EVALUATION OF EROSION CONTROL PRACTICES UNDER LARGE-SCALE RAINFALL SIMULATION FOLLOWING ASTM D6459 STANDARD TEST METHODS

by

Brian Allen Faulkner

A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
May 2, 2020

Keywords: erosion, hydromulch, rainfall simulation,
rolled erosion control blankets, stormwater, straw

Approved by

Wesley N. Donald, Chair, Research Fellow IV Civil Engineering
Wesley C. Zech, Professor of Civil Engineering
Xing Fang, Professor of Civil Engineering

ABSTRACT

Land development and construction activities remove vegetative cover, exposing bare soil to the erosive forces of rainfall. Stormwater causes dislodgement of soil particles through splash, sheet, and rill erosion, resulting in soil particles being transported off-site causing pollution in local water bodies and water conveyance systems. Erosion control practices are installed to minimize the amount of erosion caused by erosive forces and to aid in the establishment of vegetation.

A rainfall simulator has been constructed at the Auburn University Erosion and Sediment Control Test Facility (AU-ESCTF) following the ASTM D6459-19: *The Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Hillslopes from Rainfall Induced Erosion* requirements. The rainfall simulator was constructed to produce 2, 4, and 6 in. per hr (51, 102, and 152 mm per hr) rainfall intensities and has test plot dimensions of 8 ft (2.4 m) wide by 40 ft (10.1 m) long on a 3H:1V slope. Each rainfall experiment was an hour long with three sequential 20 minute rainfall intervals of increasing rainfall intensities of 2, 4, and 6 in. per hr (51, 102, and 152 mm per hr). Calibration testing was performed on each rainfall intensity to verify rainfall drop size distribution, intensity, and uniformity.

Bare soil control, loose straw, loose straw with tackifier, and crimped straw were evaluated under rainfall simulation. The mulch practices and bare soil installations were evaluated under initial and longevity performance testing. Following the completion of the straw mulch testing, the soil type of the test slope was changed from a sandy loam to a loam soil, which better followed the soil classification stated in ASTM D6459 standard. During this time, the test procedure was altered to calculate the product *C*-factor. Three hydraulic mulches, three erosion control blankets, and bare soil control tests were evaluated under the new test procedure. Following the completion of testing, the Revised Universal Soil Loss Equation (RUSLE) was used to calculate the product *C*-factor from incremental rainfall depth and soil loss results.

Rainfall simulation tests performed on the sandy loam soil resulted in an average soil loss of 738 lb. (335 kg) for bare soil, 143 lb. (64.9 kg) for loose straw, 97 lb. (44 kg) for loose straw, and 169 lb. (76.6 kg) for crimped straw. Longevity testing was performed on the straw applications following the initial product test resulting in a total soil loss 611 lb. (277 kg) for bare soil, 287 lb. (130 kg) for loose straw, 131 lb. (59.4 kg) for loose straw with Tacking Agent 3, and 82 lb. (37.2 kg) for crimped straw. The initial and longevity test results were combined to determine which practice reduced the overall soil loss. The loose straw with Tacking Agent 3 resulted in the highest reduction in soil loss of 83%, which was closely followed by the crimped straw with an improvement of 81%. This concluded that anchoring the straw mulch reduced the overall soil lose better than the non-anchored straw applications.

Hydraulic mulches and erosion control blankets were evaluated on a loam soil with a new test procedure that allows for the calculation of product *C*-factors. The loam soil had higher total soil loss rates than the sandy loam soil with a total soil loss of 2,333 lb. (1,058 kg). The hydraulic mulches resulted in *C*-factors of 0.55 for Eco-Fibre, 0.46 for Soil Cover, and 0.53 for Terra-Wood. All three hydraulic mulches experienced high erosion rates caused by the product washing from the test plot. Erosion control blankets tests resulted in *C*-factors of 0.05 for Curlex I, 0.14 for S150, and 0.12 for ECX-2. The blankets resulted in lower *C*-factors than the hydraulic mulches. The Curlex I blanket provided the best test plot coverage resulting in the lowest *C*-factor.

ACKNOWLEDGEMENTS

The author would like to thank Dr. Wesley C. Zech for his encouragement to not only pursue this graduate project, but also further guidance toward a specialized career goal. The author would also like to extend thanks to Dr. Wesley N. Donald for his continuous assistance and oversight in the greater development of the rainfall simulator and in myself as a graduate student. Thank you to Dr. Xing Fang for guidance throughout the duration of the project, Mr. Guy Savage for the extensive test facility management, and all undergraduate workers who aided in the completion of testing. The author would also like to thank the Alabama Department of Transportation for financially supporting this project. Lastly, the author would like to thank Stephanie Faulkner and his parents Mike and Beth Faulkner for their love and support throughout his graduate studies.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Land development activities consisting of clearing, grubbing, and grading remove the natural vegetative cover from sites, thereby disturbing and exposing soil to rainfall and stormwater runoff. Stormwater runoff causes the dislodgement of soil particles through splash, sheet, and rill erosion, which can hinder the establishment of vegetation. As erosion occurs, dislodged sediment is transported from construction sites into water conveyance systems causing an influx of pollutants and sediment to nearby waterbodies (Mid-America 2020). In the United States alone, it is estimated that 80 million tons (72.6 million metric tons) of sediment eroded from construction sites annually (Novotny 2003). With these large quantities of eroded soil leaving construction sites, the annual cost to society for nutrient loss due to erosion and sedimentation is $44 billion (Brady and Weil 1996). Vast quantities of soil entering municipal separate storm sewer systems (MS4s) and surface water bodies can cause negative environmental impacts. Some environmental impacts caused by sedimentation are the prevention of natural vegetation growth, clogging of fish gills, increased cost of water treatment, increasing nutrients causing algae growth, and the alteration of the flow and depth of the water conveyance systems. In addition, the buildup of sediment in water conveyance systems increases the likelihood of flooding and streambank erosion (Mid-America 2020).

In 1987, in an attempt to minimize eroded sediment in surface waterbodies, the Clean Water Act (CWA), mandated that construction sites control stormwater, erosion, and sediment (USEPA 2019). In 1990, the United States Environmental Protection Agency (USEPA) under the

CWA implemented Phase I of the National Pollution Discharge Elimination System (NPDES). Phase I of the NPDES required that all construction sites disturbing 5 acres (2.0 ha) or more of land must have a stormwater pollution prevention plan (SWPPP) and limit site runoff pollution levels. This requires small sites within these guidelines to develop a SWPPP and to implement erosion, sediment, and pollution control practices. The NPDES Construction General Permit (CGP) requires contractors to create a detailed SWPPP and obtain a permit prior to the initiation of construction. The SWPP is a comprehensive plan that implements erosion and sediment control practices to minimize the amount of erosion occurring on the permitted site (USEPA 2019).

Erosion and sediment control practices are installed on construction sites to minimize the amount of sediment transported from construction site to a nearby property or waterbody. Erosion control practices provide ground cover, which protects the soil surface from the impact force of raindrops and slows overland flow. Erosion controls consist of mulches, erosion control blankets, hydroseeding, hydromulching, sodding, dust control, and slope drains. Conversely, when erosion controls are not adequate enough, sediment controls are installed to control the site runoff and to promote sedimentation on-site (AL-SWCC 2018). Rainfall simulators have been constructed to replicate natural rainfall and flow conditions to evaluate the effectiveness of erosion control practices. As technology has progressed, rainfall simulators have been designed and constructed to simulate natural rainfall conditions to further advance the understanding of erosion control practices and overall performance (Robeson et al 2014).

1.2 RAINFALL SIMULATORS

Rainfall simulators are research tools designed to replicate natural rainfall events (Robeson et al. 2014). The first type of rainfall simulators constructed were drop forming rainfall simulators, which used yarn or glass capillary tubes to form drops (Pall et al. 1983). Drop forming simulators produce a narrow drop size ranging from medium to large drops. A drop forming rainfall simulator releases the raindrops at an initial velocity of zero. This requires the height of drop forming rainfall emitters to be tall enough to allow terminal velocity to be reached. Since the pressurized rainfall simulators require a drop fall of height of 14 ft (4.3 m) to reach terminal velocity, which requires drop forming rainfall simulators to be taller than pressurized rainfall simulators. Natural rainfall consists of a wide range of drops sizes, which are not simulated in a drop forming simulator (Elbasit et al. 2015).

Pressurized rainfall simulators were developed to advance rainfall simulator technology by creating a drop size distribution resembling that of natural rainfall (Pall et al. 1983). The pressurized rainfall simulators produce a wide-ranging drop size distribution and raindrops with an initial speed leaving the nozzle allowing the fall height of the drops to be less than the drop forming simulators (Elbasit et al. 2015). Rainfall simulators are also classified as either large or small-scale simulators. Small to intermediate-scale rainfall simulators, test plots less than 20 ft (6.1 m) long, are typically used for testing infiltration and detachment of particles. Small-scale rainfall simulators do no replicate natural erosion conditions because the simulator is unable to produce rill erosion. Large-scale rainfall simulators are defined as test plots ranging from 20 to 40 ft (6.1 to 12.2 m) long. This length allows the rainfall simulator to simulate both rill and interrill erosion. Large-scale rainfall simulators are used by laboratories and agencies to evaluate the performance of erosion control practices. The major issue with large-scale rainfall simulation testing is that each rainfall simulator is unique. These rainfall simulators vary in size, slope, rainfall intensities, test duration, and soil type, which limits the comparison of product performance between test facilities (Robeson et al. 2014).

1.3 RESEARCH OBJECTIVES

The research contained herein is part of a continuing effort at the Auburn University-Erosion and Sediment Control Test Facility (AU-ESCTF) to evaluate the effectiveness of erosion and sediment control practices through large-scale testing. The primary purpose of this research is to evaluate the performance of erosion control products under simulated rainfall following the ASTM D6459-19 standard testing methodology.

The objectives of this project are as follows:

1. Construct and calibrate a rainfall simulator to follow the guidelines of ASTM D6459 to produce 2, 4, and 6 in. per hr (51, 102, and 152 mm per hr) rainfall intensities while satisfying required uniformity and raindrop size.
2. Develop test procedures to ensure consistent and repeatable testing conditions and data collection.
3. Evaluate the performance of Alabama Department of Transportation (ALDOT) approved erosion control practices from List II-11 and II-20 and develop reports to document performance.
4. Determine the cover management factors (*C*-factors) for each product to provide the expected performance on a standardized scale.

To accomplish these research objectives, the project was separated into the following tasks.

1. Evaluate and assess literature on the design, performance, and testing results of erosion control practices under rainfall simulation testing.
2. Re-design the existing rainfall simulator to meet the uniformity, intensity, and drop size requirements of ASTM D6459-19.

3. Develop a test methodology and data collection procedure based on existing test protocols and standards.
4. Conduct large-scale rainfall simulation experiments on bare soil, loose straw, anchored straw, hydraulic mulch, and erosion control blankets.
5. Develop a procedure for the calculation of product *C*-factors using the drop size distribution, soil loss, and rain gauge measurements.

Future research objectives not included in this thesis include: (1) pursuing accreditation for ASTM D6459-19 testing through the Geosynthetic Accreditation Institute (GAI), and (2) design and construct additional rainfall simulation test plots for expanded testing capabilities at the AU-ESCTF.

1.4 ORGANIZATION OF THESIS

This thesis is divided into five chapters that organize and effectively communicate the methods used to meet the defined research objectives. Following this chapter, *Chapter 2: Literature Review*, examines the design and calibration procedures used for rainfall simulation testing of erosion control products. This chapter also analyzes existing rainfall simulator test results from other facilities for straw mulch, hydraulic mulches, and erosion control blankets. Standardized product installation procedures and application rates are examined to aid in the establishment of product installation procedures. *Chapter 3: Methods and Procedures*, outlines the methodology used for the calibration, validation, product application, soil analysis, and the Revised Universal Soil Loss Equation (RUSLE) calculations for the rainfall simulator. *Chapter 4: Results and Discussion*, provides a summary of the calibration, soil analysis, and product test results for the rainfall simulator. *Chapter 5: Conclusions and Recommendations*, provides a summary of the rainfall simulator, the erosion control practice results, and provides recommendations for future rainfall simulation research at the AU-ESCTF.

CHAPTER 2: LITERATURE REVIEW

2.1 RAINFALL SIMULATOR TYPES

Rainfall simulators are used to replicate natural rainfall conditions in a controlled environment to analyze the rainfall characteristic and to evaluate the performance of erosion control practices (Elbasit et al. 2015). The two main rainfall simulator types used for erosion control testing are drop forming or nozzle simulators (Robeson et al 2014).

2.1.1 Drop Forming Rainfall Simulators

Drop forming rainfall simulators allow water to accumulate on the tip of the drop emitter until the weight of the drop overcomes the surface tension before falling to the ground with an initial velocity of zero (Pall et al. 1983). There have been varying types of drop emitters used in rainfall simulators consisting of hanging yarns, glass capillary tubes, hypodermic needles, polyethylene tubing, and stainless steel tubes (Bubenzer and Jones Jr. 1971). Since the raindrops have an initial velocity of zero, the drop forming rainfall simulators must be at a minimum, tall enough to allow the drops to reach terminal velocity, which varies by drop size, before impacting the test plot (Elbasit et al. 2015). The drop forming rainfall simulators generate a uniform drop size distribution with larger drop sizes than pressurized rainfall simulators, which commonly range from 0.09 to 0.22 inches (2.2 to 5.5 millimeters) (Pall et al. 1983).

2.1.2 Pressurized Rainfall Simulators

Pressurized rainfall simulators can generate a wide range of drop size distributions, which are controlled by the nozzle characteristics, pressure, and spray pattern (Pall et al. 1983). The sprinklers used for pressurized rainfall simulators have a rotating disk that evenly spreads and shapes drops over the test plot area (Robeson et al 2014 and Pall et al. 1983). Drops that are discharged from the nozzles occur with an initial velocity, allowing the raindrops to reach terminal velocity over a shorter distance. Therefore, pressurized rainfall simulators do not need to be as tall as drop forming simulators. Typically, however, pressurized rainfall simulators will have a smaller raindrop size distribution (Elbasit et al. 2015).

2.2 CALIBRATION TESTING

Prior to rainfall simulation testing, calibration tests are required to ensure the simulator can meet the required rainfall intensity, uniformity, and drop size distribution meets specifications (Cabalka et al.). There are many factors influencing the intensity and uniformity for rainfall simulators consisting of the sprinkler spacing and wind speed. The rainfall intensity of a rainfall simulator is measured by measuring the rainfall for a predetermined length of time that has accumulated in a rain gauge or other container with known volume. The rainfall uniformity produced by a simulator is determined through the application of the Christiansen Uniformity Coefficient depicted in Equation 2.1 (Pall et al. 1983).

$$C_u = 100\ [\ 1.0 - \sum|d| \div (n\ \bar{X})] \tag{2.1}$$

where,

C_u = Christiansen uniformity coefficient
d = $X_i - \bar{X}$
n = number of observations
$\bar{X}$ = average depth caught, in.
X_i = depth caught in each rain gauge, in.

2.2.1 Drop Size Distribution

Rainfall simulators are designed to mimic the drop size, drop shape, and the terminal velocity of natural rainfall (Jayawardena et al. 2000 and Elbasit et al. 2015). Raindrop size distribution testing was first tested in 1895 by J. Wiesner who used an absorbent paper method. In

1904, P. Leonard published the diagram in Figure 2.1 to show the occurrence of various drop sizes in rainfall based on the rainfall rate and raindrop diameter (Laws and Parsons 1943).

