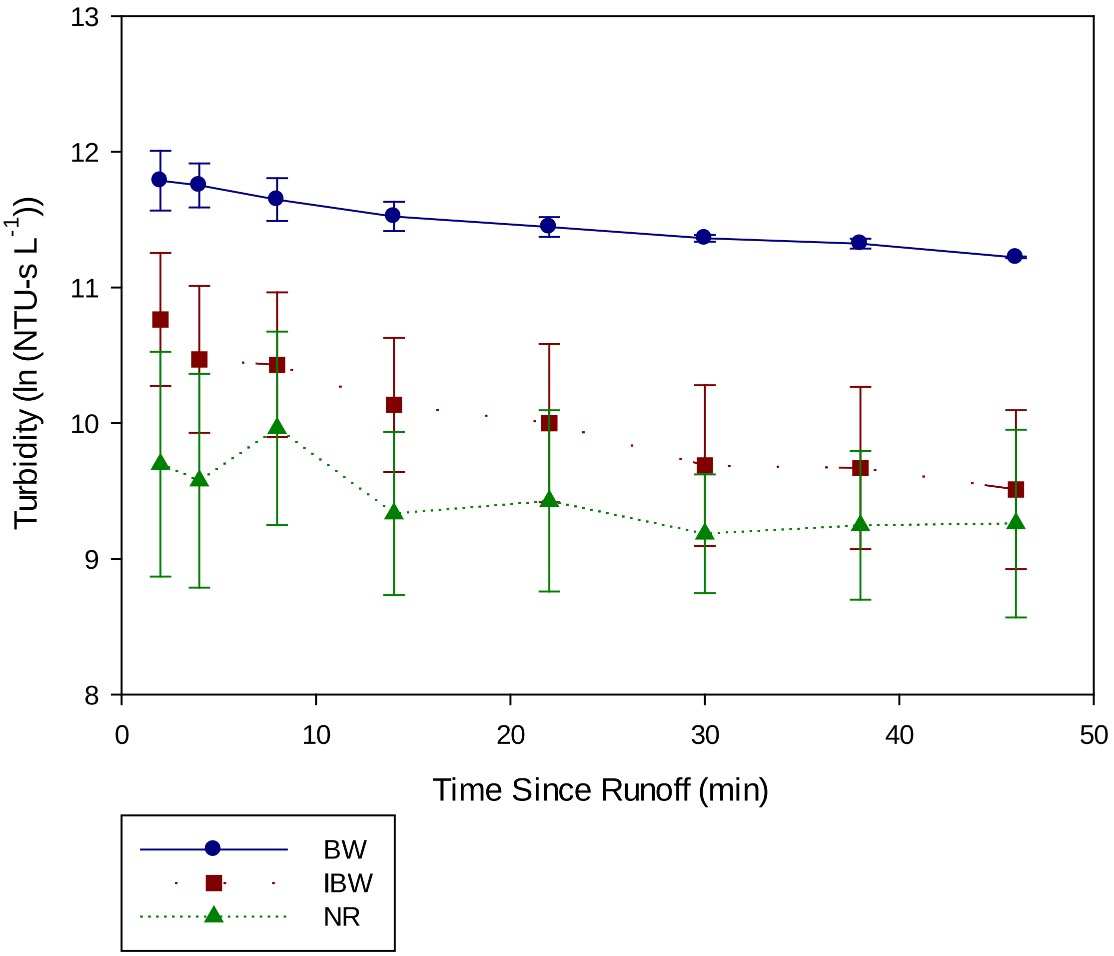


Figure 4-11 Average turbidity concentration and standard deviation (3 replications) adjusted for normalized flow (natural logarithm) at 10 % slope versus time since runoff (BW=baled windrow, IBW=in-between windrows, and NR=no removal)

Although there was no significant difference between the slopes, concerning turbidity concentrations, that might be due to the concentrations being normalized over the flow rate. Those flow rate difference would be the reason for higher turbidity concentrations on the steeper slopes. However, there was a significant difference between the cover treatments. There was a consistent trend, across all three slopes, that the NR treatment was significantly less than the BW; while the IBW varied between the NR and BW treatments. This variation in IBW could account for possible differences in the cover components and their response to erosion control.

4.2.4 Total Suspended Solids

The total suspended solids (TSS) concentrations for the NR treatment (Figure 4-12), the IBW treatment (Figure 4-13), and the BW treatment (Figure 4-14) are shown. Similar to the turbidity concentrations, the NR treatment proved to be the best management practice while the BW had higher TSS concentrations, due to the significant difference between the BW and NR cover treatments. Although the concentrations seemed to vary based on slope, there was no significant difference concerning the cover factor treatments within a given slope (p-value=0.1725).

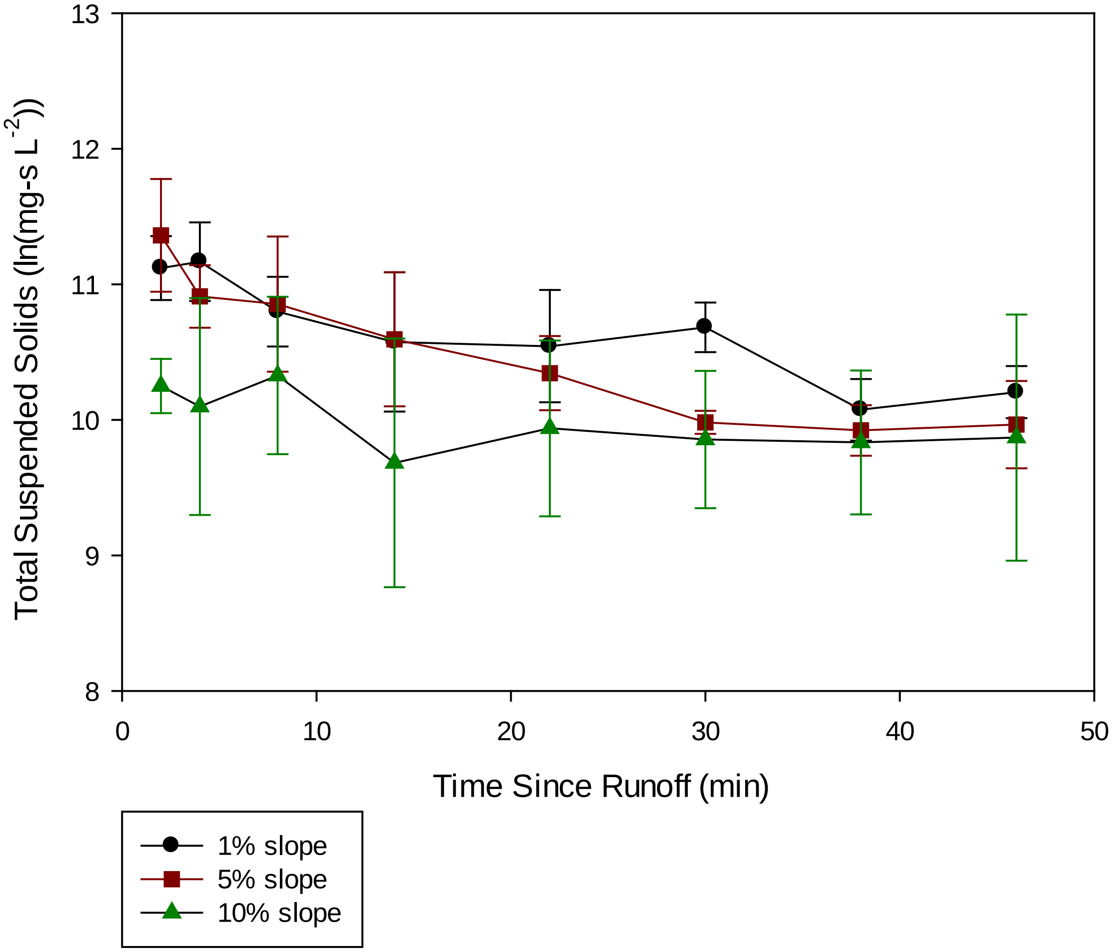


Figure 4-12 Average TSS concentration and standard deviation (3 replications) adjusted for normalized flow (natural logarithm) for the NR cover treatment versus time since runoff (1% slope, 5% slope, and 10% slope)

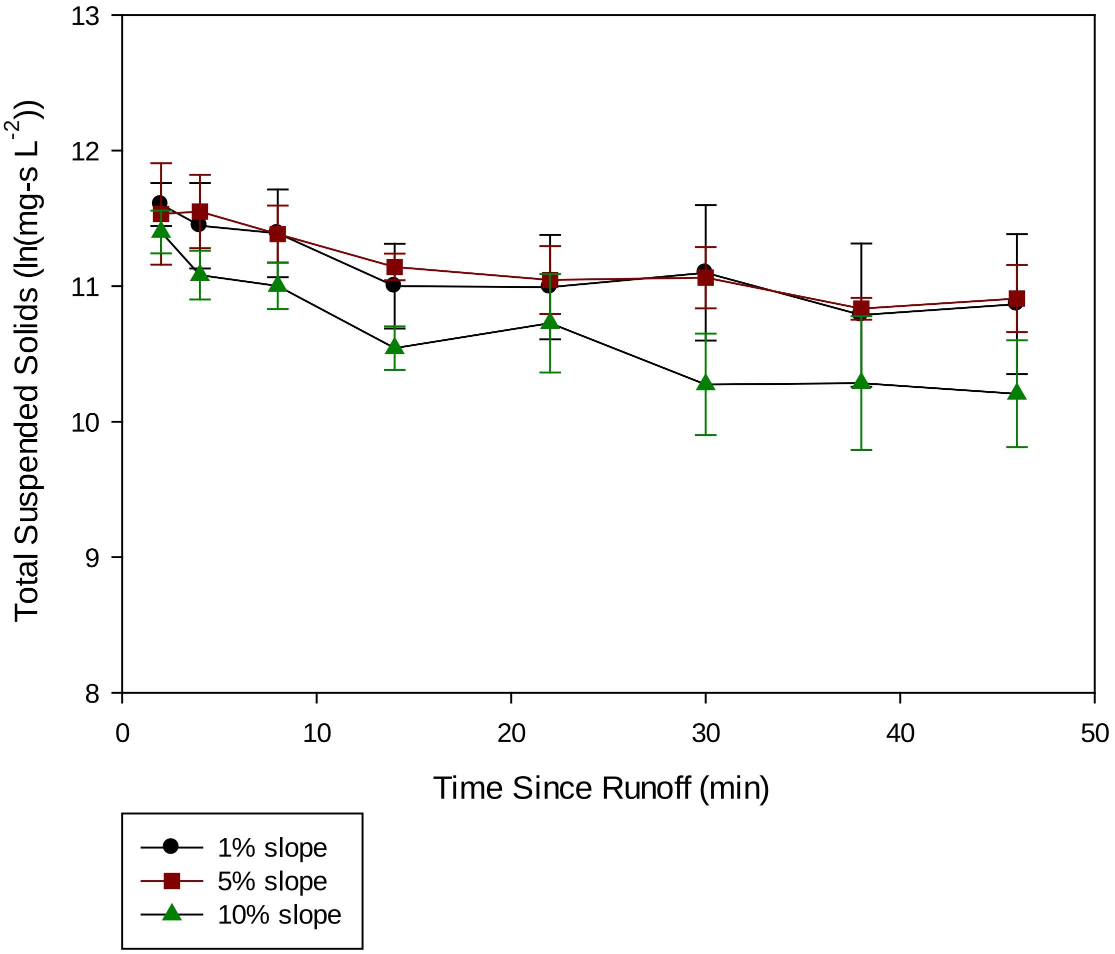


Figure 4-13 Average TSS concentration and standard deviation (3 replications) adjusted for normalized flow (natural logarithm) for the IBW cover treatment versus time since runoff (1% slope, 5% slope, and 10% slope)