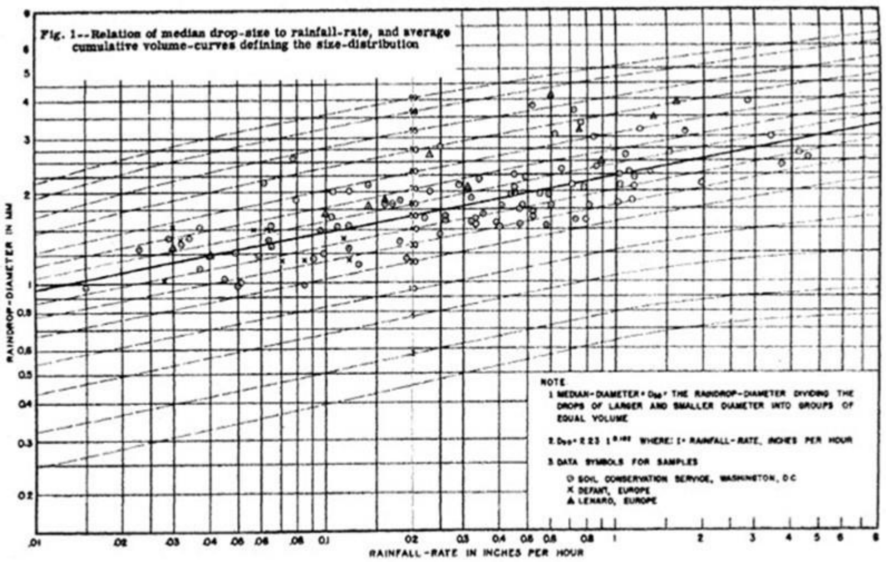


FIGURE 2.1: P. Leonard Raindrop Analysis (Laws and Parsons 1943).

Over the past 120 years, various drop size distribution testing procedures have been developed such as the flour pan method, stain method, laser method, momentum method, and the oil method. The following is a discussion about each method including each ones capabilities to accurately measure raindrop diameter, drop size distribution, and final velocity while also discussing each ones limitations.

2.2.1.1 Flour Pan Method

In 1904, Wilson Bentley developed the flour pan method to determine the drop size distribution of rainfall (Eigel and Moore 1983). The flour pan method uses ten-inch diameter pans that are one-inch thick. The pans are filled with sifted flour and leveled off across the top of the pan. Prepared pans are not allowed to sit for more than two hours before being tested. Before the flour pan was exposed to rainfall, the flour was covered and moved to a level surface under the rainfall. The cover was removed from the pan allowing the flour to be exposed to rainfall for time intervals of a few seconds to minute’s depending on the rainfall intensity (Laws and Parsons 1943).

The flour pan with raindrops was allowed to air dry overnight. The air dried pellets were sieved through a No. 70 mesh sieve to remove all excess flour. The remaining pellets and flour were placed in an oven at 110°C (230°F) for 60 minutes. Once dry, the pellets were sieved through a stack of sieves including No. 8, 10, 14, 20, 28, and 35 for two minutes. The pellets retained on each sieve were weighed and counted. To properly determine the mass of the drop, the mass of the flour pellets must be converted through the application of a mass ratio. A mass ratio curve was developed by evaluating drops of known size. An equal number of raindrops of known size were collected in an empty container and a container of flour. The weight of the resulting flour pellets was compared to the weight of the collected water to determine the corresponding mass ratio between the two samples. The results from the evaluation of known drop sizes is depicted in Figure 2.2 (Laws and Parsons 1943).

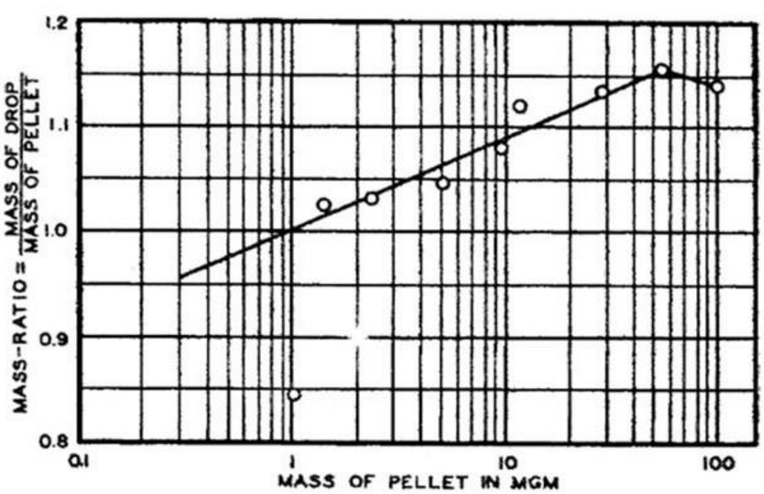


FIGURE 2.2: Mass Ratio (Laws and Parsons, 1943).

The mass of the average pellet was multiplied by the corresponding mass ratio value from Figure 2.2 to calculate the mass of the average drop. The diameter of the average drop was calculated using the average drop mass in Equation 2.2.

$$D_r = \sqrt[3]{\left(\frac{6}{\pi}\right)m} \tag{2.2}$$

where,

D_r = diameter of average drop (mm)
m = mass of average drop (mg)

2.2.1.2 Laser Method

The advancement in laser technology provides an opportunity for high-speed data collection for determining the drop size distribution of rainfall. The laser projects a horizontal beam across a surface and measures the quantity of drops and the raindrop sizes ranging from 0.0008 to 0.5118 in. (0.2 to 13 millimeters in diameter). Lasers are also capable of calculating the velocity of raindrops as they pass through the laser beam. When multiple drops simultaneously pass through the laser, an error occurs by combining the two-drop sizes to record a larger drop. Another error with lasers occurs when large drops that become distorted are measured at their maximum horizontal diameter (Kincaid et al 1996).

2.2.1.3 Momentum Method

Piezoelectric force transducers produce voltage pulses that represents one water drop. The magnitude of the pulse correlates to the drop size, kinetic energy, and momentum of the drops (Jayawardena et al. 2000). The force transducer uses a crystalline quartz plate covered by a steel plate to measure voltage pulses (Elbasit et al. 2015). Since measurements are recorded based on time, the raindrop data can be examined for any time during a storm event (Jayawardena et al. 2000).

2.2.1.4 Oil Method

The oil method is founded on the principal that water droplets will maintain their shape in a less dense, but more viscous fluid. This method combines STP oil treatment and heavy mineral oil at a 2:1 ratio mixture into a 3.94 in. (100 mm) diameter by 0.60 in. (15 mm) deep disposable petri dish. Immediately after the oil mixture is exposed to raindrops, a photograph is taken with a scale placed within the picture for size reference. The photographs were projected onto a smooth screen and the water droplets are measured while incorporating an enlargement factor determined from the scale in the image (Eigel and Moore 1983).

2.2.1.5 Stain Method

The stain method uses absorbent paper with water-soluble dye to measure the size of the raindrops. The paper with dye is placed under rainfall for a few seconds. When the raindrops come in contact with the paper, the dye leaves a permanent mark on the paper (Kathiravelu et al. 2016). The size and quantity of the drops are measured. A factor to consider when measuring the stains is that the relationships between the drop diameter and the stain diameter will be different. The difference in drop diameter and the stain diameter can be determined by prior testing of drops with known size. A difficulty with this procedure is that large drops tend to splash upon impact causing inaccurate results (Hall 1970).

2.3 EROSION CONTROL PRACTICES

This section examines the types of erosion control practices as well as their application rates and installation procedures. The performance of erosion control practices are examined from various rainfall simulation studies to compare design of the rainfall simulator and the effectiveness of erosion control practices under varying rainfall conditions.

2.3.1 Erosion Control Mulches

Mulching is the application of plant residues to the soil surface to reduce the impact of the erosive forces of raindrop impacts and the velocity of overland flow. ALDOT specifies that a seeded area must be covered with a mulch within 48 hours of seeding (ALDOT 2018). Mulching aids in the germination process when conditions are not favorable during midsummer and early winter as well as on cut and fill slopes. The mulching materials used on a jobsite should be selected by taking into account the site soil conditions, season, type of vegetation to establish, and the size of the mulching area. Mulching materials that contain weed and grass seeds should be avoided to prevent the planted seed from competing with the mulch seed. The most commonly used mulches in the state of Alabama are straw, wood chips, bark, pine straw, peanut hulls, and hydraulic erosion control practices (HECP). The application rate of mulches varies depending on the state or municipality design specifications, site characteristics, and whether the mulch is installed with or without seed. The Alabama Soil and Water Conservation Committee (AL-SWCC) have standardized mulching rates for the various mulch practices used in the state of Alabama and is depicted in Table 2.1 (AL-SWCC 2018).

TABLE 2.1: AL-SWCC Mulch Application Rates

Material	Rate Per Acre and (Per 1000 ft^2)	Notes
Straw with Seed	1 1/2 - 2 tons (70-90 lb.)	Spread by hand or machine to attain 75% groundcover; anchor when subject to blowing.
Straw Alone (no seed)	2 1/2-3 tons (115-160 lb.)	Spread by hand or machine; anchor when subject to blowing.
Wood Chips	5-6 tons (225-270 lb.)	Treat with 12 lbs. nitrogen/ton.
Bark	35 cubic yards (0.8 cubic yard)	Can apply with mulch blower.
Pine Straw	1-2 tons (45-90 lb.)	Spread by hand or machine; will not blow like straw.
Peanut Hulls	10-20 tons (450-900 lb.)	Will wash off slopes. Treat with 12 lbs. nitrogen/ton.
HECPs	0.75 - 2.25 tons (35- 103 lb.)	Refer to the Erosion Control Technology Council (ECTC) or Manufacturer's Specifications.

Note: 1 ton = 0.91 metric tons
1 lb. = 0.45 kg

All of the mulching materials vary in application rate and installation procedure. Peanut hulls and pine straw are organic materials, which may only be seasonally available or available in specific locations. When installing wood chips and peanut hulls an extra 12 lb. (5.44 kg) of nitrogen per ton of mulch should be added to the soil to replace the nitrogen that will be lost as the mulches decompose.

Straw mulch is the most commonly used mulch when seeding and can be classified as wheat, barley, oats, and rye. The target percentage soil cover rate for straw is 75% when installed with seed and 100% when installed without seed. The Alabama Department of Environmental Management (ADEM) specifies a straw application rate of 1.5 to 2.0 ton per acre (3.36 to 4.48 metric tons per hectares) when installed with seed and 2.5 to 3.0 ton per acre (5.60 to 6.72 metric tons per ha) without seed. When loose straw is exposed to high winds and overland flow, it can be removed from its intended location therefore, it should be anchored to ensure the effectiveness of the straw cover is maintained. A tackifier is an adhesive product used to bond the mulch and soil together. Tackifiers can be sprayed on the mulch following the installation or sprayed into the mulch as it is being installed. Tackifiers should be installed at an application rate recommended by the manufacturer (AL-SWCC 2018).

Crimping is an anchoring method used to imbed the loose straw into the soil surface. ALDOT requires that crimped straw must be imbedded 2.0 in. (5.08 cm) into the soil by a ¼ in. (6.35 mm) flat edged coulter blade. The coulter blades must be spaced a maximum of 8 in. (20.32 cm) apart. The crimper is pulled behind a tractor, allowing the weight of the crimper to embed the straw into the soil surface in the perpendicular direction to flow. Crimping should not be performed on slopes greater than 3H:1V for equipment safety purposes (ALDOT 2018).

An alternative to the natural mulches is a manufactured HECP. HECPs are temporary fibrous materials containing natural or man-made fibers and tackifiers that are mixed with water and installed using a hydraulic mulcher. HECPs are classified in five different categories as depicted in Table 2.2 (AL-SWCC 2018).

TABLE 2.2: HECP Classifications

Type	Term	Longevity	Application Rate (lb./acre)	Slope H:V
1	Ultra-short	1 month	1,500-2,500	≤ 5:1
2	Short	2 months	2,000-3,000	≤ 4:1
3	Moderate	3 months	2,000-3,500	≤ 3:1
4	Extended	6 months	2,500-4,000	≤ 2:1
5	Long	12 months	3,000-4,000	≤ 2:1

Note: 1 lb./acre = 1.12 kg/ha

HECPs should be selected for projects based on the site conditions and the desired longevity of the product. Seed, fertilizer, and other soil amendments can be added to the HECP while the mulch is mixing in the hydraulic mulcher. The mulch can be installed using a hose or a truck mounted sprayer. HECPs should be installed in two opposing directions to ensure proper ground coverage and application rates as specified by the manufacturer. ALDOT specifies that HECPs should not be installed in areas where channelized flow or flooding could occur during a 2-yr, 24-hr storm event. HECPs are an effective mulching practice along roadways and other areas where dry mulches could be impacted by high winds (AL-SWCC 2018).

2.3.2 Rolled Erosion Control Products

Rolled erosion control products (RECPs) are blanket type soil coverings that are also used to reduce erosion from unprotected slopes and channels. RECPs are made of a variety of practices including straw, wood, jute, plastic, nylon, paper, and cotton. RECPs are commonly installed as an alternative to mulching practices where a more structured erosion control product is required. The selection of RECP type is determined by site characteristics such as steepness of slope, length of slope, and the required product longevity. RECPs are divided into two main categories consisting of erosion control blankets (ECB) and turf reinforcement mats (TRM). An ECB is a temporary blanket used to protect the seed and soil from raindrop impacts, promote germination, vegetation establishment, and prevent soil erosion. Since ECBs are temporary, the establishment of vegetation is crucial for erosion prevention beyond the product longevity. TRMs are permanent RECPs used to provide permanent soil stabilization on steep slopes and help reduce the impact of high shear stress on channels. TRMs are constructed of a permanent matrix, which aids in the stabilization of vegetation root structure. This process allows the vegetation to withstand higher flow rates, hydraulic uplift, and shear forces (AL-SWCC 2018).

ALDOT Standard Specifications for Highway Construction specifies which classification of RECPs shall be used based on site characteristics. The maximum slope or the maximum shear stress are the two factors used for product selection as depicted in Table 2.3.