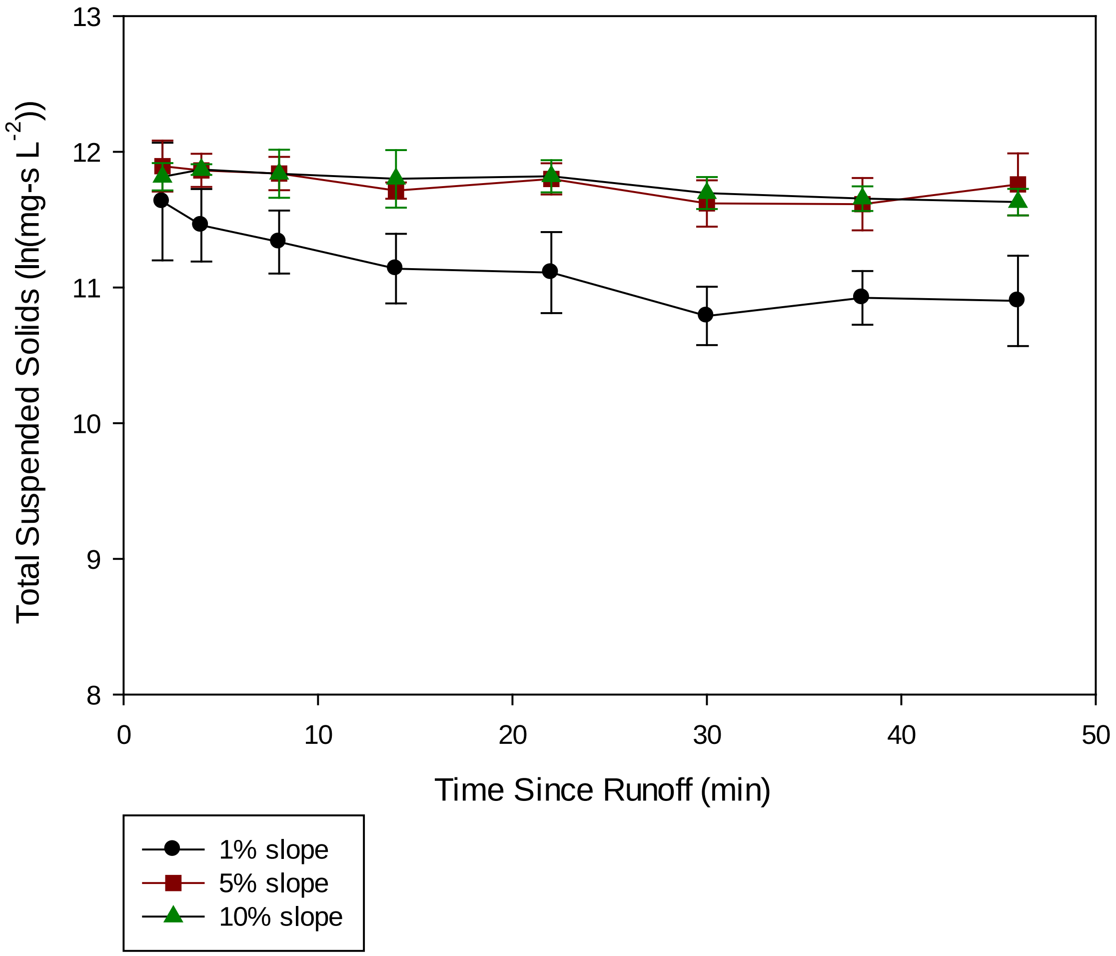


Figure 4-14 Average TSS concentration and standard deviation (3 replications) adjusted for normalized flow (natural logarithm) for the BW cover treatment versus time since runoff (1% slope, 5% slope, and 10% slope)

Like the turbidity concentrations, the TSS concentrations were analyzed and compared to one another based on the runoff sample time. This determined the effectiveness of each cover treatment with respect to the rainfall events duration. On the 1% slope (Figure 4-15), the average TSS concentrations were 780±180, 336±66, and 240±48 mg l^{-1} for the BW, IBW, and NR cover treatments, respectively. Although the NR turbidity concentration trended lower than the IBW and BW, there was no significant difference between any of the cover factor treatments, at any of the sample times (p-value=0.1791).

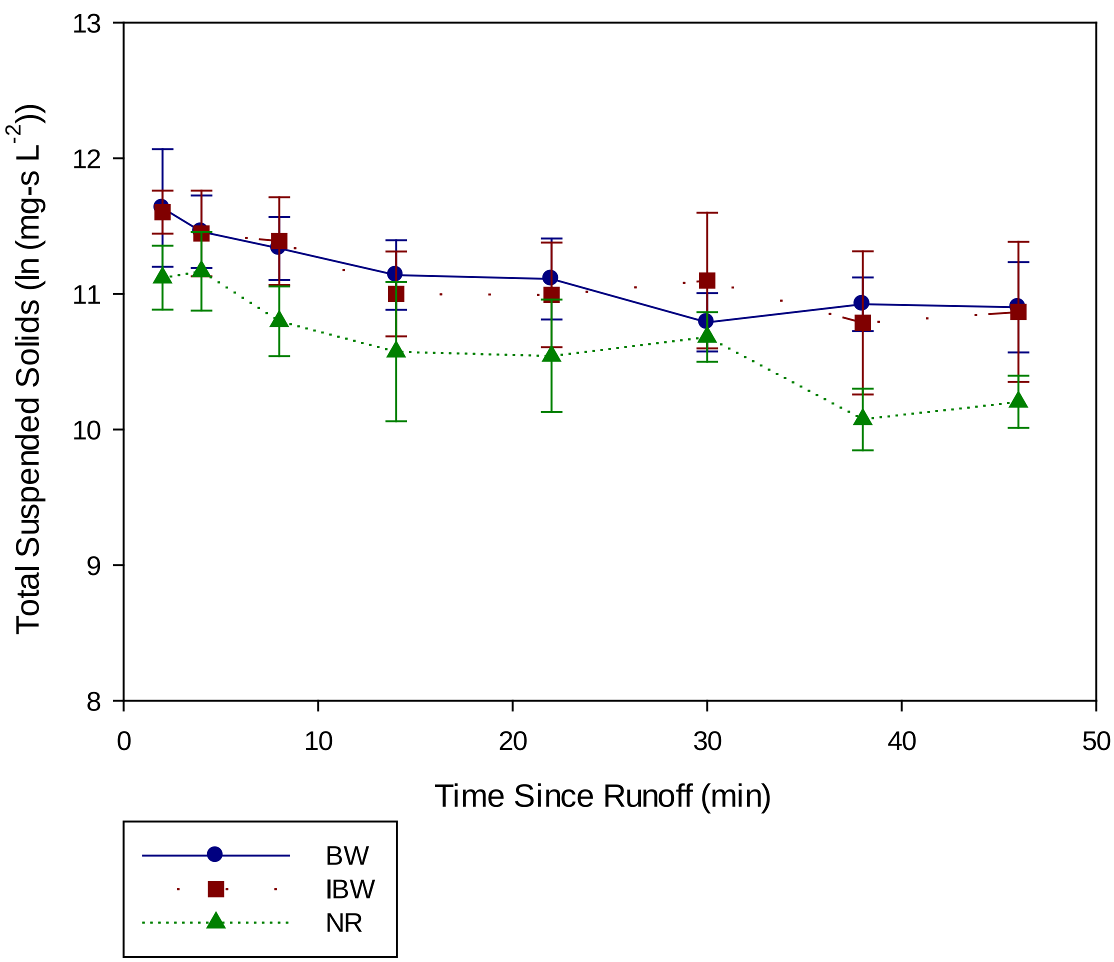


Figure 4-15 Average TSS concentration and standard deviation (3 replications) adjusted for normalized flow (natural logarithm) at 1 % slope versus time since runoff (BW=baled windrow, IBW=in-between windrows, and NR=no removal)

With the 5% slope (Figure 4-16), there was a significant difference between the cover factor treatments (p-value=0.001). At the 2 minute sample time, there was no significant difference between any of the cover treatments. Over the 4, 8, and 14 minute sample times the NR and BW TSS concentrations were significantly different from each other. On the other hand, the NR and IBW, along with the IBW and BW TSS concentrations were not statistically different from each other. All samples after the 22 minute sample time, for the duration of the rainfall event, were significantly different between all three cover treatments. The most extreme difference was seen at the 30 minute sample time where the NR, IBW, and BW TSS concentrations were 213, 656, and 1365 mg l^{-1}, respectively.

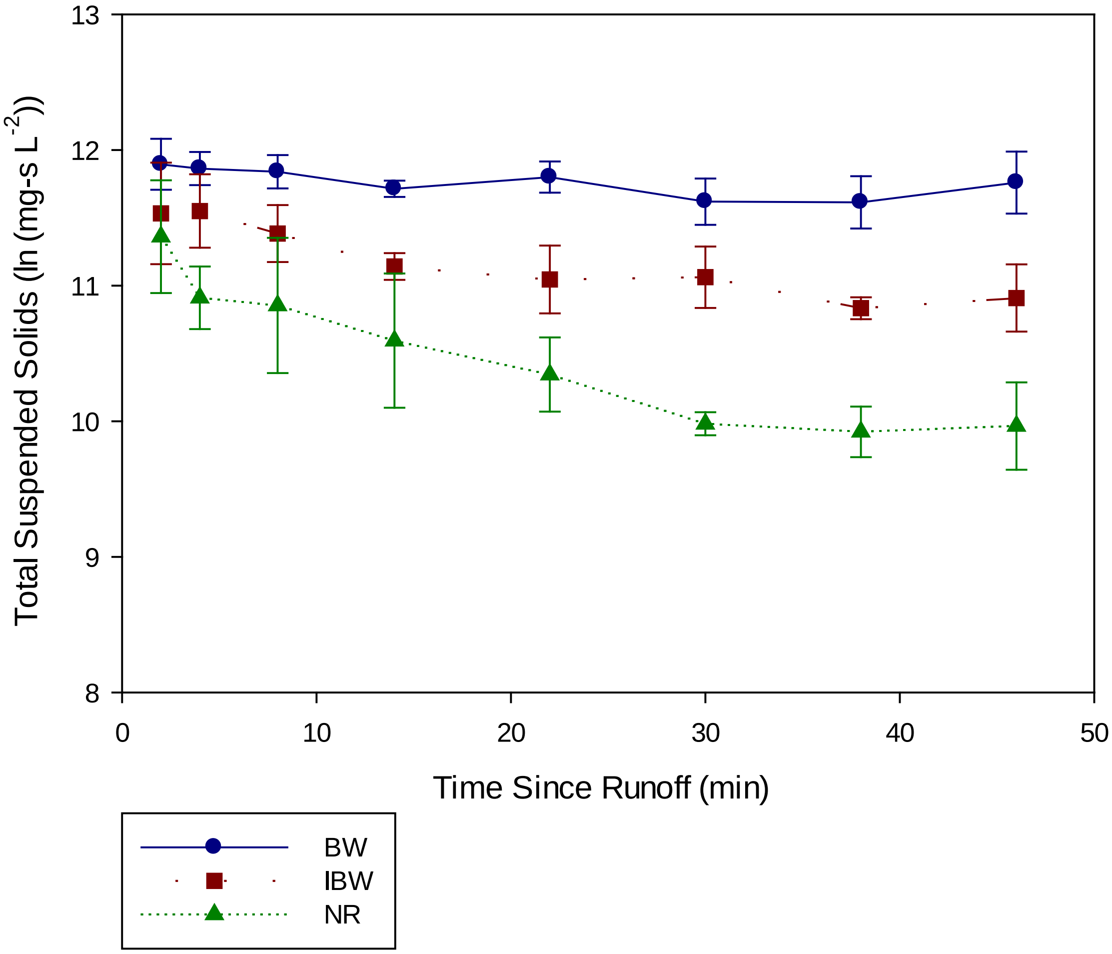


Figure 4-16 Average TSS concentration and standard deviation (3 replications) adjusted for normalized flow (natural logarithm) at 5 % slope versus time since runoff (BW=baled windrow, IBW=in-between windrows, and NR=no removal)

Regarding the 10% slope (Figure 4-17), there was an overall significant difference between the TSS concentrations for all of the cover factor treatments (p-value=0.0107). During the 2 minute sample time, the NR treatments TSS concentration was the only one that had a significant difference. For the 4, 8, 14, and 22 minute sample times, the NR and BW treatments were significantly different than one another. Comparatively, the NR and IBW, along with the IBW and BW treatments, had no significant difference between the TSS concentrations, respectively. For the next two sample times, the NR and IBW treatments TSS concentrations were the only ones not significantly different than one another. In other words, the BW treatment had significantly different TSS concentrations than the other two cover treatments. During the final sample time (46 minutes), all three cover treatments were statistically not different than one another, regarding the TSS concentrations.

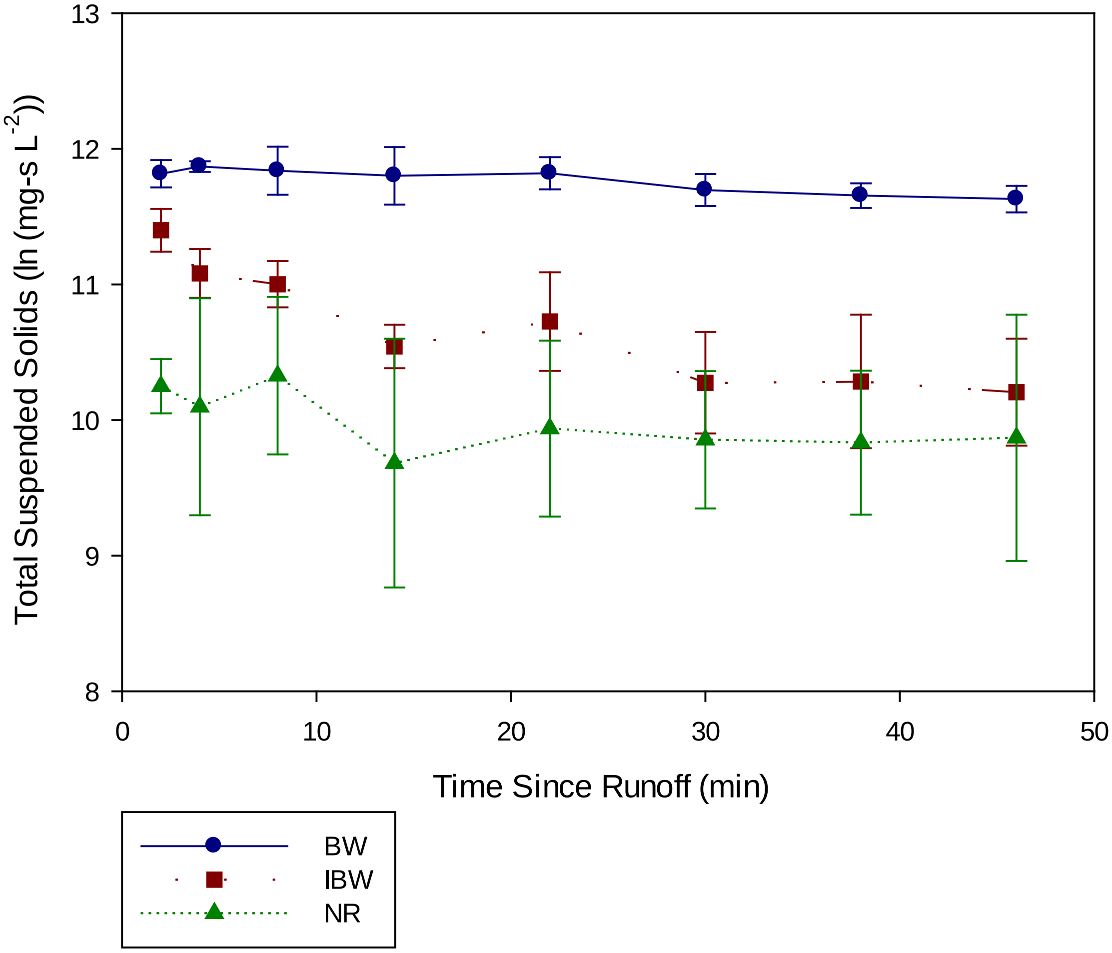


Figure 4-17 Average TSS concentration and standard deviation (3 replications) adjusted for normalized flow (natural logarithm) at 10 % slope versus time since runoff (BW=baled windrow, IBW=in-between windrows, and NR=no removal)

Turbidity and TSS are both water quality indicators that are representative of one another. Because of the time it takes to analyze for TSS concentrations, turbidity is used as a surrogate to determine TSS concentrations. With this correlation, there should be a one to one relationship for all turbidity and TSS concentrations (Figure 4-18). Based off of Figure 4-18, it can be seen that the TSS samples were slightly higher than the turbidity, but there was still a strong, linear, correlation between them for all slopes and cover factors. A disconnect between the TSS and turbidity concentrations could be due to the fine particles the soil is made up of. This particular Maury silt loam is almost 85% silt and clay, which are considered fines. The more fines present in the runoff samples would warrant a higher turbidity concentration and the some small particles may have been overlooked when the samples were analyzed for TSS.

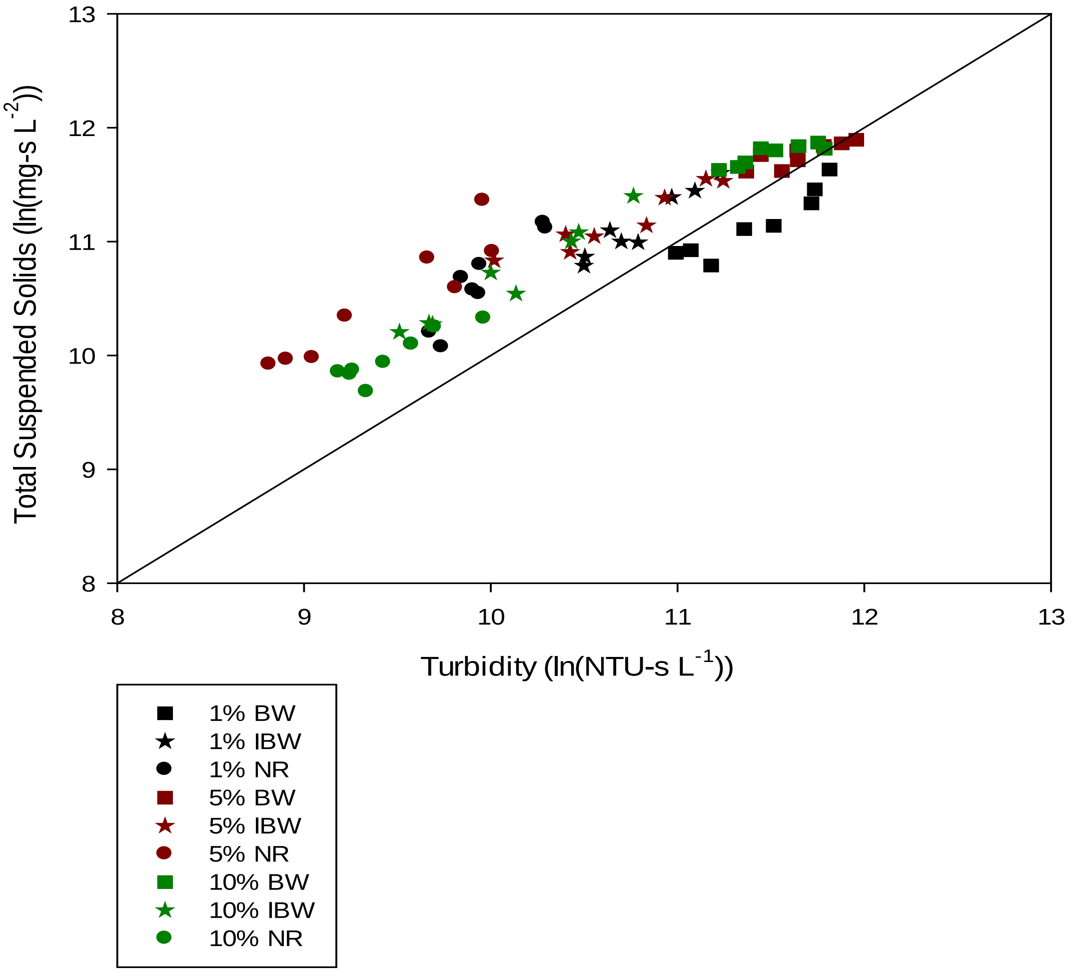


Figure 4-18 Average turbidity concentration adjusted for normalized flow (natural logarithm) versus average TSS concentration adjusted for normalized flow (natural logarithm) (BW=baled windrow, IBW=in-between windrows, and NR=no removal)

This study was specifically aimed at determining the difference between selective harvest strategies and the potential effect they would have on agricultural runoff. Although the main factor influencing runoff TSS concentrations was the cover amounts, other studies have made conclusions on cultivation practices and their effects on TSS concentrations in runoff. Puustinen, Koskiaho et al. (2005) compared different cultivation practices over different parts of the growing season to determine the best practice to reduce TSS concentrations in agricultural runoff. It was found that the maximum flow weighted TSS concentration of 1450 mg l^{-1} (normal ploughing) was 3.6 times greater than the minimum of 400 mg l^{-1} (grass ley). It was concluded that the TSS concentrations in the runoff samples were less with reduced tillage practices. The reduced tillage practice in their study would most closely resemble the NR treatment in this research and the normal ploughing would most closely represent the BW treatment. Similar to their study, this research observed that the BW treatments flow weighted TSS concentration (2681 mg l^{-1}) was 9.3 times greater than the NR treatments concentration (288 mg l^{-1}). Due to the high amounts of crop residue in the no-till practice, the soil is protected from raindrop impacts that would induce more erosion and increase TSS concentrations in water runoff (Thompson, Ghidey et al. 2001).