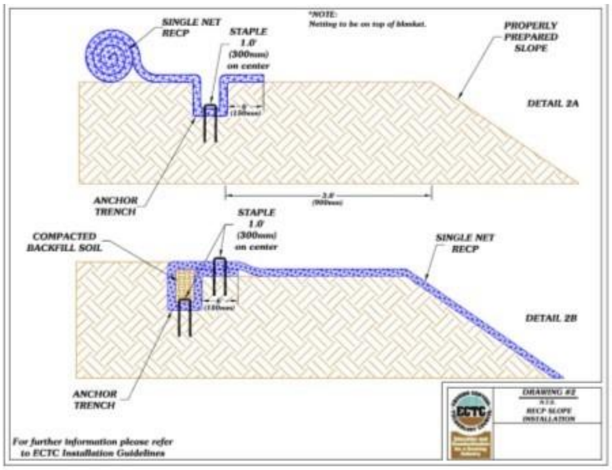
TABLE 2.3: Erosion Control Product Classification (ALDOT 2018)

Product Application	ECP Type	Maximum Slope (H:V)	Maximum Anticipated Channel Shear Stress (Pounds per Square Foot)
Slope	S4	4H:1V	-
	S3	3H:1V	-
	S2	2H:1V	-
	S1	1H:1V	-
Channel	C2	-	2.0
	C4	-	4.0
	C6	-	6.0
	C8	-	8.0
	C10	-	10.0

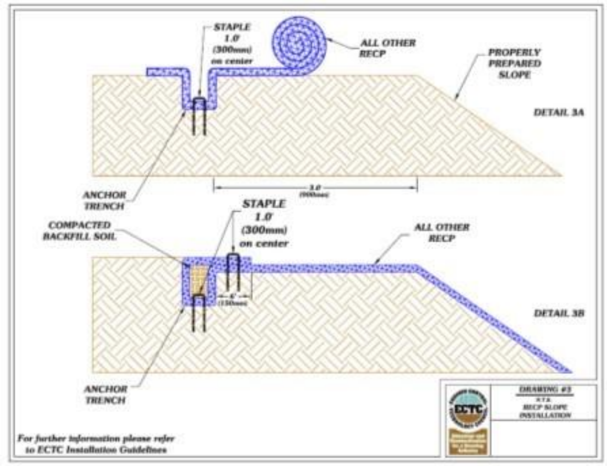
2.3.2.1 RECP Installation Procedures

The AL-SWCC references the general installation guidelines created by ECTC, but requires that product guidelines created by the product manufacturers be followed over the general guidelines developed by ECTC. Prior to RECP installation, the site must be properly prepared for optimal product performance. The site preparation consists of grading and the removal of debris such as weeds, sticks, stones, and roots. Soil amendments and seed shall be incorporated into the soil as needed for site-specific soil conditions. RECPs must be rolled in the direction of flow to reduce the amount of erosion. RECPs must also maintain close contact with the soil and must not be stretched for optimal erosion prevention. Temporary ECBs use a U-shape 11 gauge wire staple with a minimum 6 in. (152 mm) length and 1 in. (25 mm) width. TRMs must be anchored using one of the following two methods. The first is by using a minimum 8 in. (203 mm) long by 2 in. (51 mm) wide 11 gauge wire U-shaped staples. The second consists of a 1 in. by 3 in. (25 mm by 76 mm) wooden stake, which is sawed into a triangular shape with a length of 12 to 18 in. (305 to 457 mm) depending on soil compaction rates. The stakes must be spaced 4 ft (1.22 m) on center along the edge of the TRM. The U-shaped staple method is most commonly used for the installation of TRMs instead of the wooden stake method (AL-SWCC 2018).

Prior to installing the RECP, a 6 in. wide by 6 in. deep trench must be created at the top of the slope. Under ideal conditions, the trench will be located three feet from the crest of the slope. The RECPs will be anchored to the bottom of the trench with U-shape staples spaced at 12 in. (305 mm) on center. Once the blanket was anchored in the trench, the trench was backfilled and compacted. There are two primary methods for trenching the blanket into the trench. The first leaves an extra 12 in. (305 mm) of blanket downslope of the trench while the rest of the blanket was rolled from the upslope side of the trench over the trench and down the slope. The second method leaves 12 in. (305 mm) of extra blanket upslope of the trench and is laid over the trench and stapled downslope of the trench (ECTC 2014). These trenching procedures are depicted in Figure 2.3.



(a) Trenching Method 1



(b) Trenching Method 2

FIGURE 2.3: RECP Anchoring Methods (ECTC 2014).

Once the RECP is anchored, the blanket can be rolled down the slope with the guidance of an installer. The blanket shall be gently pulled to remove any slack at 20 to 25 ft (6.1 to 7.6 m) increments down the slope. Once the blankets have been rolled out to the end of the slope, the stapling pattern designated by the product manufacturer should be followed. The Federal Highway Administration (FHWA) FP-03 specifies that an RECP should have a minimum stapling rate of 1.5 staples per square yard. The staples are most commonly staggered 18 to 24 in. (0.46 to 0.61 m) horizontally across the slope and the edges of the blankets shall be connected or overlapped to adjacent blankets as specified by the product manufacturer. The terminal end of the blanket should be trenched into the ground following the same procedures as the upslope trench. The downslope trench and stapling patterns are depicted in Figure 2.4 (ECTC 2014).

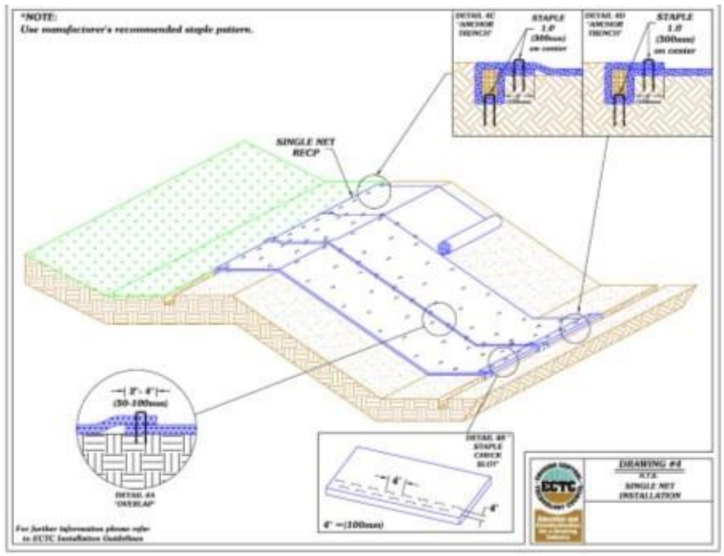


FIGURE 2.4: Downslope RECP Anchoring (ECTC 2014).

2.3.3 Erosion Control Practice Testing

Khan et al. (2016) created a drop forming rainfall simulator to evaluate the performance of mulches on the purple soil of South-Western Sichuan Province, China. The drop forming rainfall simulator was constructed of 324 rain needles that vibrated to produce rain like conditions. The average drop size for the rain needles was 0.07 to 0.11 in. (1.7 to 2.8 mm). The test plot size was 3.28 ft (1 m) long by 1 ft (0.3 m) wide by 1.3 ft (0.4 m) deep with a slope of 5˚, 15˚, or 25˚. The rainfall simulator was designed to produce four different rainfall intensities of 1.29, 2.13, 3.70, and 4.72 in. per hr (33, 54, 94, and 120 mm per hr). The drop forming rainfall simulator is depicted in Figure 2.5.

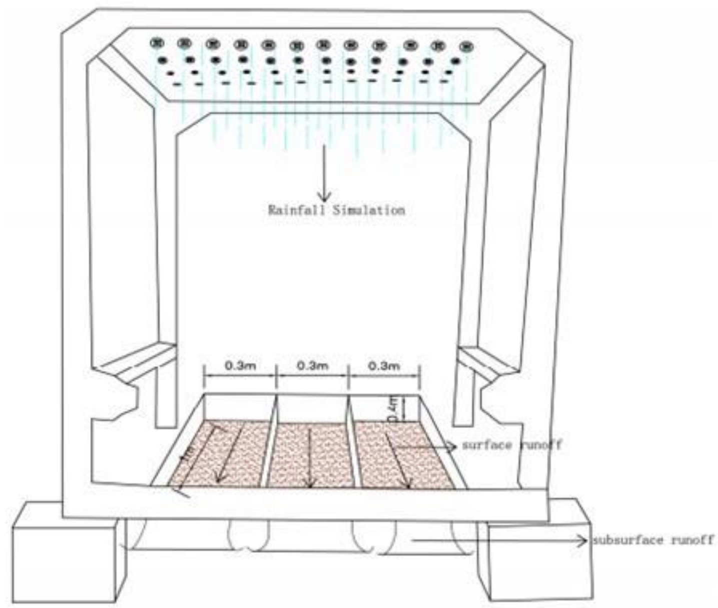


FIGURE 2.5: Drop Forming Rainfall Simulator (Khan et. al., 2016).

Khan et al. (2016) installed wheat straw to a depth of 1.57 in. (4 cm) to evaluate the effectiveness of wheat straw under the varying rainfall intensities and slopes. The results of the straw were compared with the results from a bare soil control test. During the experiments, the total soil loss significantly increased as the slope increased from 5˚ to 25˚. The addition of wheat straw considerably reduced the sediment losses by 81 to 100% as compared to the bare soil control conditions. The most notable improvement was from the 25˚ slope at 3.70 in. per hr (94 mm per hr) rainfall intensity. The soil loss decreases from 0.18 lb. per ft^2 (876.2 g per m^2) un-mulched to 0.007 lb. per ft^2 (34.69 g m^2), which is a 96% improvement. The total amount of infiltration was measured for each experiment. It was determined that under all testing conditions that the infiltration rate was higher on mulched slopes than under bare soil conditions.

Wilson et al. (2010) evaluated the performance of straw mulch and hydraulic mulches under small-scale rainfall simulation at the Auburn University Erosion and Sediment Control Test Facility (AU-ESCTF). The rainfall simulation was constructed using one FullJet ½ HH-30WSQ nozzle and a 10 psi (0.068 MPa) Norgren R43-406-NNLA pressure regulator. The test plots were

2 ft (0.6 m) wide by 4 ft (1.2 m) long by 3.5 in. (6.2 cm) in depth and were supported by saw horses which created a testing slope of 3H:1V. The rainfall simulator test consisted of four 15-minute rainfall events and was calibrated to generate a total rainfall depth of 4.4 in. (11.18 cm). The layout of the rainfall simulator is displayed in Figure 2.6.

FIGURE 2.6: Small Scale Rainfall Simulator at AU-ESCTF (Wilson et al. 2010).

Wilson et al. (2010) evaluated six erosion control products and practices consisting of: conventional crimped straw, conventional straw mulch with tackifier, and four hydromulches. During the rainfall experiment, the slope runoff was diverted by a metal apron to a single location for collection to evaluate the total soil loss and the runoff turbidity over time. The data collected for each product was compared to a bare soil control test to calculate the percent reduction in soil loss and turbidity. The crimped straw was the worst performing product with a percent reduction in turbidity of 80% and soil loss of 98%. The straw with tackifier performed at a much higher rate than the crimped straw with a percent reduction in turbidity of 98% and soil loss of 99%. The hydraulic mulch performance ranged from a percent reduction in turbidity of 85-99% and soil loss of 95-99%.

Rainfall simulation testing was performed at the Sediment and Erosion Control Laboratory at Texas A&M Transportation Institute (TTI) to evaluate the performance of crimped straw under varying straw application rates, soil types and slopes. The test plot was 30 ft (9.1 m) long by 6 ft (1.8 m) wide by 9 in. (22.9 cm) deep. The test plot was evaluated at a 2H:1V and 3H:1V slopes. Each rainfall simulation experiment consisted of three, 30-minute storm events with a rainfall intensity of 3.5 in. per hr (88.9 mm per hr). Wheat straw was installed to the test slope at application rates of 1 ton per acre (2.24 Mg per ha), 2 ton per acre (4.49 Mg per ha), 3 ton per acre (6.73 Mg per ha), and 4 ton per acre (8.98 Mg per ha). The average sediment loss for each application rate was compared to the Texas Department of Transportation (TxDOT) allowable threshold for a RECP to determine if the application was as effective as an RECP. All four of the application rates tested on the 3H:1V slope met the threshold of 0.79 lb. per $10ft^2$ (3.86 kg per $10m^2$) for clay and 28.47 lb. per $10ft^2$ (138.9 kg per $10m^2$) for sand. However, on the 2H:1V slope, the 3 and 4 ton per acre (6.73 and 8.98 Mg per ha) were the only two application rates that met the required thresholds for both soils (Ming-Han 2014).

Barnett et al. (1967) evaluated several straw mulching applications on seeded highway backslopes in Oconee, Peach, and Wilkes Counties, Georgia. Each test slope was graded to 2.5H:1V and seeded. Bare soil conditions, surface applied mulch with a tackifier, and crimped mulch were evaluated. A grain straw mulch was installed at an application rate of 2 ton per acre (4.49 Mg per ha). Two 30-minute increments of 2.5 in. per hr (63.5 mm per hr) rainfall intensities were performed for each experiment. The soil loss rate for the bare soil plots averaged 96.57 ton per acre (216.48 Mg per ha). The straw with asphalt tackifier decreased the average soil loss rate to 31.54 ton per acre (70.70 Mg per ha), while the crimped straw decreased the soil loss rate to 9.88 ton per acre (22.15 Mg per ha). This experiment concluded that crimping straw was on average the most effective erosion control method as compared with straw with an asphalt tackifier.

Foltz and Dooley (2003) evaluated the performance of straw, wide wood strands, and narrow wood strands on a small-scale rainfall simulator and compared their results to bare soil control tests. The straw and wood applications were installed at a target cover factor of 70%. The test plot was a 4.07 ft (1.24 m) wide by 13.12 ft (4.0 m) long plot filled with a gravely sand and had a slope of 30%. Each rainfall experiment consisted of a 15-minute storm event of 1.97 in. per hr (50 mm per hr) rainfall intensity followed by the same rainfall intensity and an inflow of 0.26 gpm (0.97 L per min) for 5 minutes. The second inflow consisted of the same rainfall intensity and an inflow of 1.08 gpm (4.1 L per min) for 5 minutes. The design of this simulator is depicted in Figure 2.7.

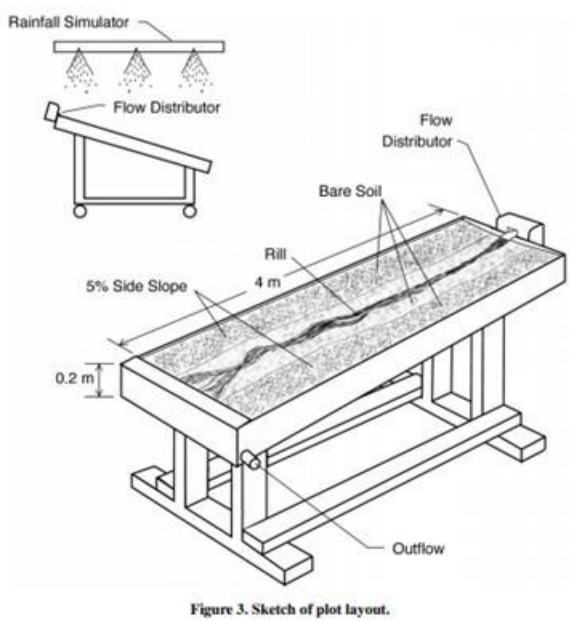


FIGURE 2.7: Foltz and Dooley (2003) Rainfall Simulator.

The loose straw and wood strands all resulted in a 98 to 100% improvement as compared to the bare soil control test. The average sediment loss under the second inflow for a bare soil control test was 64.82 lb. (29.4 kg) while the loose straw averaged a total sediment loss of 1.17 lb.

(0.53 kg) and the wide wood strands was 0.86 lb. (0.39 kg). The wide wood strand was the best performing product with a 98% improvement from bare soil control tests for the second inflow. The study found that the majority of the soil loss occurred during the second inflow (Foltz and Dooley 2003).