A study conducted on a fine-silty soil with a slope of 5.2% and a rainfall intensity of 28 mm hr^{-1} used varying corn residue rate applications to determine sediment concentrations in runoff. The residue rates were applied to the simulation plots with 0.00, 1.12, 3.36, 6.73, and 13.45 t ha^{-1}, in a random orientation. These application rates represent a 0, 10, 31, 51, and 83% surface cover, respectively. The 10, 51, and 83% surface covers in their study would most closely resemble the BW (21%), IBW (66%), and NR (90%) cover treatments in this research. The sediment concentrations observed in their study were 7.5, 2.1, and 0.0 ppm x 10^3 for the 10, 31, and 83% surface covers, respectively. Following the same pattern, the sediment concentrations found in this study were 1457, 731, and 324 mg l^{-1} for the BW, IBW, and NR cover treatments, respectively. Similar to the results found in this study, the 10 and 51% cover factor as well as the 51 and 83% were not significantly different than one another. However, the 10 and 83% surface covers were significantly different (Gilley, Finkner et al. 1986).

4.3 Objective 3: Evaluate the application of The Revised Universal Soil Loss Equation (RUSLE) to selective harvest strategies of corn stover

4.3.1 Overview

This section compares the results from the RUSLE equation using cover factor coefficients from literature to the experimental data obtained in objective 2. The model parameters were calculated based on the soils, slopes, and cover factors associated with the soil erosion boxes. Literature values for the RUSLE equation tended to over-estimate the amount of soil erosion that might occur with selective harvest strategies relative to the empirical data provided for RUSLE.

4.3.2 Revised Universal Soil Loss Equation (RUSLE) parameters

The data collected with the soil erosion boxes utilized one rainfall intensity (R-value), one soil type (K-value), and one conservation practice value (P-value). A rainfall intensity of 30 mm hr^{-1} for 46 minutes resulted in an R-value of 175.76 MJ-mm ha^{-1} hr^{-1}. The average annual R-value was found to be approximately 3000 MJ-mm ha^{-1} according to the map located in Schwab (1992) for Lexington, KY. The K-value was found using the soil parameters shown in Table 4-5 and was calculated to be 0.08 Mg ha^{-1} ha hr MJ^{-1} mm^{-1}. The P-value was chosen to be 1 because no conservation practices (contouring, strip cropping, terracing, etc.) were employed. All of the other values within RUSLE were a function of the three slopes and three cover factor investigated in this study.

Photographs of erosion box covers, shown in Appendix B. were used to determine an average C-value for each treatment. The C-values were 0.1, 0.79, and 0.34 for NR, BW, and IBW treatments, respectively. The C-values were also determined for the bare soil and actual corn roots. Those C-values were 1 and 0.95, respectively. The L and S values are shown in Table 4-6 for each slope. All of the supporting variables needed to calculate the final RUSLE parameters are shown in Appendix B.

Table 4-5 Soil properties for the soil erodibility factor (K) analyzed by the University of Kentucky Regulatory Services

Soil Parameter	Value
% silt	71.8
% sand	13.21
% clay	14.98
% OM	4.01
M	7227.55
a	0.0401
b	2
c	3

Table 4-6 Slope length (L) and slope steepness (S) calculated values for slopes of 1, 5, and 10%

Slope (%)	**1**	**5**	**10**
L	0.65	0.31	0.22
S	0.14	0.57	1.17

4.3.3 RUSLE results

The total soil loss that occurred over the 46 minute exposure to a 30 mm hr^{-1}rain event was estimated using RUSLE for each test condition. The predicted soil loss for the storm with the NR, BW, and IBW cover treatments are shown in Figure 4-19. The soil loss predicted for corn roots only and bare soil are also shown. The results showed a linear increase in the soil loss for the three cover factors as the slope increased. It can also be noted that as the cover amount decreased, the total soil loss increased. This was an expected result from RUSLE and demonstrated the importance of cover.

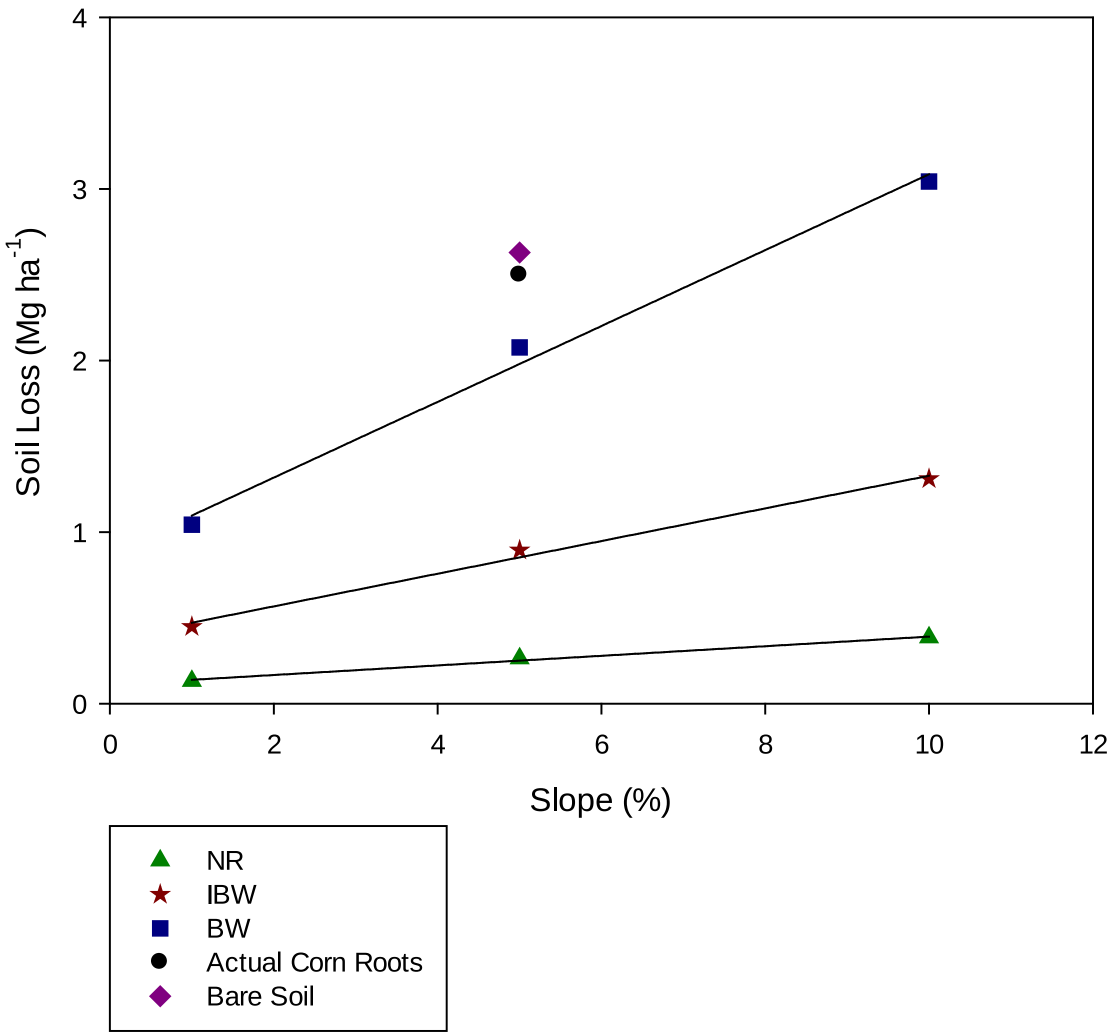


Figure 4-19 Total soil loss calculated by RUSLE versus slope (NR=no removal, IBW=in-between windrows, BW=baled windrow, actual corn roots, and bare soil)

Also shown in Figure 4-19, is the soil loss calculated from actual corn roots and bare soil. As expected, the bare soil loss was higher than the actual corn roots with losses of 2.63 and 2.50 Mg ha^{-1}, respectively. These were a separate trial, but are shown for comparison and fit the expected trend with RUSLE.

4.3.4 Runoff soil yields

After all of the experiments were conducted, the TSS concentrations were used to calculate the total amount of soil lost over the 30 mm hr^{-1} rain event (Figure 4-20). The amount of soil lost was a linear fit for the NR ($R^2=0.99$) and BW ($R^2=0.95$) treatments, but the IBW treatment had an $R^2=0.73$, across the slope profile. Similar to the predicted RUSLE amounts, the cover treatments follow the expected trend of the NR and IBW treatment having a lower soil loss, while the BW treatment was higher. Following the predicted trends, the slope and cover both had a significant impact on the soil loss, with p-values of 0.0003 and <0.0001, respectively. The 10% slope had significantly different soil losses than the 1 and 5% slopes. Also, the BW treatment had a significantly different soil loss than the NR and IBW treatments. As for the actual corn roots and bare soil treatments, they had a higher soil loss than the BW, IBW, and NR cover treatments. The root comparison was a different set of experiments, but behaved as expected when compared to the cover factor treatments. The actual corn roots, for the 2013 growing season, had less soil erosion than the bare soil experiments. This demonstrates that even the cover provided by corn roots plays an important role in reducing soil erosion.

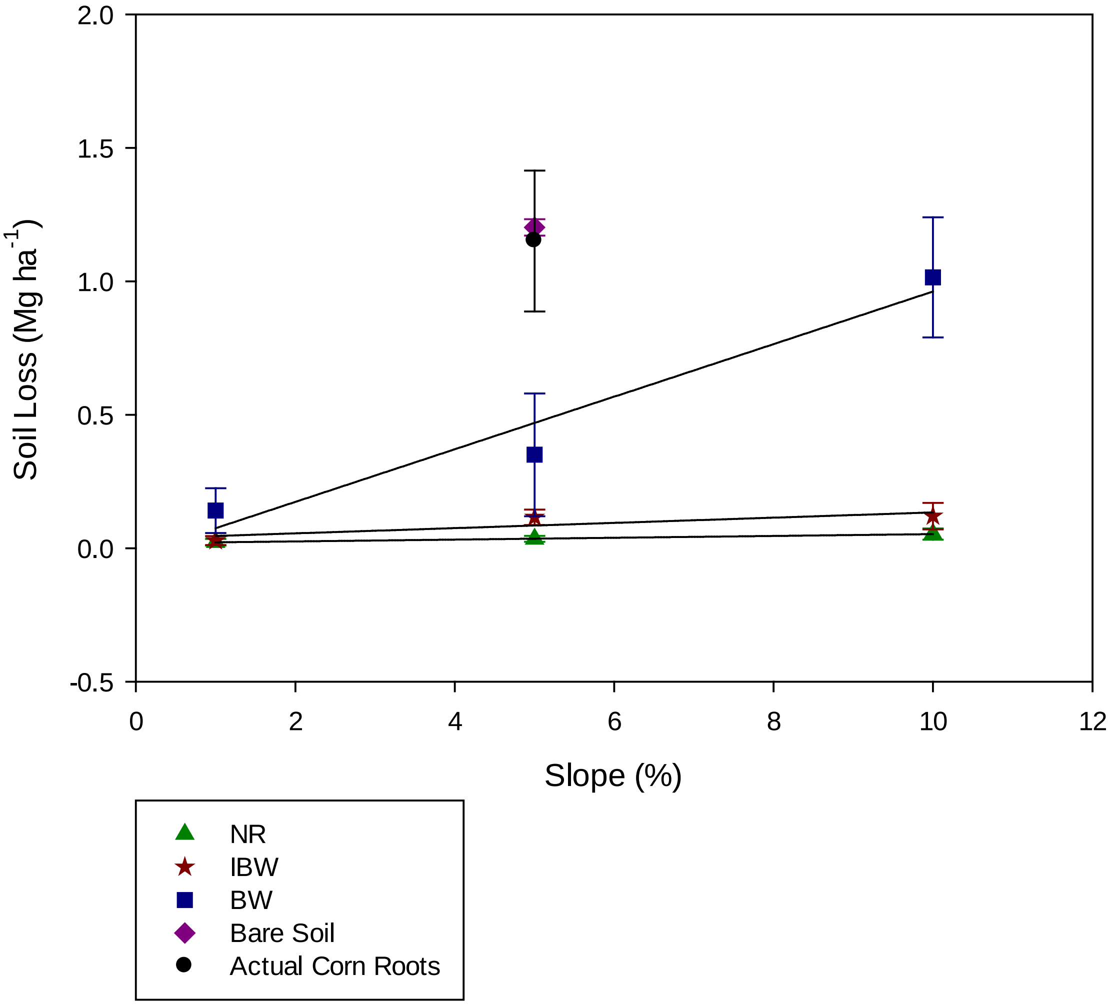


Figure 4-20 Average soil loss and standard deviation (3 replications) versus slope (BW=baled windrow, IBW=in-between windrows, and NR=no removal, bare soil, and actual corn roots)