Gholami et al. (1994) evaluated the performance of rice straw mulch under rainfall simulation at the Faculty of Natural Resources of Tarbiat Modares University, Noor, Iran. The rainfall simulator test plots were 19.7 ft (6 m) long by 3.3 ft (1 m) wide by 1.64 ft (0.5 m) deep with a slope of 30%. The rainfall simulator produced rainfall intensities of 1.18, 1.97, 2.76, and 3.54 in. per hr (30, 50, 70, and 90 mm per hr) from 27 calibrated nozzles. The average raindrop size for this simulator is 0.051 in. (1.3 mm) with a fall height ranging between 13.1 ft and 19.7 ft (4 m and 6 m). The variation in drop fall height is due to the slope of the plot changing the distance from the top and bottom to the sprinklers. Each experiment had a duration of 15 minutes with one rainfall intensity. The performance of the test plots under varying rainfall intensities was compared with the same straw application rate. Rice straw mulch was installed on each test plot at an application rate of 0.10 lb. per ft^2 (0.5 kg per m^2) with a target of 90% cover. During each experiment, three test plots were evaluated simultaneously. The slope runoff was collected and oven dried to determine the total sediment yield for each test plot. Each test plot was compared to a bare soil control test to determine the effectiveness of the rice straw. The 1.18 in. per hr (30 mm per hr) rainfall intensity resulted in an average of 54% improvement from bare soil conditions. The highest percentage improvement occurred with the 3.54 in. per hr (90 mm per hr) rainfall intensity with an improvement of 63%. The rice straw was not as effective with the 1.96 and 2.76 in. per hr (50 and 70 mm per hr) intensities resulting in a percent improvement of 47% and 45%.

Bjorneberg et al. (2000) evaluated the performance of polyacrylamide (PAM) under small-scale rainfall simulation. The rainfall simulator was 4.92 ft (1.5 m) long by 3.94 ft (1.2 m) wide by 0.66 ft (0.2 m) deep with a 2.4% slope. Veejet nozzles were mounted 9.84 ft (3 m) above the soil surface and produced a drop size of 0.047 in. (1.2 mm) and a rainfall intensity of 3.15 in. per hr (80 mm per hr). The rainfall simulation test lasted for a duration of 15 minutes exposing the soil to 0.79 in. (20 mm) of total rainfall. Wheat straw was installed on the test plots at an application rate of 2,230.45 lb. per ac (2,500 kg per ha) with a target of 70% cover factor. Each experiment consisted of three 15-minute irrigations. The PAM was installed during the first irrigation onto the bare soil control test and the straw test at an application rate of 0, 1.78, and 3.57 lb. per acre (0, 2, and 4 kg ha). The cumulative soil loss for the bare soil with PAM significantly decreased as the amount of PAM was increased from 0 to 3.57 lb. per acre (0 to 4 kg per ha). The bare soil test with no PAM had a cumulative soil loss of 1,811 lb. per acre (2,030 kg per ha) while the soil loss for the bare soil with PAM installed at an application rate of 0.57 lb. per acre was 704.82 lb. per acre (4 kg per ha was 790 kg per ha). The straw installed without PAM decreased the cumulative soil loss to 122 lb. per ac (137 kg per ha). The straw with PAM installed at an application rate of 1.78 lb. per acre (2 kg per ha) had a cumulative soil loss of 44.6 lb. per acre (50 kg per ha) and the straw with PAM installed at an application rate of 3.57 lb. per acre (4 kg per ha) resulted in 50.85 lb. per acre (57 kg per ha) soil loss. The PAM decreased the runoff by 85% with straw and decreased runoff by 40% with bare soil. This study concluded that adding straw to bare soil instead of PAM was a more effective method in reducing soil loss.

Holt et al. (2005) developed a pressurized rainfall simulator to compare the performance of cotton, wood, and paper hydraulic mulches. The rainfall simulator consisted of three test plots measuring 10 ft (3.05 m) long by 2 ft (0.6 m) wide by 3 in. (7.6 cm) deep with a slope of 9%. The rainfall simulator produced a single rainfall intensity of 4.1 in. per hr (104 mm per hr). The recycled cotton products from stripper waste, picker waste, and ground stripper waste were compared to traditional hydro-mulches. Each experiment lasted for a duration of 30 minutes once runoff started. The COBY red was the best performing mulch with a soil loss of 3.80 ton per acre (8.52 MG per ha). The peanut hulls was the second best performing product with a sediment loss of 5.07 ton per acre (11.37 Mg per ha). The worst performing product was the paper hydromulch with a sediment loss of 12.12 ton per acre (27.17 Mg per ha). This study found that the cotton-based hydromulches performed equal to if not better than the traditional wood and paper hydromulches.

Ming Han et al. (2013) evaluated the performance of erosion control products under indoor rainfall simulator at TTI. The indoor rainfall simulator was 30 ft (9.1 m) long by 6 ft (1.83) wide by 9 in. (3.54 cm) deep with a 33% slope. The rainfall simulator generated rainfall intensities of 3.5 in. per hr (88.9 mm per hr) from drip emitters at a height of 14 ft (4.3 m). The average drop size for this rainfall simulator ranged from 0.12 to 0.16 ft (3 to 4 mm). The products were evaluated for 30 minutes once every 24 hours for three tests. The products evaluated for this experiment were a straw ECB bound by jute netting, straw ECB bound by polypropylene netting, excelsior ECB, and bonded fiber matrix. A bonded fiber matrix is a hydraulically applied erosion control product consisting of fiber strands bonded together by a water resistant adhesive. The products were installed on clay and sand. The clay soil produced significantly lower erosion rates than the sand soil. The best performing erosion control product installed on the clay soil was the straw ECB with jute netting with a soil loss rate of 7.91 lb. per 10ft^2 (1.62 kg per 10 m^2). The worst performing product was the bonded fiber matrix with a soil loss rate of 19.6 lb. per 10ft^2 (4.02 kg per 10 m^2). The sand soil produced much larger amounts of soil loss than the clay soil. The excelsior ECB was the best performing erosion control practice on the sandy soil with a soil loss rate of 281.25 lb. per 10ft^2 (57.6 kg per 10 m^2). The bonded fiber matrix was again the worst performing erosion control practice with a soil loss rate of 831.5 lb. per 10ft^2 (170.3 kg per 10 m^2).

Faucette et al. (2007) constructed a small-scale pressurized rainfall simulator to evaluate the performance of erosion control blankets. The rainfall simulator test plot was 16 ft (4.9 m) long by 3.3 ft (1 m) wide with a slope of 10%. The simulator produced a rainfall intensity of 4 in. per hr (102 mm per hr) for a 1-hour duration at a pressure of 6 psi (41.4 kPa). The ECBs evaluated for this experiment were straw with PAM, wood mulch, 1:2 blend of compost to wood mulch, 2:1 blend of compost to wood mulch, 100% yard waste compost, and compost with a biopolymer derived from corn starch (Bio-floc). The results from these product evaluations were compared to bare soil control conditions. The results of these products are depicted in Table 2.4.

TABLE 2.4: Faucette et al. 2007 ECB Results

Blankets	Total Solids lb./ac (kg/ha)	TSS Total lb./ac (kg/ha)	Turbidity (NTU)
Bare Soil	6,108 (6,846)	4,710 (5,279)	7,686
Straw w/ PAM	990 (1,110)	583 (654)	940
100% Wood Mulch	86 (96)	46 (52)	36
1:2 Blend	115 (129)	54 (60)	60
2:1 Blend	186 (208)	58 (65)	87
100% Compost	364 (408)	252 (283)	288
Compost with Bio-Floc	-	192 (215)	139

The best performing erosion control blanket for all three parameters was the wood mulch blanket. The wood mulch blanket had a reduction in total solids of 98.6% as compared to the bare soil control test. The wood mulch blanket had a calculated *C*-factor of 0.013. The straw with PAM blanket was the worst performing product with a percent reduction from bare soil control testing for total solids of 84%. The straw with PAM blanket had a *C*-factor of 0.189. The runoff from the 100% compost blanket had a turbidity of 139 NTU, which is higher than the runoff from the 2:1 blend that resulted in a turbidity of 87 NTU, and the runoff from the 1:2 blend that had a turbidity of 60 NTU. These results show that the compost is more effective at reducing turbidity when combining the compost with wood mulch (Faucette et al. 2007).

Lipscomb et al. (2006) conducted a study using a large-scale rainfall simulator following ASTM D6459 to compare the effectiveness of blown straw and an erosion control blanket. The rainfall simulator was a pressurized system that produced three sequential 20 minute rainfall segments of 2, 4, and 6 in. per hr (51,102, and 152 mm per hr). The test plot is 40 ft (12.2) long by 8 ft (2.4 m) wide. The blown straw was installed to the test plot at an application of 2,500 lb. per acre (2,837 kg per ha). A single netted, temporary erosion control blanket was installed to compare the blankets erosion control effectiveness to blown straw. The blanket was installed with U-staples at the rate recommended by the manufacturer. During each rainfall experiment, the runoff was collected to quantify the total sediment yield of the test. Unprotected bare soil control tests were performed to obtain a reference of the product performance. This study found that blown straw had little benefit on the steep slopes. The study concluded that straw was most effective when installed on shallow slopes. The single net ECB was over 98% effective on the sandy loam soil and 80% on the clay soil as compared to corresponding bare soil control tests. This experiment concluded that ECBs perform better on steep slopes due to their resistance to runoff and the minimal blanket filler displacement.

Benik (2003) created a large-scale pressurized rainfall simulator to evaluate the performance of erosion control blankets on hillslopes. The simulator test plot was 32 ft (9.75 m) long by 7.9 ft (2.4 m) wide with a 2.8H:1V slope. The rainfall simulator had a regulated pressure of 8 psi (55 kPa) and produced a rainfall intensity of 2.4 in. per hr (61 mm per hr). This experiment evaluated bare soil control, crimped straw mulch at an application rate of 0.092 lb. per ft^2 (0.45 kg per m^2), bonded fiber matrix at an application rate of 160.8 lb. per ft^2 (785 kg per m^2), straw/coconut blanket, and a wood fiber blanket. The products were evaluated during various conditions with and without the establishment of vegetation. The sediment yield results are depicted in Table 2.5.

TABLE 2.5: Sediment Yield Results (Benik 2003)

Product	Spring No Vegetation lb./ac (kg/ha)	Fall Vegetation lb./ac (kg/ha)
Bare Soil	8,505 (9,533)	1,001 (1,122)
Straw Mulch	1,469 (1,647)	267 (299)
Bonded Fiber Matrix	216 (242)	196 (220)
Straw/Coconut Blanket	188 (211)	137 (153)
Wood-Fiber Blanket	263 (295)	88 (99)

The spring tested evaluated the performance of the erosion control practices without the establishment of vegetation. The straw/coconut blanket was the best performing product with a sediment yield of 188 lb. per ac (211 kg per ha), which is a 98% reduction in sediment yield from the bare soil control conditions. The straw mulch was the worst performing erosion control practice with a sediment yield of 1,467 lb. per acre (1,647 kg per ha), which is an 83% reduction is sediment yield from the bare soil control test. The second testing evaluated the performance of erosion control practices with the establishment of vegetation in the fall. The wood-fiber blanket was the top performing erosion control product with a sediment yield of 88.32 lb. per acre (99 kg per ha), which is a 91% reduction in sediment yield from the bare soil conditions with vegetation. The straw mulch was again the worst performing erosion control practice evaluated. There was a significant difference in the sediment yield between the spring test and the fall test. The establishment of vegetation alone allowed the sediment yield for a bare soil control test to decrease by 88% (Benik 2003).

Rickson (2006) evaluated the performance of erosion control geotextiles under small-scale rainfall simulation and runoff simulation. This study evaluated the performance of geojute, fine geojute, enviramat, enkamat s, bachbett, enkamat b, and tensarmat as compared to bare soil control tests. The rainfall simulator experiments consisted of a 1.4 in. per hr (35 mm per hr) rainfall intensity for 15 minutes or 4.53 in. per hr (115 mm per hr) rainfall intensity for 10 minutes. The rainfall simulation was used to determine the effectiveness of the geotextiles in protecting the soil from splash erosion. The geojute, fine geojute, enviramat, bachbett were the best performing products. This study found that the higher the coverage area of the geotextile, the more effective the product was in protecting from splash erosion. The thicker geotextiles were more effective at ponding water, which aided in the reduction of splash erosion. Another factor that prevented erosion was the water holding capacity of the geotextiles. The geotextiles with the highest water holding capacity weighed more and therefore maintained good contact with the soil surface. Following the rain splash testing, a runoff experiment was conducted on a test plot measuring 6.6 ft (2 m) long by 3.28 ft (1 m) wide by 3.94 in. (10 cm) deep at a 10˚ slope. The flow rate introduced to the test plot was 0.63 gpm (2.4 L per min) for 10 minutes, which is the equivalence of a 2.83 in. per hr (72 mm per hr) rainfall intensity for ten minutes. The only geotextile the noticeably reduced the amount of runoff from a bare soil control test was the buried tensarmat. The results from the runoff experiment showed that geotextiles are not effective in reducing runoff.

2.4 REVISED UNIVERSAL SOIL LOSS EQUATION

The Revised Universal Soil Loss Equation (RUSLE) is an update to the original Universal Soil Loss Equation (USLE). USLE and RUSLE predicts average annual soil loss resulting from erosion, which allow researchers to evaluate the performance of best management practices (BMPs). USLE was developed in 1954 at the National Runoff and Soil Loss Data Center. USLE method for quantifying soil erosion was developed from 49 locations with more than 10,000 test plots (USDA 1978 and USDA 1997). This method uses a rainfall runoff erosivity factor (*R*), soil erodibility factor (*K*), slope length and slope steepness factor (*LS*), cover-management factor (*C*), and a support practice factor (*P*) to calculate the average annual soil loss in tons/acre/year. In 1992, RUSLE was released by the United States Department of Agriculture (USDA). RUSLE applied additional research to USLE by introducing new isoderent maps, a sub factor approach for evaluating the *C*-factor, a new equation for the *LS* factor and new *P*-factor values (USDA 1997). The RUSLE equation is depicted in Equation 2.2.

$$A = R \times K \times LS \times C \times P \tag{2.2}$$

where,

A = average annual soil loss (tons/acre/year)
R = Rainfall Erosivity Factor
K = Soil Erodibility Factor
LS = Length Slope Steepness Factor
C = Cover Management Factor
P = Support Practice Factor

2.4.1 Rainfall Erosivity Factor – *R*

The rainfall erosivity factor (*R*) quantifies the effect of the total storm kinetic energy (*E*) and the maximum 30-minute rainfall intensity (I_{30}) (USDA 1978). The total storm kinetic energy is calculated by determining the unit energy of the storm using the calculated rainfall intensity and the depth of rainfall for the desired storm increment (Clopper et al. 2004). I_{30} is determined by using the rainfall intensity when a time increment exceeds 30 minutes or by calculating the weighted average of varying intensities over a 30-minute interval (Early et al.). Once *E* and I_{30} are calculated and multiplied together, ExI_{30} values for the number of storms are summed together and divided by the number of years to get the *R*-factor (USDA 1997). The runoff erosivity factor and the rainfall energy are calculated using Equations 2.3 and 2.4 (Clopper et al. 2004).

$$R = \frac{\sum_{i=1}^{J}(EI_{30})i}{N} \tag{2.3}$$

where,

R = Runoff Erosivity Factor (hundreds ft-ton-in/acre-hour)
E =total storm kinetic energy (hundred ft-tons/acre)
I_{30} = maximum 30-minute rainfall intensity (in./hr)
N = number of years

$$e = 1099(1 - 0.72e^{-1.27\times i}) \tag{2.4}$$

where,

e = rainfall energy per unit depth of rainfall per unit area
i = rainfall intensity (in/hr)

2.4.2 Soil Erodibility Factor – *K*

The soil erodibility factor (*K*) is the ease at which soil is eroded from splash erosion and overland flow during rainfall events. The soil erodibility factor accounts for the impact of rainfall, runoff, and infiltration on the soil loss. The *K*-factor is measured as "the rate of soil loss per erosion index unit as measured on a unit plot (USDA 1997)." The *K*-factor for a given soil can be calculated from bare soil plots, which have a cover management (*C*-factor) and support practice (*P*-factor) factors of one. The *K*-factor is determined by using the *R*-factor, *LS* factor, and the soil loss per test plot (*A*) as depicted in Equation 2.5. A new *K*-factor can be calculated for each *R*-factor (Clopper et al. 2004).

$$K = \frac{A}{(LS)(R)} \tag{2.5}$$

where,

K = Soil Erodibility Factor
A = Average Annual Soil Loss (tons/acre/year)
LS = Length slope steepness factor
R = Rainfall Erosivity Factor

2.4.3 Length Slope Steepness Factor – *LS*

The length slope steepness factor (*LS*) is dimensionless and is broken down into the slope length factor (*L*) and the slope steepness factor (*S*). *LS* represents the soil loss ratio of the test plot to the standard RUSLE plot of 72.6 ft (22.13 m) in length and a slope of 9% (Clopper et al. 2004). The slope length factor (L) is calculated using Equation 2.6.

$$L = (\frac{\lambda}{72.6})^{m} \tag{2.6}$$

where,

L = slope length factor
λ = horizontal projection of slope length
m = variable slope length exponent

To determine the L-factor, the variable slope length exponent (m) must be calculated. The slope angle is used to in Equation 2.7 to calculate the ratio of rill to interrill erosion (β). β should be adjusted to meet site specific conditions and will vary throughout the duration of the project. β should be halved for preconstruction and post-construction conditions and double for construction site conditions. The β adjusted for specific site conditions can then be used in Equation 2.8 to calculate m (USDA 1997).

$$\beta = (\frac{sin\theta}{0.0896})/[3.0(sin\theta)^{0.8} + 0.56] \tag{2.7}$$

where,

β = ratio of rill to interrill erosion
θ = slope angle

$$m = \frac{\beta}{1+\beta} \tag{2.8}$$

where,

m = variable slope length exponent
β = ratio of rill to interrill erosion

The slope steepness factor (S) is calculated in Equation 2.9 or 2.10 by using the slope angle (θ). Equation 2.9 is used to calculate S on slopes that have a steepness of less than 9%, while Equation 2.10 is for slopes with a steepness greater than or equal to 9% (USDA 1997).

$$S = 10.8\ sin\theta + 0.03 \tag{2.9}$$

$$S = 16.8\ sin\theta - 0.50 \tag{2.10}$$

where,

S = slope steepness factor
θ = slope angle

2.4.4 Cover Management Factor – *C*

The cover management factor (*C*) is a dimensionless ratio used to represent the performance of cropping and BMPs on a scale ranging from zero to one (USDA 1997). Soil that is well protected will result in a *C*-factor close to zero and a poorly protected soil results in a value close to one (Karpilo 2004). In order to calculate the *C*-factor of BMPs, the *K*-factor must first be determined from bare soil results. The least squares linear regression method is often used to determine the *C*-factor for the BMP. The least squares linear regression method plots the soil loss and the *R*-factor to create a trendline equation to calculate the *C*-factor (Early et al.).

2.4.5 Support Practice Factor – *P*

The support practice factor (*P*) is a dimensionless ratio of the soil loss due to support practices. The practices evaluated by *P* adjust the flow pattern, grade or direction of runoff. Some commonly used *P*-factors consist of contouring, strip-cropping, terracing, and subsurface drainage (USDA 1997).

2.5 SUMMARY

This section provides an overview of how rainfall simulation testing is used to evaluate erosion control practices. This study examined drop forming and pressurized rainfall simulators and how these two types of simulators vary in design and performance. The most important aspects of a rainfall simulator are the raindrop size distribution, rainfall intensity, and the uniformity. The drop size distribution of a simulator can be determined in a number of ways consisting of the flour pan, laser, momentum, oil, and stain method. Rainfall simulators have many design characteristics that effect the test results such as the rainfall simulator type, test plot dimensions, slope, experimental rainfall intensity, and the products being evaluated. There were four main categories that the erosion control practices evaluated in this study could be divided into consisting of blown mulch, anchored mulch, hydraulic mulches, and ECBs. The performance of straw mulch throughout all of the studies is summarized in Table 2.6.

TABLE 2.6: Blown Mulch Summary

Study	Rainfall Simulator Type	Test Plot Dimensions	Slope	Rainfall Intensity	Tested Product	Soil Loss % Improvement
Khan, M.N. et. al. 2016	Drop Forming	3.28 ft x 1 ft	5°, 15°, and 25°	1.29, 2.13, 3.70, and 4.70 in. per hr	Wheat Straw	96%
Foltz and Dooley 2003	Pressurized/Flow	4.07 ft x 13.12 ft	30%	1.97 in. per hr Induced flow of 0.26 gpm	Loose Straw	98%
					Wide Wood Strands	99%
Gholami, C. et. al. 1994	Pressurized	19.7 ft x 3.3 ft	30%	1.18, 1.97, 2.76, and 3.54 in. per hr	Rice Straw	45-63% depending on intensity
Holt, G. et. al. 2005	Pressurized	10 ft x 2 ft	9%	4.1 in. per hr	Peanut Hulls	No Bare Soil Data
Benik, S. R. 2003	Pressurized	32 ft x 7.9 ft	2.8H:1V	2.4 in. per hr	Straw Mulch	No Vegetation: 83% Vegetation: 73%

Note: 1 foot = 3.28 meters
1 inch per hour = 25.4 millimeters per hour

The studies that evaluated blown mulch varied in rainfall simulator type, test plot size, test slope, rainfall intensity, and mulch type. There was a wide range of soil loss results that occurred throughout these experiments. The first two studies listed in Table 2.6 were small-scale rainfall simulators and resulted in a minimum of 96% reduction in soil loss from the bare soil control test results. The wide wood strand mulch evaluated by Foltz and Dooley outperformed the wheat straw. The Gholami and Benik rainfall simulator studies resulted in much lower reductions in soil loss from bare soil control results ranging from 45-83% improvement. However, these two studies used large-scale rainfall simulators while the first two studies used small-scale rainfall simulators. In addition to blown straw, several studies examined the performance of anchored straw applications, which is depicted in Table 2.7.

TABLE 2.7: Anchored Straw Summary

Study	Rainfall Simulator Type	Test Plot Dimensions	Slope	Rainfall Intensity	Tested Product	Soil Loss % Improvement
Wilson, W.T. et. al. 2010	Pressurized	4 ft x 2 ft	3H:1V	4.4 in. per hr	Crimped straw	98%
					Straw w/ Tackifier	99%
Ming-Han 2014	Drop Forming	30 ft x 6 ft	2H:1V 3H:1V	3.5 in. per hr	Crimped Wheat Straw	Sand: 87-99.7% Clay: 98-99.7%
Barnett et. al. 1967	Pressurized	30 ft x 6 ft	2.5H:1 V	2.5 in. per hr	Crimped Straw	90%
					Straw w/ Tackifier	67%
Bjorneberg, D. L. et. al. 2000	Pressurized	4.92 ft x 3.94 ft	2.4%	3.15 in. per hr	Wheat Straw with PAM	99%

Note: 1 foot = 3.28 meters
1 inch per hour = 25.4 millimeters per hour

All four of the rainfall simulators used to evaluate the performance of anchored straw varied in rainfall simulator type, test plot dimensions, test slope, and rainfall intensity. Through the examination of the results, crimped straw was on average the best performing straw anchoring method. The straw with tackifier and the crimped straw were effective in reducing the amount of soil loss as compared to the bare soil control test. Barnett recorded results that were different from the other three studies, concluding that the crimped straw had a 90% soil loss improvement from the bare soil test, which was lower than the other studies. The straw with tackifier for Barnett's study only had a soil loss improvement of 67%, which is the lowest of all the anchored straw experiments. In addition to mulches, several studies examined the performance of hydraulic mulches, which is depicted in Table 2.8.

TABLE 2.8: Hydraulic Mulch Summary

Study	Rainfall Simulator Type	Test Plot Dimensions	Slope	Rainfall Intensity	Tested Product	Soil Loss % Improvement
Wilson, W.T. et. al. 2010	Pressurized	4 ft x 2 ft	3H:1V	4.4 in. per hr	Hydraulic Mulches	95-99%
Holt, G. et. al. 2005	Pressurized	10 ft x 2 ft	9%	4.1 in. per hr	Cotton	No Bare Soil Data
					Wood	
					Paper	
Ming-Han, Li et. al. 2013	Drop Forming	30 ft x 6 ft	2H:1V 3H:1V	3.5 in. per hr	Hydraulic Mulch	No Bare Soil Data
Benik, S. R. 2003	Pressurized	32 ft x 7.9 ft	2.8H:1V	2.4 in. per hr	Hydraulic Mulch	No Vegetation: 97% Vegetation: 80%

Note: 1 foot = 3.28 meters
1 inch per hour = 25.4 millimeters per hour

All four of the rainfall simulators used to evaluate the hydraulic mulches varied in rainfall simulator type, test plot size, test slope, and rainfall intensity. The hydraulic mulches evaluated in these experiments resulted in soil loss reduction of 95-99% as compared to a bare soil control test. Both the small-scale plot evaluated by Wilson and the large-scale simulator evaluated by Benik had similar results for the initial product test. However, Wilson's experiment consisted of a 4.4 in. per hr (112 mm per hr) rainfall intensity, while Benik's experiment only had a 2.4 in. per hr (61 mm per hr) rainfall intensity. In addition to various mulching applications, several studies evaluated the performance of erosion control blankets, which is depicted in Table 2.8.

TABLE 2.9: Erosion Control Blanket Summary

Study	Rainfall Simulator Type	Test Plot Dimensions	Slope	Rainfall Intensity	Tested Product	Soil Loss % Improvement
Ming-Han, Li et. al. 2013	Drop Forming	30 ft x 6 ft	2H:1V 3H:1V	3.5 in. per hr	Turf Reinforcement Mat	No Bare Soil Data
					Open Weave Textile	
					Straw ECB w/ Jute netting	
					Straw ECB	
					Excelsior ECB	
Faucette, E. B. et. al. 2007	Pressurized	16 ft x 3.3 ft	10%	4 in. per hr	Straw with PAM ECB	84%
					Wood Mulch ECB	99%
					1:2 Blend Compost to Wood Mulch ECB	98%
					2:1 Blend Compost to Wood Mulch ECB	97%
					100% Yard Waste Compost ECB	94%
Lipscomb et. al. 2006	Pressurized	40ft x 8 ft	3H:1V	2, 4, and 6 in. per hr	Excelsior ECB	80-98% Depending on Soil
Benik, S. R. 2003	Pressurized	32 ft x 7.9 ft	2.8H:1V	2.4 in. per hr	Straw/ Coconut ECB	No Vegetation: 98% Vegetation: 86%
					Wood-Fiber ECB	No Vegetation: 97% Vegetation: 91%

Note: 1 foot = 3.28 meters
1 inch per hour = 25.4 millimeters per hour

The four experiments that evaluated ECBs had varying rainfall simulator types, test plot dimension, test slopes, and rainfall intensity. ECB reduction in soil loss ranged from 80-99% depending on the soil type and rainfall simulator. Lipscomb evaluated the performance of an excelsior blanket on a clay soil that resulted in an 80% soil reduction, while the sand test resulted in a 98% reduction in soil loss as compared to the bare soil experiments. Faucette determined that wood mulch, compost, and a blend of wood and compost blankets resulted in a larger reduction in soil loss than the straw ECB. Faucette also determined that the straw blanket with PAM reduced the soil loss by 84% while Benik determined that a straw/coconut blanket reduced the soil loss by 98%. The rainfall simulators had similar results; however, due to the large variation in rainfall simulator design it is difficult to know if the results are comparable.

With the large variation is design and testing procedures of the rainfall simulators, it is evident that a standardized testing procedure and rainfall simulator design should be followed to allow for comparison of results. Through the examinations of these rainfall simulation experiments, it was determined that the small-scale rainfall simulators produced lower erosion rates than the larger-scale rainfall simulators. These studies also showed that installing an erosion control with anchoring greatly increases the overall performance of the product. Based on these results, it was decided to follow a standardized testing procedure in order to produce product performance results that are comparable to other testing facilities.

CHAPTER 3: METHODS AND PROCEDURES

3.1 INTRODUCTION

This section presents experimental procedures for the calibration, validation, and product installation of the large-scale rainfall simulator at the Auburn University Erosion and Sediment Control Test Facility (AU-ESCTF). Test methodologies and product installation procedures are based on *The Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Hillslopes from Rainfall-Induced Erosion* (ASTM D6459-19), the Erosion Control Technology Council (ECTC), manufacturer recommendations, and additional ASTM test procedures.

The primary research objective of this project was to evaluate the performance of various erosion control practices used on Alabama Department of Transportation (ALDOT) projects through large-scale rainfall simulation. Calibration testing was initially performed to determine the optimal location of sprinkler risers, nozzle size, and operating pressure to achieve desirable rainfall uniformity, rainfall intensity, and drop size distribution. The flour pan method was used to evaluate the drop size distribution for each rainfall intensity. Upon completion of the calibration testing, bare soil control tests were completed to develop the slope preparation procedure, experimental testing procedure, and to evaluate bare soil performance. Each test was evaluated from the collection of water samples to determine the total suspended solids (TSS) and turbidity, soil loss in the catch basin, and the discharge over time measurements. The product-testing phase of the project evaluated loose straw, loose straw with tackifier, crimped straw, hydraulic erosion control products (HECP), and rolled erosion control products (RECP).

3.2 CALIBRATION TESTING

Calibration testing was performed to verify if the designed rainfall simulator met the ASTM D6459 standards for uniformity, intensity, and drop size distribution. Nozzle size and sprinkler location were adjusted during the calibration process to achieve consistent and repeatable rainfall conditions for the 2, 4, and 6 in. per hr (51, 102, and 152 mm per hr) rainfall intensities.

3.2.1 Rainfall Uniformity and Intensity

The rainfall intensity was measured by installing 20 rain gauges throughout the test plot. The layout of the rain gauges is depicted in Figure 3.1.