In a study conducted by Lindstrom (1986) a Barnes loam soil on a 6% slope had a similar R-value to this study. One of the storm events had an R-value of 179 MJ-mm ha^{-1} hr^{-1}. The soil erosion that was observed on the conventional tillage plot was 110 kg ha^{-1}. The conventional tillage would most closely represent the BW treatment in this study. Additionally, the Y and 0.5Y residue levels would most closely resemble the NR and IBW treatments, respectively. The soil erosion they observed was 60 and 20 kg ha^{-1} for the 0.5Y and Y cover treatments, respectively. However, their soil erosion was not significantly different based on the cover treatments and associated rainfall event. Similar to the observed values in this research, on a 5% slope, the NR, IBW, and BW treatments generated a soil loss of 35, 116, and 230 kg ha^{-1}, respectively. However, the soil loss calculated in this experiment based on different cover factors were statistically different from one another and were higher than those discussed in their study. The difference in their values and this study may be attributed to the difference in soil type, slope, or associated cover factors. Nonetheless, the same trends appeared and conclusions can be made that the more cover present, the less soil erosion will occur.

The soil loss seen in this study trends similarly to those observed by Gilley, Finkner et al. (1986). Sorghum residue was applied to erosion plots (6.4 % slope) at rates of 0.00, 0.84, 1.68, 3.36, 6.73, and 13.45 t ha^{-1}. The application rates produced soil cover percentages of 0, 4, 17, 26, 44, and 72. In their study the 17, 44, and 72% soil covers would most likely resemble the BW, IBW, and NR cover treatments for this research, respectively. The soil loss observed was 6.03, 0.51, and 0.00 t ha^{-1} for soil cover percentages of 17, 44, and 72%, respectively. No soil loss was predicted from the 72% cover and no runoff was produced with the 13.45 t ha^{-1} residue application rate. The average soil loss, on a 5% slope, was 0.35, 0.11, and 0.03 Mg ha^{-1} for the BW, IBW, and NR cover treatments, respectively. There could be many explanations for the variance between the studies observed soil loss including slopes, rainfall intensity, soil type, and cover residue type and percentages; although, it can be recognized that there seems to be a relationship between soil cover and soil loss (Gilley, Finkner et al. 1986).

4.3.5 RUSLE and runoff soil yields comparison

It was seen that RUSLE over predicted the total soil loss, based on the measured soil loss from all experiments (Figure 4-21). The C-values used in the original calculation were determined from photo recognition, but they had to be adjusted to fit the measured data (Table 3-1). For the NR treatment, the C-value was lowered to 0.014 for the 10 and 5% slopes and 0.017 for the 1% slope to match the soil yield measured from the erosion boxes. For the BW treatment, the C-values were considerably decreased to 0.26 for the 10% slope, 0.09 for the 5% slope, and 0.11 for the 1% slope. When it came to the IBW treatment, the C-values were drastically changed to match the measured soil loss values.

From photo recognition, the C-value was 0.34 and it had to be adjusted to 0.03 for the 10% slope, 0.04 for the 5% slope, and 0.02 for the 1% slope. Although the C-values were all lowered to fit the measured data, the same trend appeared. The NR had the least soil exposure while the BW treatment had the most, and the IBW treatment was in the middle of the two extremes.

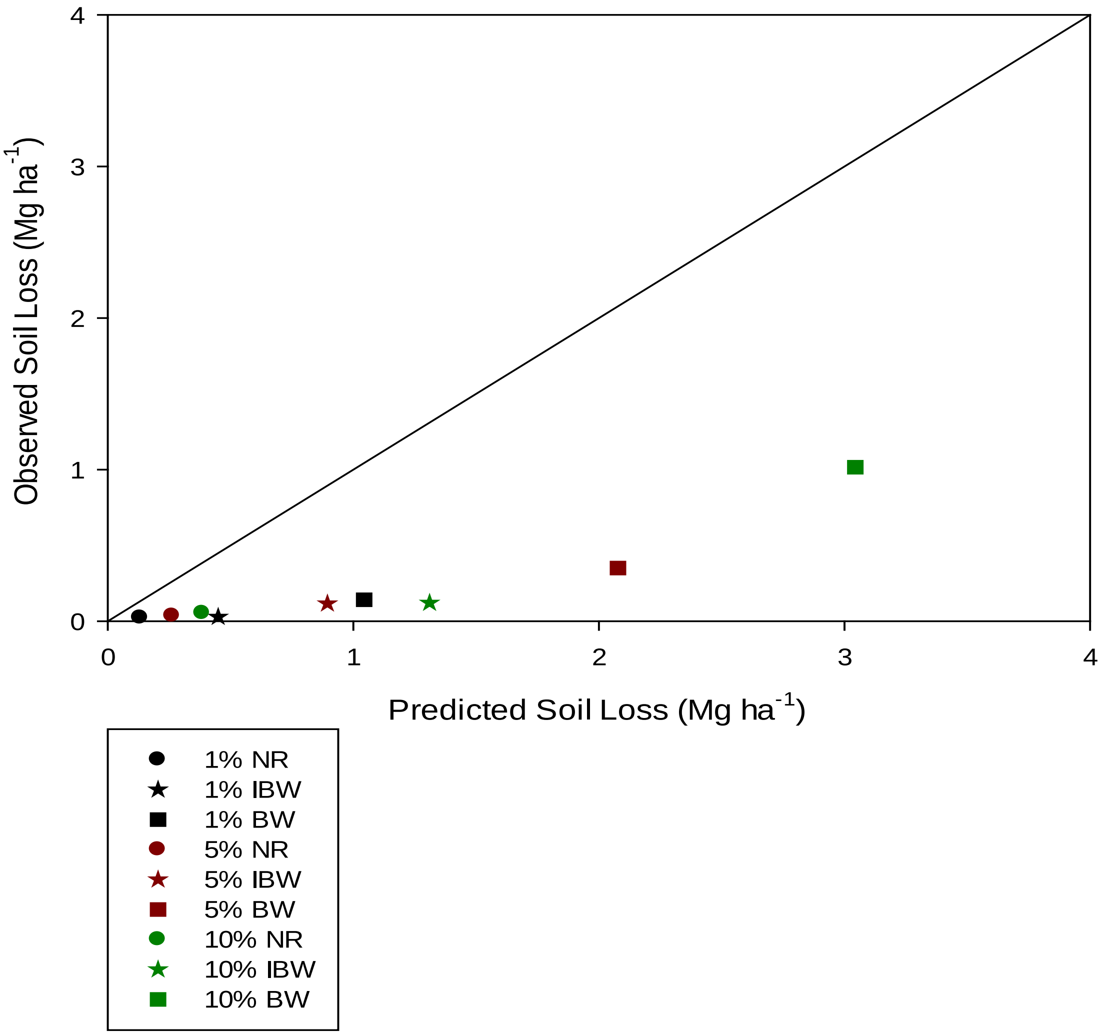


Figure 4-21 Total soil loss predicted by RUSLE versus average observed soil loss (BW=baled windrow, IBW=in-between windrows, and NR=no removal)

Table 4-7 RUSLE predicted C-values from photo recognition and adjusted C-values based on slope and cover factor treatments

Slope (%)	**Cover treatment**	**C-value (predicted)**	**C-value (adjusted)**
1	NR	0.10	0.02
1	IBW	0.34	0.02
1	BW	0.79	0.11
5	NR	0.10	0.01
5	IBW	0.34	0.04
5	BW	0.79	0.09
10	NR	0.10	0.01
10	IBW	0.34	0.03
10	BW	0.79	0.26

[1] Adjusted C-values: These values are not recommended C-values for RUSLE. They are the values that fit the predicated data to the observed soil loss for this study.

In this study, RUSLE over predicted the total soil loss for all three cover treatments, across all three slopes. Brooks, Spencer et al. (2014) studied how accurate the predictions from the RUSLE model were concerning observed data during the wet-dry season in the tropics of Cape York, northern Australia. To calculate the rainfall erosivity (R-value) rain gauges were used to quantify the total rainfall and rainfall intensities. The cover factor was estimated by the product of the canopy and ground layer sub-factors. The slope length (L-value) and slope steepness (S-value) were both determined using LiDAR data. The K-value was back calculated from the runoff material to determine the soil erodibility parameters. The runoff material was analyzed for total suspended load and particle size distributions.

The research conducted by Brooks, Spencer et al. (2014) was over a two year period, and they concluded that the R-value contributed to the over estimations seen in the RUSLE calculated soil losses. At one of their sites, the yields varied by an order of magnitude, when the total rainfall during the wet season was about the same. They concluded that such anomalies most likely have several contributing factors, but a single rain event could account for a large portion of the annual soil loss. These types of large rain events are not well represented in the annual rainfall erosivity data. Another observation was that the RUSLE predicted soil losses on a similar plot scale as the calculated losses had a 4.5 fold variance between the modeled and observed data, at the different model resolutions. Therefore, the scale of observation, concerning the L-value, could explain part of the discrepancy between the observed and predicted sediment yields. Another source of error in the RUSLE prediction could be the use of late dry season cover factors throughout the year. It is assumed that most erosion would occur during the late dry to early wet season, while the ground cover is low, therefore assuming the late dry season cover factor as being sufficient. However, using this cover factor to predict soil loss for the entire wet season would over predict actual soil loss. The results from this study showed that the use of late dry season cover factors over predicted the soil loss by a factor of 2 to 3 times verses the wet season cover factors. Their suggestions for more accurate predicted results would be an improvement on the topographic data resolution and a more detailed representation of the R and C values over time.

In an effort to compare soil loss to different harvest strategies, the measured soil loss data were used to predict in-field conditions (Figure 4-22, Figure 4-23, and Figure 4-24) for corn stover harvest. Over the BW and IBW values shows the percent increase from the NR treatment. This demonstrates the increase in soil loss as compared to the control amount of no removal. The NR treatment remained the same because there was no removal occurring after grain harvest. The IBW also remained the same because those numbers reflect a single pass harvest system, which would leave the field with an even amount of cover after harvesting the grain. As for the BW treatment, it was calculated to reflect the two rows of stalks, cobs, husks, and leaves that were baled, in accordance to a double pass harvest system, as well as, the 10 rows of stover components that remained in field (in-between the baled windrows). The BW was calculated by multiplying the BW soil loss by 2/12 and adding that value to the IBW soil loss multiplied by 10/12. This allows the value to represent the uneven surface cover that is across the field’s soil surface.