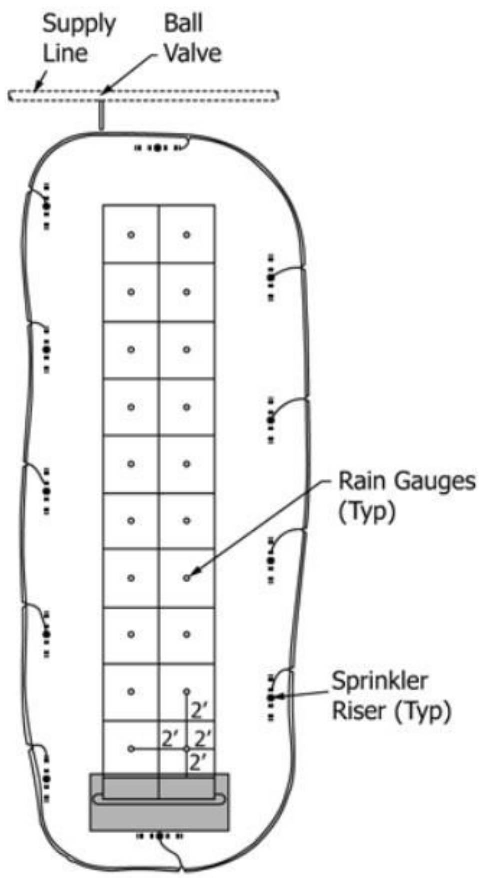


FIGURE 3.1: Rain Gauge Layout (ASTM 2019).

Prior to calibration testing, an anemometer was used to monitor wind speeds. If the wind speed at the time of the test exceeded 1 mph (1.61 kph), the wind curtains were used to encompass the plot. For the 2, 4, and 6 in. per hr (51, 102, and 152 mm per hr) rainfall intensities, a group of

15-minute calibration tests were performed. Following the completion of the test, each rain gauge depth was recorded in a spreadsheet to calculate the Christiansen Uniformity Coefficient (Equation 3.1) and the rainfall intensity (Equation 3.2).

$$C_u = 100\ [\ 1.0 - \sum|d| \div (n\ \bar{X})] \tag{3.1}$$

where,

Cu = Christiansen uniformity coefficient
$d = X_i - \bar{X}$
n = number of observations
$\bar{X}$ = average depth caught, in.
Xi = depth caught in each rain gauge, in.

$$i = 60[\sum_{j=1}^{J} P_j \div (Jt)] \tag{3.2}$$

where,

i = rainfall intensity, cm/hr
P_j = depth of rainfall, cm
J = number of rain gauges
t = time of test

Calibration tests were repeated a minimum of 10 times for each rainfall intensity to ensure consistency and repeatability of the rainfall simulator. The rain gauge layout and calibration testing is depicted in Figure 3.2.

(a) Rain gauge layout (b) Rainfall during calibration test

FIGURE 3.2: Uniformity and Intensity Testing.

3.2.1 Drop Size Distribution

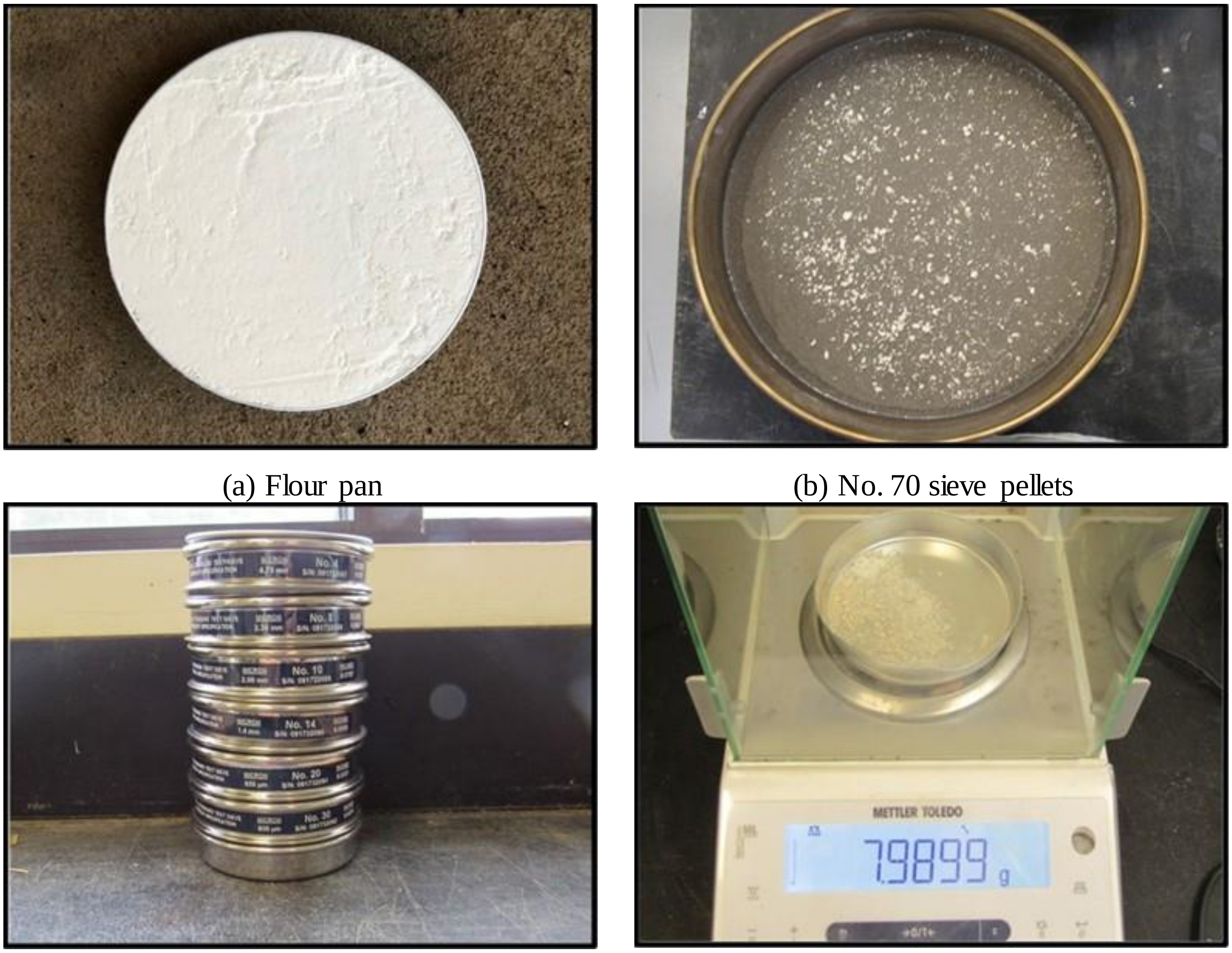
After the desired uniformity and rainfall intensity was reached, the flour pan test was used to evaluate the drop size distribution for the 2, 4, and 6 in. per hr (51, 102, and 152 mm per hr) rainfall intensities (Laws and Parsons 1943). An 8.5 in. (216 mm) diameter aluminum pie pan was filled to the edge with sifted Pillsbury all-purpose flour. The excess flour was struck off with a straight edge to create a smooth surface along the edge of the pie pan. The rainfall simulator was turned on to the desired rainfall intensity and the covered flour pan was placed on a level wooden stand. The top of the aluminum pie pan was removed by pulling the cover toward the experimenter for 2 to 4 seconds before recovering the pan. This procedure was performed at the top, middle, and bottom of the slope for each rainfall intensity. The flour pan sampling procedure is depicted in Figure 3.3.

(a) Covered flour pan

(b) Uncovered flour pan

FIGURE 3.3: Flour Pan Field Procedure.

The flour was air dried for a minimum of 12 hours. The air-dried flour was gently sieved through a No. 70-wire mesh sieve. The pellets were inspected to remove combined or misshapen pellets and the remaining flour pellets were placed in the oven for 2 hours at 230˚F (110˚C). The oven dried pellets were sieved through the No. 4, 8, 10, 14, 20, and 30 sieves. The flour pellets retained on each sieve were counted and weighed. The analysis of the flour pellets is depicted in Figure 3.4.



(a) Flour pan (b) No. 70 sieve pellets

(c) Testing sieves (d) Weighing pellet samples

FIGURE 3.4: Flour Pan Lab Testing.

Each rainfall intensity collected three flour pan samples, which were all added together for drop size distribution analysis. The total weight of the flour pellets retained on each sieve was calculated by adding the weights for all three samples. The average weight of the pellets retained on each sieve is determined by dividing the total weight per sieve by the total number of pellets. The mass ratio was calculated to convert the mass of the average pellet into the mass of the average drop using Equation 3.3.

$$M_R = (0.038) * \ln(W_{avg}) + 1 \tag{3.3}$$

where,

M_R = mass ratio
W_{avg} = average pellet weight, mg

The average diameter of the pellets was calculated by multiplying the average weight and the mass ratio as depicted in Equation 3.4.

$$D_{avg} = \sqrt[3]{\frac{6}{\pi} \times W_{avg} \times M_R} \tag{3.4}$$

where,

D_{avg} = average drop diameter, mm
W_{avg} = average weight, mg
M_R = mass ratio

The adjusted pellet weight was calculated by multiplying the total pellet weight for each sieve by the sieves corresponding mass ratio. The adjusted mass percentage was calculated by dividing the adjusted total pellet weight per sieve by the total adjusted pellet weight for pellets retained on all the sieves. The fall velocity was calculated by developing a regression equation from the raindrop fall velocity measurements from 15 ft (4.7 m). The regression equation was formed by plotting the raindrop size and the corresponding fall velocity from Figure 3.5. The regression equation is depicted by Equation 3.5.

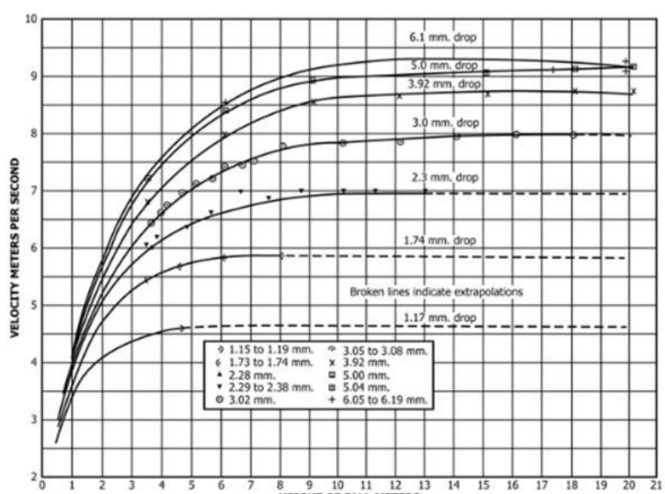


FIG. 6 Velocity of Fall of Seven Sizes of Water Drops After Heights of Fall from 0.5 to 20.0 m.

FIGURE 3.5: Raindrop Fall Velocity Chart (ASTM 2015).

$$y = -0.1667x^2 + 1.8235x + 2.8602 \quad (3.5)$$

where,

y = fall velocity, m/s
x = raindrop size, mm

The total rainfall volume for each rainfall intensity was calculated by converting the rainfall intensity to feet and multiplying by the test plot area of 320 ft^2 (29.7 m^2). The rainfall weight was calculated by multiplying the rainfall volume by 62.4 lb. per ft^3 (1000 kg per m^3), the density of water. The total rainfall weight was converted to slugs by dividing the weight by 32.2 ft per s^2 (2.97 m^2 per s). The incremental weight of rainfall retained on each sieve was calculated by multiplying the rainfall mass by the percentage of rainfall. The kinetic energy for each sieve was calculated by implementing Equation 3.6.

$$KE = \frac{1}{2}mv^2 \quad (3.6)$$

where,

KE = kinetic energy of sieve,
m = incremental rainfall mass, slug
v = raindrop fall velocity, ft/s

The kinetic energy was then converted to foot-tons by dividing the original kinetic energy by 2000 lb. per ton (0.5 kg per metric ton). The total kinetic energy for the test plot is calculated by dividing the *KE* in foot-tons by the area of the test plot in acres as depicted by Equation 3.7.

$$E = \frac{KE}{\left(\frac{A}{43560}\right)} \quad (3.7)$$

where,

E = total kinetic energy
A = total test plot area, ft^2
KE = kinetic energy, ft-ton

The total kinetic energy for each sieve was summed together for all three-rainfall intensities. The maximum 30-minute rainfall intensity was calculated by determining the maximum possible rainfall intensity occurring during the hour-long experiment. Therefore, I_{30} was calculated using Equation 3.8.

$$I_{30} = \frac{\left(4\frac{in}{hr}\times 10\ \text{min}\right)+\left(6\frac{in}{hr}\times 20\ \text{min}\right)}{30\ min} \quad (3.8)$$

where,

I_{30} = maximum 30-minute rainfall intensity, in.

The theoretical erosivity index was calculated by multiplying the total kinetic energy with a conversion of 0.01 and I_{30}. The theoretical erosivity index was later used to aid in the Revised Universal Soil Loss Equation (RUSLE) calculations analyzing product performance.

3.3 VALIDATION PROCEDURES

Following the completion of calibration testing for the 2, 4, and 6 in. per hr (51, 102, and 152 mm per hr) rainfall intensities, bare soil control tests were performed to provide a benchmark comparison to erosion control product performance.

3.3.1 Slope Preparation

Prior to rainfall simulation testing, the test slope must be prepared in a consistent and repeatable manner. To remove rills or slope damage from prior testing, the entire test slope was tilled to a minimum depth of 4 in. (10.2 cm). The tilling process is depicted in Figure 3.6.

(a) Tilling test slope

(b) Till bottom of test slope

FIGURE 3.6: Tilling Test Slope.

After the slope was tilled, the soil was raked to remove any clumps and to create a level soil depth across the slope. Dry screened soil was raked into the test plot until the optimal soil elevation was reached across the entire test plot. If the soil was too dry, water was added until the moisture content was within 5% of the optimal moisture content. A 24 by 48 in. (0.61 by 1.22 m) turf roller was placed at the bottom of the test slope against one edge of the plot. The turf roller was rolled up and down the slope with a mounted electronic winch three times. Then the turf roller was moved to the other half of the test plot and the same number of passes was performed. Lastly, the turf roller was moved to the center of the plot where one pass is performed to remove any inconsistencies from prior compacting. The desired compaction rate for the loam and sandy loam soils is 86±6%. The compaction process is depicted in Figure 3.7.

(a) First half compacted (b) Second half compacted

FIGURE 3.7: Slope Compaction.

3.3.2 Drive Cylinder Compaction

Once the slope is compacted, the compaction and moisture content are evaluated through the *Standard Test Method for Density of Soil in Place by the Drive-Cylinder Method* (ASTM D2937). Three numbers between 1 and 60 were selected by a random number generator to determine the drive cylinder test locations depicted in Figure 3.8.

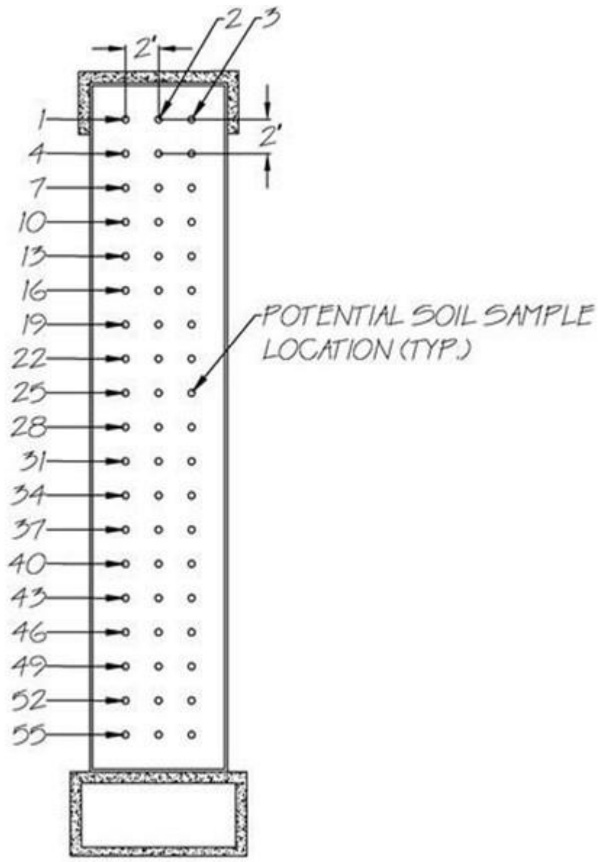


FIGURE 3.8: Drive Cylinder Test Locations (Horne et al. 2017).

The drive cylinder was driven into the slope. The cylinder was removed by digging around the front edge and picking the sample and cylinder up with a flat tool. Excess soil was removed from the bottom and cylinder edge. The approximate thickness of the soil sample was measured with a caliper. The wet soil sample was weighed before the moisture content and percent compaction were determined. The drive cylinder compaction test procedure is depicted in Figure 3.9.

(a) Aligning cylinder with the slope (b) Dropping the weight

(c) Leveled bottom (d) Weighing sample

FIGURE 3.9: Drive Cylinder Compaction Procedure.

Immediately following the drive cylinder compaction test, the moisture content of the soil sample was determined by following the *Determination of Water Content of Soil by Microwave Oven Heating* (ASTM D4643). The drive cylinder soil sample was placed in a microwave safe dish, which was weighed and then heated in the microwave for three minutes. The sample was removed, weighed, and placed back in the microwave for one additional minute. This process was repeated until the change in mass was 0.1% of the initial wet mass or there is no change in mass. The final dry mass was used to calculate the moisture content in Equation 3.6.

$$w = \left(\frac{M_1 - M_2}{M_2 - M_c}\right) \times 100 \quad (3.6)$$

where,

w = water content, %
M_1 = mass container and wet soil, g
M_2 = mass container and dry soil, g
M_c = mass container, g

The allowable moisture content must be within 5% of the optimal moisture content. The wet density of the soil sample was calculated using Equation 3.7.

$$\rho_{wet} = \frac{(M_1 - M_2)}{V} \quad (3.7)$$

where,

ρ_{wet} = wet density, g/cm^3
M_1 = mass cylinder and wet soil sample, g
M_2 = mass cylinder, g
V = volume of cylinder, cm^3

The in-place dry density was then calculated using the wet density of the soil shown in Equation 3.8.

$$\rho_d = \frac{\rho_{wet}}{(1 + \left(\frac{w}{100}\right))} \quad (3.8)$$

where,

ρ_d = dry density, g/cm^3
ρ_{wet} = wet density, g/cm^3
w = water content, %

The dry unit weight was then calculated using the in-place dry density in Equation 3.9.

$$\gamma_d = 62.4 \times \rho_d \quad (3.9)$$

where,

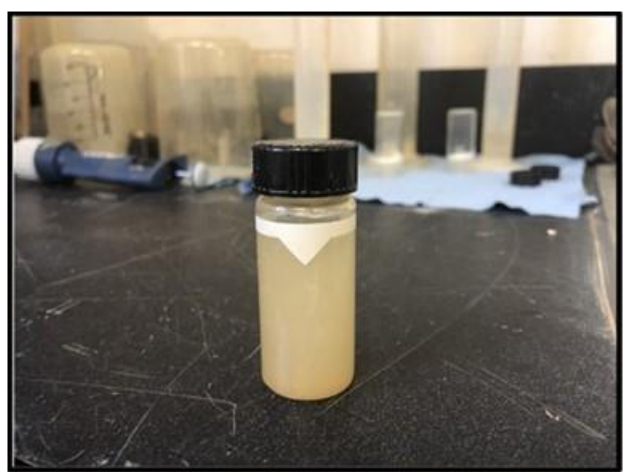
γ_d = dry unit weight, lb/ft^3
ρ_d = dry density, g/cm^3

The dry unit weight for each drive cylinder sample was divided by the maximum dry unit weight of the soil to determine the percent compaction. The ASTM D6459-19 does not specify a compaction rate for the test plot soil. Therefore, a compaction rate of 86±6% was selected for rainfall simulation testing. This compaction rate does not meet the typical 90 to 95% compaction rate for fill slopes, but since these slopes are typically dressed with top soil, which is only tracked in, this compaction amount will be more reflective of field conditions. If the percent compaction was not within 86±6 % limits, then additional slope preparation must be performed. This process was repeated until the water content and compaction meet the desired values.

3.3.3 Turbidity

Water samples were collected at the bottom of the test plot where all runoff was funneled to a single location where a 7 fl oz. (200 mL) sampling bottle catches the water sample. The collection of water samples started once the runoff began and continued at a three minute increment until runoff stops. Following the completion of the rainfall simulation and the collection of water samples, the samples were transferred to the lab for testing. First, the turbidimeter was recalibrated using standard samples. Then each water sample bottle was shaken to thoroughly mix all sediment in the solution. The water sample was transferred to a 33.8 fl oz. (1,000 mL) beaker and placed on a magnetic stirrer. The sample was continuously mixed throughout the entire testing process. A pipette was used to fill the turbidity sample cell to the line with 0.51 fl oz. (15 mL) of sample. The cell was placed in the turbidimeter and the reading was recorded. The preparation and testing of the turbidity measurements is depicted in Figure 3.10.

(a) Turbidimeter



(b) Turbidity sample

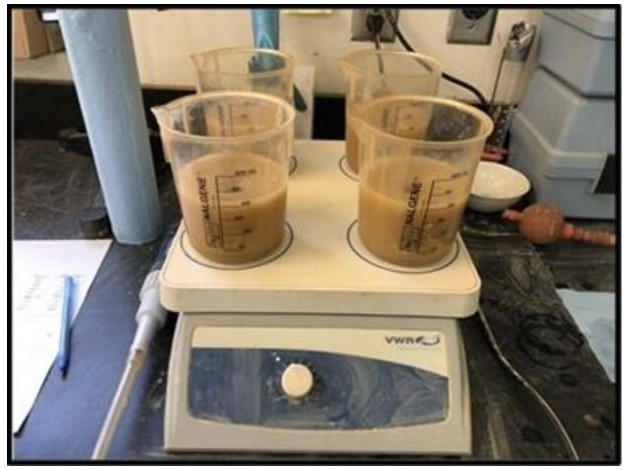
FIGURE 3.10: Turbidity Lab Testing.

If the water sample over ranges, the original sample was diluted 1:2 by mixing 3.4 fl oz. (100 mL) of deionized water in a beaker with 1.70 fl oz. (50 mL) of sample. The cell was filled with the diluted sample and the measurement recorded. The dilution process was repeated until the turbidimeter recorded a measurement.

3.3.4 Total Suspended Solids

Following the completion of the turbidity testing, the same diluted sample was used to determine the TSS for each water sample. Before testing began, the glass microfiber filter membranes were pre-washed with 0.34 fl oz. (10 mL) of deionized water. The filter membranes were placed in numbered aluminum crinkle dishes and placed in the oven at 117˚F (103˚C) for one hour. The crinkle dishes were removed from the oven and placed in a desiccator to cool to room temperature. Once at room temperature, the crinkle dish and filter membrane were weighed on the analytical balance and recorded to the nearest 0.0001 grams. Tweezers were used to move the filter membrane from the crinkle dish to the filtering apparatus. A pipette transferred 0.85 fl oz. (25 mL) of diluted solution to the filter. The filtering machine was turned on to suction the water through the filter. The filtrate on the filter was rinsed with three 0.34 fl oz. (10 mL) portions of deionized water. The filter membrane was removed from the apparatus with tweezers, placed in the assigned crinkle dish, and placed in the oven at 103˚C for one hour. Once the filter membranes were dry and have cooled to room temperature, each filter membrane and crinkle dish were weighed to the nearest 0.0001 grams. The procedure used to determine the TSS for water samples is depicted in Figure 3.11.

(a) Rinsing filters



(b) Mixing water samples

(c) Filtered sample

(d) Drying samples

FIGURE 3.11: TSS Lab Testing.

3.4 PRODUCT APPLICATION

All tested product installation followed the standards in the Alabama Handbook for Erosion Control, Sediment Control and Stormwater Management on Construction Sites and Urban Areas and the ALDOT Standard Specifications for Highway Construction. Product manufacturer's recommendations were also followed when necessary.

3.4.1 Loose Straw

Once the slope preparation procedure has been completed, loose dry wheat straw was applied to the slope for the blown, crimped, and tackifier straw tests. An application rate of 2 tons per acre (4483 kg per ha) was installed by hand as designated by the Alabama Handbook for seeding applications and ALDOT. The test plot and straw was divided into four even sections and spread by hand across the test plot to ensure a consistent application rate. The loose straw application is depicted in Figure 3.12.


(a) Straw application


(b) Finished application

FIGURE 3.12: Loose Straw Application.

3.4.2 Loose Straw with Tackifier

Once the slope preparation and loose straw application procedures were completed, a tackifier was sprayed on the straw. The tackifier was installed at an application rate of 50 lb. per acre (56 kg per ha). Four metal buckets were filled with 8 gallons (30.3 L) of water and one fourth of the tackifier to be installed. The tackifier was mixed with a drill mixer until the powder dissolved into a thick blue solution. Four gallons of tackifier solution was poured into a backpack sprayer and spread across one eighth of the test plot (40 ft^2). Manufacturer recommendations were followed for the curing time of the tackifier solution before rainfall simulation testing was performed. The powder and mixed Tacking Agent 3 are depicted in Figure 3.13.

(a) Power form Tacking Agent 3 (b) Mixed tackifier

FIGURE 3.13: Tackifier Application.

3.4.3 Crimped Straw

Once the slope preparation and loose straw application procedures were completed, the straw was crimped using the following procedure. A crimper was constructed using two notched flat coulter blades and wheelbarrow handles. Each blade was spaced eight inches (20.3 cm) apart as specified by Section 656 in the ALDOT Standard Specifications for Highway Construction. The crimper was rolled across the straw covered slope perpendicular to the flow direction. The straw was imbedded a minimum of two inches (5.1 cm) into the soil. The crimping procedure is depicted in Figure 3.14.

(a) Crimping perpendicular to slope (b) Crimped straw

FIGURE 3.14: Crimping Straw.

3.4.4 Hydraulic Erosion Control Products

A 300-gallon (1,135 L) Turf Maker hydroseeder was used for the mixing and application of the hydraulic erosion control products (HECP). Prior to rainfall simulation testing, the hydroseeder was calibrated. Eight four-foot by two-foot (1.21 m by 0.3 m) plywood sheets were placed on a 3H:1V slope. The hydroseeder sprayed the hydraulic mulch onto the plywood sheets by moving the nozzle side to side. Following each pass of the hydraulic mulch nozzle, one sheet of plywood was removed. Once the installation for all eight sheets of plywood were complete, the hydraulic mulch was allowed to dry. The dry product was scrapped from the boards and weighed to the nearest gram. The weight of mulch on each plywood sheet was converted to pounds per acre to determine the optimal number of sprays per application rate. The hydroseeder used for testing is depicted in Figure 3.15.

FIGURE 3.15: Hydroseeder used for Hydromulch Testing.

To prevent clogging in the hydroseeder, the hydraulic mulch was hand shredded prior to mixing. One 50 lb. (22.7 kg) bale of hydraulic mulch was used for each experiment. Following a water to mulch ratio of 2:1, 100 gallons (379 L) of water was needed to mix with 50 lb. (22.7 kg) of mulch. Prior to mixing the product, an extra 50 gallons (189 L) of water was added to the tank and pumped out to prime the pump and flush the system. With the remaining 100 gallons (379 L) of water in the tank, the agitator was turned on and the product was slowly added to the tank. The hydraulic mulch was allowed to mix for 20 minutes before installation began.

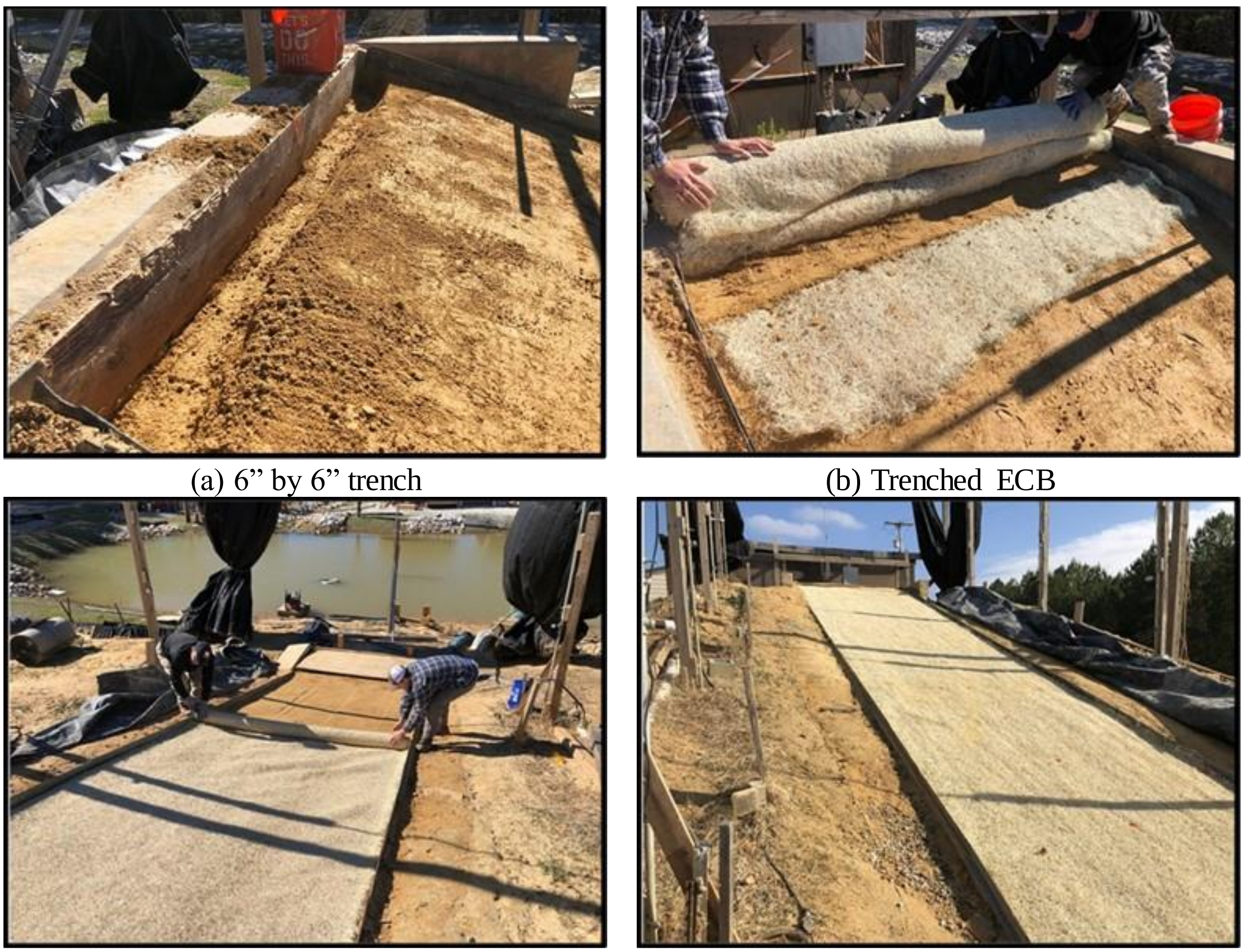
Once the hydraulic mulch had mixed for 20 minutes, the product can be installed. Plywood sheets were placed along one edge of the test plot to monitor the product application rate. The pump was turned on and all excess water was removed from the pump and hose until the product was flowing at a steady rate. The product was first installed from the bottom of the test plot by spraying the hydraulic mulch side to side. Then the hydraulic mulch was sprayed from the top of the slope to ensure consistent coverage. The hydraulic mulch was allowed to cure for a minimum of 24 hours before being tested. Once the hydraulic mulch on the plywood boards was dry, the application rate was checked by weighing the product to the nearest gram and converting to pounds per acre. Target application rates for products were installed as designated by the manufacturer. The hydraulic mulch installation is depicted in Figure 3.16.