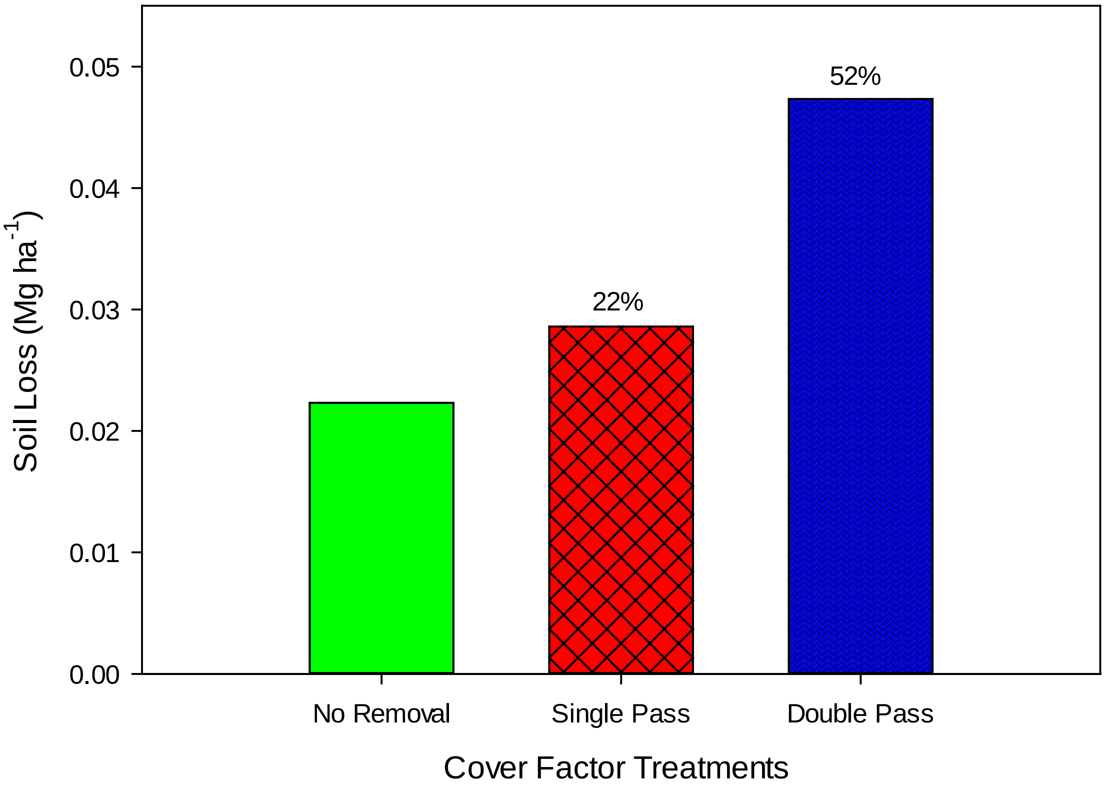


Figure 4-22 Average measured soil loss at 1% slope in relation to harvest removal strategies

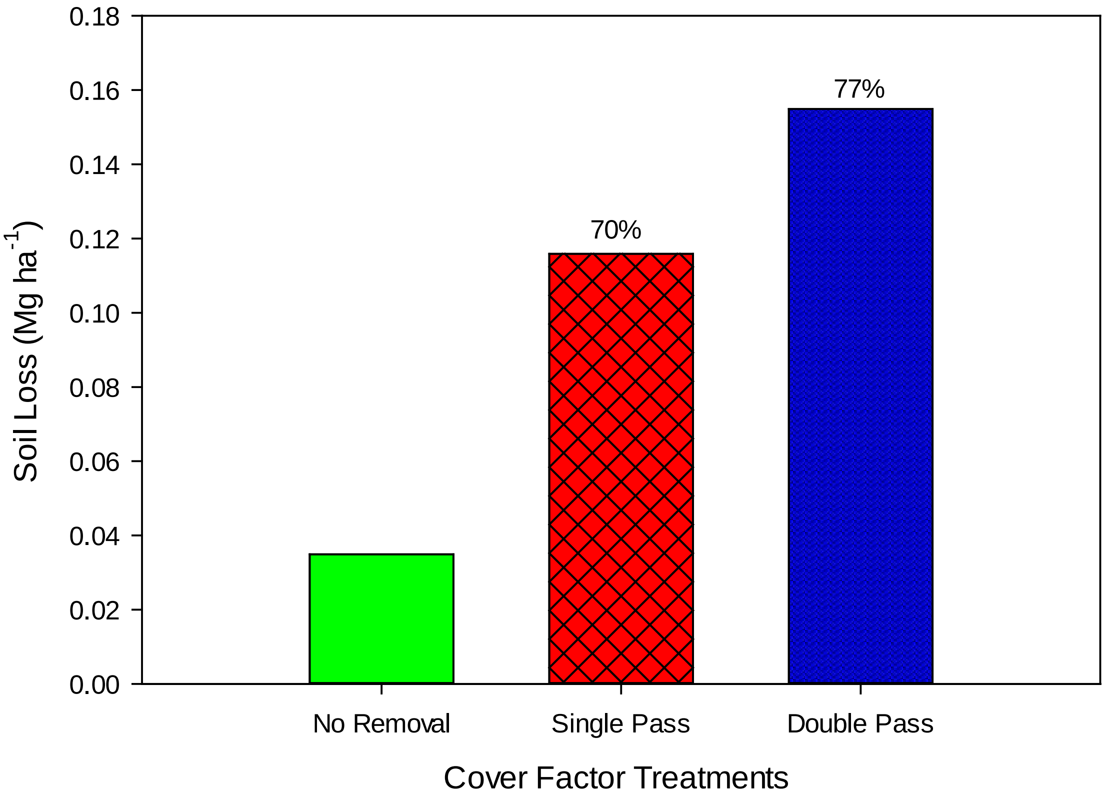


Figure 4-23 Average measured soil loss at 5% slope in relation to harvest removal strategies

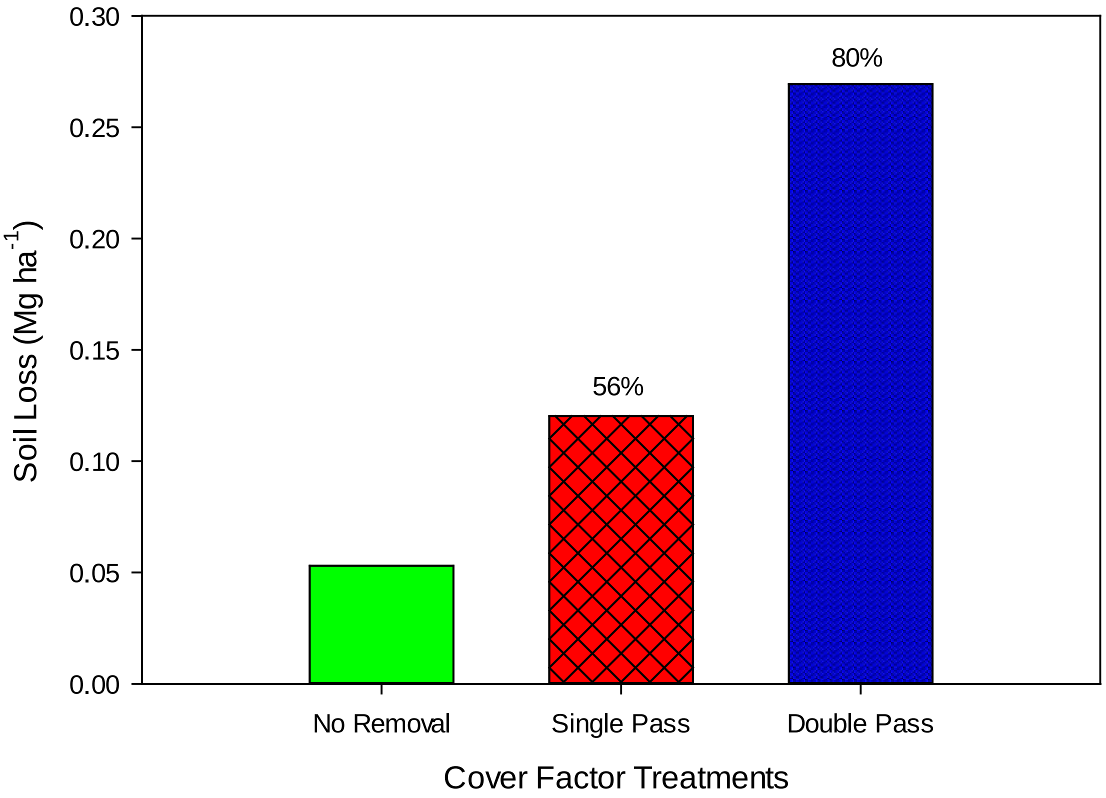


Figure 4-24 Average measured soil loss at 10% slope in relation to harvest removal strategies

Across all three slopes, the NR treatment had the lowest amount of soil loss while the BW was consistently higher. However, there was no statistical difference between the slopes and cover treatments with p-values of 0.2096 and 0.1785, respectively. Although there was no significant difference in the soil loss for each baling system, it cannot be assumed that removing all of the biomass would be the best management practice. There is still a trend that the double pass baling system has higher amounts of soil loss, and these values are based off of one rain event and not a yearly erosion amount. This trend reflects the idea of no removal being the best management practice, while double pass baling would be the worst case scenario (Naudin, Scopel et al. 2012). Thomas, Ahiablame et al. (2014) investigated the impact of corn silage harvest and corn stover removal on the potential soil losses using the RUSLE 2.0 model and Groundwater Loading Effects of Agricultural Management Systems-National Agricultural Pesticide

Risk Analysis (GLEAMS-NAPRA) model. They assumed a shredding and raking scenario that would collect 70% of the corn stover. The no-till continuous corn would have similar characteristics to this studies NR treatment. The no-till 70% removal would most likely be close to the BW treatment.

For the RUSLE predictions, they found a cover factor of 0.47 for corn silage harvest that would approximate the corn root only treatment in this study. As for the GLEAMS-NAPRA model, the cover factor was determined to be 0.85 for corn silage harvest. On a silt loam soil (Blount) with a slope of 4%, they calculated an annual erosion rate of 4.70 t ha^{-1} for corn silage harvest and an erosion rate of 3.84 t ha^{-1} from traditional grain harvest with 70% of the stover removed. Under a no-till continuous corn scenario, they calculated an annual soil loss of 0.88 t ha^{-1}. The increase in soil erosion from a no-till and 70% stover removal was a 3 fold increase. Their data were based on annual rates, but the results from this study indicate a 4 fold increase, on the 5% slope, between the NR and BW treatments.

CHAPTER 5: SUMMARY AND CONCLUSIONS

The primary goal of this thesis was to determine the potential soil erosion from no corn stover removal and simulated single or double pass harvest of corn stover. The motivation behind corn stover removal is due to interest in producing biofuels from cellulosic sources of biomass. The main questions addressed by this study were:

1. Can the creation of simulated corn roots emulate the function of actual corn roots?
2. Are there advantages to the double pass or single pass harvest of corn stover across a variety of slopes?
3. Can the existing RUSLE model account for varied harvest practices within the cover factor parameter?

Experiments were conducted on soil erosion boxes to quantify the influence the corn root system has on soil erosion. All experiments were conducted using a rainfall simulator with a rainfall intensity of 30 mm hr^{-1} for 46 minutes. These experiments were conducted using constructed soil erosion boxes and a rainfall simulator, on a 5% slope, and no additional crop cover was added to the soil surface. Turbidity and total suspended solids (TSS) analyses were conducted on all of the runoff samples to determine the impact roots have on soil loss.

These experiments showed that within the first 2 to 4 minutes of runoff, turbidity and TSS concentrations were higher due to the first flush effect. The treatments with the simulated roots and actual corn roots were compared to a control treatment with bare soil. Although the simulated roots had lower turbidity and TSS concentrations, as compared to the bare soil, the actual corn roots had higher concentrations. It was hypothesized that the actual corn roots and simulated roots would not be significantly different in terms of TSS and turbidity, and that both root systems would have lower TSS and turbidity concentrations than the bare soil treatment. However, the actual corn roots, simulated roots, and bare soil had no significant difference on the turbidity and TSS concentration. Because of this it was believed that the simulated roots were appropriate for further testing of cover factors to prevent the corn stover from being washed away during the experiments.

Once the varied cover factors were introduced, the measured runoff volume varied. The runoff flow rate significantly varied by slope and cover factor treatment. At a 10% slope, the BW flow rate was approximately double the NR and IBW flows. The higher flow rates may be due to the percentage of cover present in each treatment. The NR and IBW treatments had similar cover percentages and were much higher than the BW treatment. With a slope of 1%, the biomass may have slowed down the water or prohibited it from flowing at all resulting in a much lower flow rate. There could also have been pooling behind the biomass, specifically husks and leaves, resulting in lower flow rates.

As for the TSS and turbidity concentrations, the NR treatment had lower concentrations for all slopes. However, there was no significant difference between any of the TSS or turbidity concentrations, due to the slope. The slopes may not have had an effect on the TSS and turbidity concentrations because all of them were normalized over the flow rate. This normalization adjusted the concentrations to account for the variations in slope. For the turbidity and TSS concentration analysis, the concentrations were compared to one another based on runoff sample time, to determine the influence cover has on soil erosion over the duration of a rain event. Looking at turbidity from a 1% slope, there was an overall significant difference between the various cover treatments. As the rainfall event progressed, the NR and BW treatments were the only ones whose turbidity concentrations were significantly different. The 5% slope also had significant differences between turbidity concentrations for the three cover treatments. From the 22 minute sample time, until the end of the rain event, all three cover treatments had significantly different turbidity concentrations. With a 10% slope, the turbidity concentrations had an overall significant difference in relation to the cover treatments. However, it was not until the 30 minute sample time that the turbidity concentrations for the BW treatment became significantly different than the NR and IBW treatments.

Similar to the turbidity concentrations, the slope had no significant impact on the TSS concentrations with relation to the cover factor treatments. On the 1% slope, there was no significant difference in the TSS concentration between any of the cover treatments, at any sample time. With a 5% slope, TSS concentrations were significantly different between the cover treatments. All of the TSS concentrations were significantly different than one another for all cover treatments after the 22 minute sample time. Like the 5% slope, the TSS concentration from a 10% slope had an overall significant difference between all three cover factor treatments. On the 10% slope, there was sizeable variation in the TSS concentrations throughout the rainfall event. There was a significant difference between the cover treatments until the last sample time. At the 46 minute sample time, all three cover treatments TSS concentrations converged together and had no significant difference between each other.

In an effort to determine if RUSLE can account for selective harvests systems, the amount of soil loss was measured across several slopes with varied cover factors. All of the parameters in RUSLE were calculated, representing the characteristics of the soil erosion boxes, to evaluate the predicted amount of soil erosion. The empirical formula calculated that the soil loss would be the worst at the 10% slope with the BW treatment. Conversely, the lowest amount of soil loss was on the 1% slope with the NR cover treatment. The soil loss over the range of slopes and cover treatments varied from 0.13 to 3.04 Mg ha^{-1} for the modelled storm intensity.

One objective was to determine if the empirical RUSLE formula could account for varied harvest strategies. In order to evaluate the application of RUSLE, the predicted soil loss and the measured losses were compared to one another. It was found that RUSLE over predicted the amount of soil loss compared to the experimental data. The only variable that could be adjusted within RUSLE to match the data was the cover factor variable. The C-value provided in the literature for the NR treatment was lowered from 0.1 to 0.01-0.02 to match the experimental data, depending on the slope. There was a large difference, depending on the slope, for the BW treatment. The C-value decreased from 0.79 to 0.11, 0.09, and 0.26 for the 1, 5, and 10% slopes, respectively.

The data would allow for the evaluation of soil erosion from two potential corn stover harvest strategies compared to no biomass removal. The same trends appeared throughout each slope, with no biomass removal having the lowest soil loss of 0.02, 0.03, and 0.05 Mg ha^{-1} for slopes of 1, 5, and 10%, respectively. Single pass corn stover harvest would correspond to the IBW treatment and would have a soil loss of 0.03, 0.12, and 0.19 Mg ha^{-1} for slopes of 1, 5, and 10%, respectively. Double pass corn stover harvest would have a soil loss of 0.14, 0.35, and 1.02 Mg ha^{-1} for slopes of 1, 5, and 10%, respectively.

This research provided confirmation that soil loss fluctuates across slopes along with varied cover factors. It was found that the most effective way of minimizing soil loss was to keep as much cover as possible, especially on steeper slopes. There is not a one-size-fits-all solution to biomass removal, but should be based on the land owners better judgment. There can be a lot of variation in soil loss depending on the slope, harvest strategy, and rainfall events. Although none of the soil loss amounts exceeded the NRCS tolerable soil loss limit, in this study, that is not enough evidence to promote corn stover removal. With the use of empirical models, such as RUSLE, soil loss can be predicted for selective harvest systems if the appropriate cover factors can be determined to accurately describe the soil cover.

CHAPTER 6: FUTURE WORK

The research showed that soil loss from alternative corn stover harvesting systems can be quantified; the next logical step would be to determine the effect individual corn stover components have on soil loss. As shown in the results, the IBW treatment had no cobs and a similar amount of husks, stalks, and leaves to the NR treatment. This would suggest that the cobs did not contribute to soil erosion as much as the stalks, husks, and leaves. With further investigation, it could be shown that the cobs, husks, leaves, and stalks all behave differently and help control soil erosion in their own way. The quantification of individual corn stover components on the C-values within the RUSLE equation could be updated by including selective cover factors, rather than just soil exposure. Since the stalks and cobs are more rigid than the leaves and husks, they could potentially be represented in the current RUSLE model as rocks. This cover calibration method would most likely effect the K-value, by forcing the soil to be more rigid and less permeable, but could possibly account for some of the over predictions seen in this study.

Along with the updated cover factors, there is a need for RUSLE to take into consideration the variation of soil cover throughout the year. After grain harvest, corn stover components degrade at different rates depending on the weather conditions and type of harvest strategies. If models could account for variations in corn stover components on the surface, RUSLE could be modified to more accurately predict soil erosion.

Another concern that many researches have, when it comes to removal of corn stover for bio-energy production, is the loss of soil nutrients (Hoskinson, Karlen et al. 2007; Hammerbeck, Stetson et al. 2012; English, Tyner et al. 2013). Now that the effects of removal on soil loss have been quantified, the next step would be to quantify the nutrient losses or potential changes with soil organic matter associated with stover removal. The soil nutrient losses and soil organic matter changes could be tied in with selective harvesting systems and the amount of nutrients individual stover components have and their contributions to soil health.

APPENDICES

Appendix A. Rainfall Simulator Calibrations

The Rainfall simulator was calibrated using five duty cycles: 10, 20, 50, 75, and 100%. Each percentage represents the time the valves were open. Forty-eight Tru-Chek rain gauges (Edwards Manufacturing Company, Albert Lea, MN) were distributed evenly underneath the rainfall simulator. The simulator ran for 15 minutes on the 10 and 20% duty cycles and 10 minutes on the 50, 75, and 100% duty cycles. The longer time periods for the lower duty cycles were to ensure enough water was in the rain gauges to accurately read the measured graduations. Water levels were recorded for each rain gauge at the end of each duty cycle.

The rainfall simulator was divided into four square sections to find the optimal placement for the soil erosion box. For each square section an average water level was computed for using the rain gauges located within the perimeter. Based on the rainfall depth and duration of rainfall, an average intensity was computed. The section underneath the rainfall simulator that most closely matched the preferred rainfall intensity of 30 mm hr^{-1} was chosen. The location chosen was in the center of the rainfall simulator. Figure A-1 shows the calibration curve for the rainfall simulator.

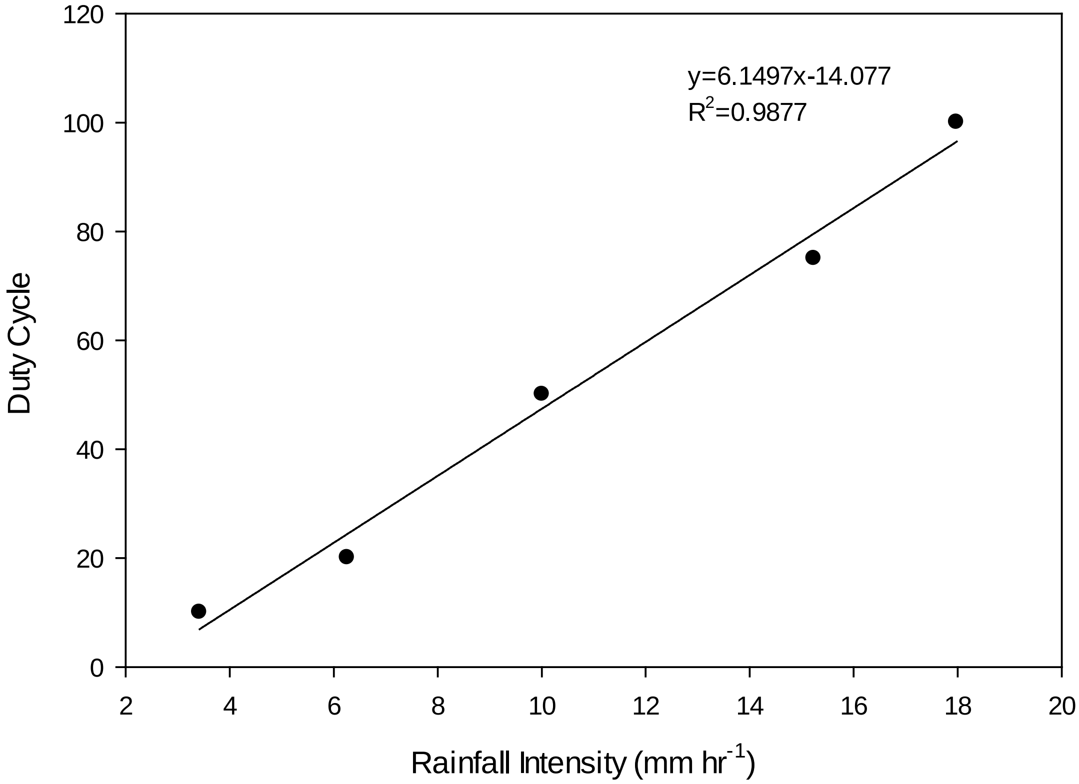


Figure A-1 Rainfall simulator calibration curve

Appendix B. RUSLE Parameters Determination

To calculate the R-value for the individual storm event of 30 mm hr^{-1}, Table B-1 was used (Pitt 2004). The cover factor determination for the RUSLE C-value was completed by using photo recognition. As explained in the methods section, pictures of a baled windrow, in-between windrows, and a windrow were taken after grain harvest in a field to determine the amount of soil cover. These pictures were then compared to pictures of the soil erosion boxes to determine the percent cover value that would be used in RUSLE to compute soil loss.

Table B-1 Rainfall erosivity kinetic energy calculation

Sampling time (min)	**Duration of interval (min)**	**Cumulative rainfall depth (mm)**	**Rainfall in interval (mm)**	**Intensity (mm hr^{-1})**	**Unit Energy (MJ ha^{-1} mm^{-1})**	**Energy in Interval (MJ ha^{-1})**	**Total Rainfall Erosivity**
2		0					
4	2	0.99	0.99	29.7	0.27	0.27	7.99
8	4	2.97	1.98	29.7	0.27	0.54	15.98
14	6	5.94	2.97	29.7	0.27	0.81	23.97
22	8	9.9	3.96	29.7	0.27	1.08	31.96
30	8	13.86	3.96	29.7	0.27	1.08	31.96
38	8	17.82	3.96	29.7	0.27	1.08	31.96
46	8	21.78	3.96	29.7	0.27	1.08	31.96
			Total Rainfall Erosivity (MJ-mm ha^{-1} hr^{-1})				**175.76**

Figure B-2 Corn stover in a windrow (represents NR cover)

Figure B-3 Windrow corn stover, representing NR cover

Figure B-4 Corn stover in-between windrows (represents IBW cover)

Figure B-5 In-between windrows corn stover, representing IBW cover

Figure B-6 Corn stover in a baled windrow (represents BW cover)

Figure B-7 Baled windrow in field, representing BW cover

Figure B-8 NR cover factor on soil erosion box

Figure B-9 NR cover factor on soil erosion box

Figure B-10 IBW cover factor on soil erosion box

Figure B-11 IBW cover factor on soil erosion box

Figure B-12 BW cover factor on soil erosion box

Figure B-13 BW cover factor on soil erosion box

Appendix C. Individual Erosion Box Details

For Table C-2 and Table C-3, the box numbers are labeled as follows. T represents the replication number for that particular slope and cover combination. The number following the S is the slope for that box treatment. As for the C, the 100, DP, and 0 represent the NR, IBW, and BW treatments, respectively.

Table C-2 Moisture content and mass of biomass applied to the soil erosion boxes

		Moisture Content (%)				**Dry mass (g)**		**Wet mass (g)**	
Date	Box Number	Husks	Leaves	Stalks	Cob				
9/29/2014	T1:S10:C100	12.39	12.55	11.43	9.39	Cobs	212.16	Cobs	234.07
		11.77	12.50	12.09	9.33	Stalks	648.97	Stalks	729.37
		13.09		9.55		Leaves	381.35	Leaves	435.95
Average Moisture Content:		12.42	12.53	11.02	9.36	Husks	141.04	Husks	161.04
9/29/2014	T1:S5:C0 T1:S1:C0	12.39	12.55	11.43	9.39	Cobs	120.68	Cobs	133.14
		11.77	12.50	12.09	9.33	Stalks	105.36	Stalks	118.41
		13.09		9.55		Leaves	52.32	Leaves	59.81
Average Moisture Content:		12.42	12.53	11.02	9.36	Husks	11.07	Husks	12.64
10/20/2014	T1:S10:C0 T2:S10: C0	9.73	9.88	9.60	8.64	Cobs	120.68	Cobs	132.75
		13.23	9.84	7.98	9.08	Stalks	105.36	Stalks	115.84
		12.19		9.56	9.56	Leaves	52.32	Leaves	58.04
Average Moisture Content:		11.72	9.86	9.05	9.09	Husks	11.07	Husks	12.54
10/20/2014	T2:S10:C100	9.73	9.88	9.60	8.64	Cobs	212.16	Cobs	233.38
		13.23	9.84	7.98	9.08	Stalks	648.97	Stalks	713.52
		12.19		9.56	9.56	Leaves	381.35	Leaves	423.06
Average Moisture Content:		11.72	9.86	9.05	9.09	Husks	141.04	Husks	159.76
11/3/2014	T3:S10:C100 T1:S5:C100	8.90	7.92	6.16	6.98	Cobs	212.16	Cobs	227.55
		8.68	8.05	8.84	6.50	Stalks	648.97	Stalks	698.64
		8.91	8.27	6.33	6.81	Leaves	381.35	Leaves	414.87
Average Moisture Content:		8.83	8.08	7.11	6.76	Husks	141.04	Husks	154.70
11/3/2014	T1:S10:CDP T1:S1:CDP	8.90	7.92	6.16	6.98	Cobs	0.00	Cobs	0.00
		8.68	8.05	8.84	6.50	Stalks	526.80	Stalks	567.12
		8.91	8.27	6.33	6.81	Leaves	289.83	Leaves	315.31
Average Moisture Content:		8.83	8.08	7.11	6.76	Husks	94.5	Husks	103.65
11/19/2014	T2:S5:C0	7.07	8.05	6.69	5.21	Cobs	120.68	Cobs	127.50
		6.55	7.41	6.26	5.61	Stalks	105.36	Stalks	112.36
		7.06	7.85	5.73	5.23	Leaves	52.32	Leaves	56.73
Average Moisture Content:		6.89	7.77	6.23	5.35	Husks	11.07	Husks	11.89
11/23/2014	T2:S5:C100 T1:S1:C100 T3:S5:C100	9.16	8.51	5.83	6.33	Cobs	212.16	Cobs	226.52
		8.67	8.37	5.67	6.05	Stalks	648.97	Stalks	688.76
		8.90	7.96	5.83	6.64	Leaves	381.35	Leaves	415.78
Average Moisture Content:		8.91	8.28	5.78	6.34	Husks	141.04	Husks	154.84
11/23/2014	T2:S10:CDP	9.16	8.51	5.83	6.33	Cobs	0.00	Cobs	0.00

		8.67	8.37	5.67	6.05	Stalks	526.80	Stalks	559.10
		8.90	7.96	5.83	6.64	Leaves	289.83	Leaves	315.99
Average Moisture Content:		8.91	8.28	5.78	6.34	Husks	94.5	Husks	103.74
12/10/2014	T3:S10:C0	10.21	9.72	2.06	7.00	Cobs	120.68	Cobs	130.00
	T2:S1:C0	9.71	9.62	6.60	7.02	Stalks	105.36	Stalks	111.11
		8.61	9.07	6.86	7.48	Leaves	52.32	Leaves	57.79
Average Moisture Content:		9.51	9.47	5.17	7.17	Husks	11.07	Husks	12.23
12/10/2014	T1:S5:CDP	10.21	9.72	2.06	7.00	Cobs	0.00	Cobs	0.00
		9.71	9.62	6.60	7.02	Stalks	526.80	Stalks	555.54
		8.61	9.07	6.86	7.48	Leaves	289.83	Leaves	320.15
Average Moisture Content:		9.51	9.47	5.17	7.17	Husks	94.5	Husks	104.43
12/27/2014	T2:S1:CDP	8.49	12.59	6.24	6.28	Cobs	0.00	Cobs	0.00
	T3:S10:CDP	8.67	10.75	6.06	6.01	Stalks	526.80	Stalks	560.74
	T3:S1:CDP	8.14	12.71	5.86	6.34	Leaves	289.83	Leaves	329.41
Average Moisture Content:		8.43	12.02	6.05	6.21	Husks	94.5	Husks	103.20
12/27/2014	T2:S1:C100	8.49	12.59	6.24	6.28	Cobs	212.16	Cobs	226.21
		8.67	10.75	6.06	6.01	Stalks	648.97	Stalks	690.79
		8.14	12.71	5.86	6.34	Leaves	381.35	Leaves	433.43
Average Moisture Content:		8.43	12.02	6.05	6.21	Husks	141.04	Husks	154.03
1/2/2015	T3:S1:C100	9.53	8.94	7.54	6.19	Cobs	212.16	Cobs	226.99
		9.50	8.25	6.55	6.80	Stalks	648.97	Stalks	695.00
		8.85	8.39	5.78	6.61	Leaves	381.35	Leaves	416.90
Average Moisture Content:		9.29	8.53	6.62	6.53	Husks	141.04	Husks	155.49
1/2/2015	T2:S5:CDP	9.53	8.94	7.54	6.19	Cobs	0.00	Cobs	0.00
	T3:S5:CDP	9.50	8.25	6.55	6.80	Stalks	526.80	Stalks	564.17
		8.85	8.39	5.78	6.61	Leaves	289.83	Leaves	316.85
Average Moisture Content:		9.29	8.53	6.62	6.53	Husks	94.5	Husks	104.18
1/2/2015	T3:S1:C0	9.53	8.94	7.54	6.19	Cobs	120.68	Cobs	129.12
	T3:S5:C0	9.50	8.25	6.55	6.80	Stalks	105.36	Stalks	112.83
		8.85	8.39	5.78	6.61	Leaves	52.32	Leaves	57.20
Average Moisture Content:		9.29	8.53	6.62	6.53	Husks	11.07	Husks	12.20

Table C-3 Average density and standard deviation (3 replications) for each soil erosion box

Box Number	**Density (g cm^{-3})**	**Stdv.**
T1:S5:SR	1.20	0.047
T2:S5:SR	1.20	0.013
T3:S5:SR	1.19	0.013
2C	1.12	0.028
7C	1.13	0.028
9C	1.14	0.050
11C	1.19	0.081
T1:S5:BS	1.13	0.032
T2:S5:BS	1.17	0.014
T3:S5:BS	1.20	0.010
T1:S1:C0	1.18	0.024
T2:S1:C0	1.20	0.007
T3:S1:C0	1.18	0.029
T1:S1:CDP	1.15	0.011
T2:S1:CDP	1.17	0.017
T3:S1:CDP	1.21	0.014
T1:S1:C100	1.15	0.076
T2:S1:C100	1.10	0.028
T3:S1:C100	1.18	0.013
T1:S5:C0	1.20	0.030
T2:S5:C0	1.16	0.017
T3:S5:C0	1.22	0.001
T1:S5:CDP	1.13	0.028
T2:S5:CDP	1.19	0.017
T3:S5:CDP	1.17	0.008
T1:S5:C100	1.14	0.023
T2:S5:C100	1.18	0.026
T3:S5:C100	1.14	0.043
T1:S10:C0	1.15	0.022
T2:S10:C0	1.16	0.016
T3:S10:C0	1.20	0.009
T1:S10:CDP	1.20	0.031
T2:S10:CDP	1.16	0.017
T3:S10:CDP	1.21	0.019
T1:S10:C100	0.91	0.205
T2:S10:C100	1.16	0.007
T3:S10:C100	1.16	0.053

Appendix D. SAS Code

All of the statistical analysis for objectives 1 and 2 were performed using the same code. An example of the SAS code is shown below. For objective 3, the SAS code was altered slightly and an example is shown below.

SAS code for objectives 1 and 2

```
Data turbidity;
input slope conc2 conc4 conc8 conc14 conc22 conc30 conc38 conc46 cover
$;
datalines;


proc glm data=turbidity;
class cover;
model conc2 conc4 conc8 conc14 conc22 conc30 conc38 conc46 = cover
/nouni;
repeated intensity 8 / printe;
means cover / TUKEY;
run;
```

SAS code for objective 3

```
Data turbidity;
input slope cover $ conc;
datalines;

proc glm data=turbidity;
class slope cover;
model conc = slope cover slope*cover;
means slope cover slope*cover/ TUKEY;

run;
```

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