(a) Bottom install (b) Top install

FIGURE 3.16: Hydraulic Mulch Application.

3.4.5 Rolled Erosion Control Products

Temporary erosion control blankets (ECBs) were installed on the test plot using the following installation procedure. Based on the ALDOT Standard section 659, type S3 blankets were evaluated for the 3H:1V slope. The test slope must first be prepared resulting in a smooth and level slope. Once the slope preparation procedure was complete, a 6 in. by 6 in. (15.2 cm by 15.2 cm) trench was created along the top of the test plot. The ECB was anchored into the trench following the manufacturer guidelines. The product was rolled down the slope without stretching or pulling the blanket. The product manufacturers slope anchoring guidelines were followed for an 8-foot (2.43 m) wide blanket. Once the product reached the bottom of the test plot, it was cut so that the blanket was flush with the bottom of the test plot. The ECB installation process is depicted in Figure 3.17.



(a) 6” by 6” trench

(b) Trenched ECB

(c) Installing ECB

(d) Installed ECB

FIGURE 3.17: Erosion Control Blanket Installation.

3.5 RAINFALL SIMULATION TEST PROCEDURE

Throughout the duration of this project, two different test procedures have been used. The first test procedure was used on a sandy loam soil. After testing on the sandy loam soil, the studies interpretation of ASTM D6459 was changed. The soil type and test procedure initially used were not meeting the standard as well as not providing the data for product *C*-factor calculations. The soil type was changed to a loam soil and a new test procedure used for testing. Prior to testing for both procedures, the compaction and moisture content of the slope met the designated limits. Once the slope was properly prepared, six rain gauges were installed on the slope at 10, 20, and 30 ft (3, 6, and 9 m) and from the top of the slope in 2 columns.

3.5.1 Sandy Loam Test Procedure

The sandy loam test procedure consisted of a 60 minute test duration with three sequential 20 minute rainfall intensities of 2, 4, and 6 in. per hr (51, 102, and 152 mm per hr). At the beginning of testing, the pump was turned on to build up pressure in the rainfall simulator. Once the desired pressure was reached, the first switch was turned on to initiate the 2 in. per hr (51 mm per hr) rainfall intensity. Once runoff beings entering the catch basin, waters samples were collected at 3-minute increments until runoff stops following the experiment. Just before the 20 minute point of the test, photos were taken of the test plot conditions. Once the test duration reaches 20 minutes, turn on an additional switch to initiate the 4 in. per hr (102 mm per hr) rainfall intensity. Just before the 40 minute point in the test, photos were taken of the test plot conditions. Then, the third switch was turned on to produce the 6 in. per hr (152 mm per hr) rainfall intensity. After 60 minutes of testing, the pump and rainfall simulator were turned on. Immediately following the test, the total rainfall depth collected during the experiment was recorded and the slope conditions were photographed. The discharge over time that entered the catch basin was measured with a water depth logger, which was placed in the catch basin.

3.5.2 Loam Test Procedure

Each test had a duration of 60 minutes and was divided into three sequential 20 minute sections with 2, 4, and 6 in. per hr (51, 102, and 152 mm per hr) rainfall intensities. The rainfall intensity was adjusted by using three switches that each control ten sprinklers. The test was momentarily paused at the 20 and 40 minute mark. During the pause, the rain gauge measurements were recorded, the soil collection container was changed, and the slope was photographed. Once these tasks were completed, the test was continued. Water samples were collected every three minutes. If no discharge off the slope was occurring, then no runoff sample would be collected. Runoff was collected at three-minute intervals with time being measured once rainfall is initiated. These water samples were later evaluated for TSS and turbidity measurements using the previously discussed analysis procedures. The discharge over time of the test plot was determined by recording the time it takes the runoff to fill a known volume. The same known volume could not be used for each storm event due to the significant differences in runoff. Therefore, a smaller volume is used for the 2 in. per hr storm event and a larger known volume for the 4 and 6 in. per hr (102 and 152 mm per hr) events. The discharge measurements were recorded every two minutes for the full duration of the test. The sample collection process is depicted in Figure 3.18.

(a) Water sample collection (b) Discharge measurement

FIGURE 3.18: Water Runoff Analysis.

The runoff caused by each rainfall intensity was separated into separate containers. The 2 and 4 in. per hr (51 and 102 mm per hr) rainfall intensity runoffs were diverted into independent galvanized metal tanks. The 6 in. per hr (152 mm per hr) rainfall intensity runoff was collected in the catch basin located at the bottom of the test slope. The sediment was allowed to settle for a minimum of 24 hours before the excess water was removed from the surface. The total dry mass of sediment for each rainfall intensity was determined by weighing all of the wet sediment and collecting representative samples to determine the moisture content of the soil. The runoff collection and dry sediment determination processes are depicted in Figure 3.19.

(a) Galvanized tanks

(b) Catch basin

(c) Weighing soil

(d) Moisture sample

FIGURE 3.19: Soil Loss Analysis.

3.6 SOIL ANALYSIS

Before rainfall simulation testing and the GAI accreditation was pursued, a soil classification must be determined for the United States Department of Agriculture (USDA) classification system and Unified Soil Classification System (USCS). The soil stockpile on site was analyzed through a sieve analysis, proctor compaction, Atterberg limits, and a hydrometer test. Several soils were evaluated to determine the soil that best fit ASTM D6459 requirements.

3.6.1 Dry Sieve Analysis – ASTM C136

A dry sieve analysis was performed following ASTM C136. A 0.66 lb. (300-g) soil sample was weighed and dried to constant mass at a temperature of 110±5˚C (230±10˚F). Sieves No. 4, 10, 20, 40, 60, 100, 200, and pan were selected for the analysis. Before the soil was placed in sieves, each sieve and the pan was weighed. The entire sample was placed on the No. 4 sieve and covered by the lid. The stack of sieves was placed in a mechanical sieve shaker, which was run for 5 minutes. Once the shaking process was completed, the sieve stack was removed from the mechanical shaker. Each sieve was individually weighed with the retained soil. The percent passing and percent retained on each sieve was calculated to obtain the particle size distribution. The sieve analysis process is depicted in Figure 3.20.

(a) Weighed soil sample

(b) Soil placed in sieve

(c) Sieve shaker

(d) Post sieve machine

FIGURE 3.20: Dry Sieve Analysis.

3.6.2 Wet Sieve Analysis – ASTM C117

A wet sieve analysis was performed on the proposed testing soil because the finer soil particles were clumping together with larger soil particles resulting in an inaccurate particle size distribution. Before the soil analysis was started, the soil was dried at 230˚F (110˚C) until a constant mass was reached. A soil sample of 0.22 lb. (100 g) was weighed and placed in a container. Water was added to the soil sample and thoroughly mixed to separate the soil particles. The water containing the suspended and dissolved solids was poured over the No. 16 and 200 sieve. Another charge of water was added to the bowl and mixed to separate any additional particles. The mixed water was poured through the sieves. This process was repeated until the water was clear. The material washed through the sieve was dried on a hot plate and in the oven. The soil not passing the No. 16 and 200 sieve was dried in the oven. Once the retained soil was dried, the soil was evaluated following the procedure for a dry sieve analysis. The soil passing the No. 200 sieve was weighed and used for hydrometer testing. The wet sieve analysis procedure is depicted in Figure 3.21.

(a) Wetting soil (b) Pouring water through sieves

FIGURE 3.21: Wet Sieve Analysis Testing.

3.6.3 Proctor Compaction Test – ASTM D698

The optimal moisture content and the maximum dry unit weight of the soil sample was determined through the *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort* (ASTM D698). The moist soil sample was sieved through the No. 4 sieve before being used in the experiment. A minimum of five test sub-specimens were created to generate a compaction curve. A sub-specimen of 5.51 lb. (2,500 g) was placed in a large metal bowl and water was mixed into the soil sample. Before placing the soil into the mold, the proctor mold was weighed without the extension collar. The soil was installed in three separate lifts to the mold and compacted with 25 blows following the pattern in Figure 3.22.

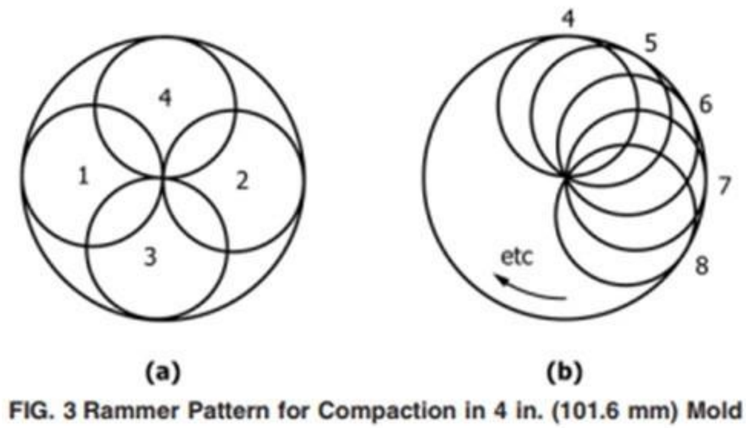


FIGURE 3.22: Proctor Compaction Pattern (ASTM 2012).

Once the compaction was completed, the extension collar was removed and a flat edge was used to remove all excess soil. The mold and soil were weighed before the soil cylinder was removed from the mold. Representative soil samples were collected from different areas of the compacted soil cylinder, weighed, and placed in the oven at a temperature of 140˚F (60˚C). This process was repeated by incrementally increasing the amount of water added to a new 5.51 lb. (2,500 g) soil sample. Once the dry weights of the representative samples were measured, a compaction curve was created to determine the optimal moisture content and maximum dry unit weight of the soil stockpile. The proctor compaction procedure is depicted in Figure 3.23.

(a) Adding water to soil

(b) Compacting soil into cylinder

(c) Leveling top of cylinder

(d) Leveled cylinder

FIGURE 3.23: Proctor Compaction Procedure.

3.6.4 Atterberg Test – ASTM D4318

The procedures in ASTM D4318 were followed to determine the liquid limit, plastic limit and the plasticity index of each soil sample. Before the sample was sieved through the No. 40 sieve, the soil was dried and removed any clumps. All material passing the No. 40 sieve was used for the liquid limit and plastic limit test.

3.6.4.1 Liquid Limit

A sample of the soil passing the No. 40 sieve was placed in a mixing bowl and water was added from a spray bottle. The target moisture content for the first trial will result in 25 to 35 drops. Once the desired moisture content was reached, the soil was spread with a spatula into the cup with a depth of 0.39 in. (10 mm). The soil was evened out and moved around to ensure no air bubbles were in the soil. A groove was formed down the center of the cup to divide the soil in half. The drop cup was lifted by turning the handle at a rate of 2 drops per second until the two halves come in contact. The number of drops required for the two halves to touch was recorded. A moisture sample was then selected and weighed before placed in the oven. The liquid limit procedure is depicted in Figure 3.24.

(a) Mixing sieved soil

(b) Cup installation

FIGURE 3.24: Liquid Limit Testing.

Once the 25 to 35 drop target sample was reached, two additional samples with a 20 to 30 and 15 to 25 drops target was pursued. Water was added to the previous soil sample to achieve the lower drop ranges. The sample dropping and measuring process was repeated for these two samples.

3.6.4.2 Plastic Limit

A 0.71 oz. (20 g) sample of the soil prepared by the liquid limit test from the second mixing was used to determine the plastic limit of the soil. A 0.05 to 0.07 oz. (1.5 to 2 g) portion of the sample was selected and formed into an ellipsoidal mass. The soil mass was rolled between the palms of the experimenters hands and on the glass plate until a uniform diameter of 0.13 in. (3.2

mm) is reached. The sample was then reformed into an ellipsoid and rolled again. The soil was continually rolled and reformed until the sample crumbles. The crumbled soil was placed in a dish and the process was repeated until 0.21 ounces (6 g) of soil was obtained. This entire process was repeated to result in having two 0.21 ounces (6 g) samples to dry in the oven. The plastic limit test is depicted in Figure 3.25.


(a) Rolling wet soil (b) Rolled soil sample

FIGURE 3.25: Plastic Limit Testing.

3.6.5 Hydrometer Analysis – ASTM D7928

Prior to the performance of a hydrometer test, a wet sieve analysis was performed to soil particles passing the No. 200 sieve. A 1.76 ounce (50 g) sample of the soil passing the No. 200 sieve was weighed out and placed into a dispersion (or malt mixer) cup. Then, 3.38 fluid oz. (100 mL) of sodium metaphosphate was measured in a graduated cylinder and placed in the dispersion cup with the soil sample. Water was used to wash all soil to the bottom of the cup. The dispersion cup was placed on the mixer and run for 5 minutes. The solution was transferred from the dispersion cup to the sedimentation cylinder. The dispersion cup was rinsed with a plastic squeeze bottle and added to the sedimentation cylinder. The sedimentation cylinder was filled with distilled water to 33.81 fluid ounces (1,000 mL). The preparation of the soil solution is depicted in Figure 3.26.

(a) Soil sample passing No. 200 sieve

(b) Malt mixer

(c) Turning sedimentation cylinder

(d) Hydrometer reading

FIGURE 3.26: Hydrometer Analysis Procedure.

A control cylinder was filled with 33.81 fluid oz. (1000 mL) of water used to calibrate the hydrometer (152H model). Before the hydrometer test time started, a rubber stopper was placed over the sedimentation cylinder to agitate for 1 minute by turning the cylinder upside down and back 60 times. Immediately following the agitation, the stopper was removed and the hydrometer was placed in the soil solution. A stopwatch was started when the hydrometer was placed in the sedimentation cylinder. Hydrometer readings were taken at 0.25, 0.5, 1, and 2 minutes. The hydrometer was removed from the sedimentation cylinder and placed in the control cylinder. Thirty seconds before the next reading, the hydrometer was placed back in the sedimentation cylinder. Measurements were recorded at 4, 8, 15, 30, and 60 minutes and 2, 4, 6, 8, 24, and 48 hours. After each measurement was recorded, the hydrometer was removed from the sedimentation cylinder and placed in the control cylinder. The sedimentation cylinder was covered with the stopper between measurements to prevent evaporation. The water temperature was measured during each measurement with a thermometer. The temperature correction factor was determined through the use of Equation 3.10.

$$F_t = -4.85 + 0.25T \tag{3.10}$$

where,

F_t = temperature correction
T = measure temperature, ˚C

Once the test was complete, the corrected hydrometer reading was calculated using Equation 3.11. The percent finer for the hydrometer readings was determined using Equation 3.12.

$$R_{cp} = R + F_t + F_z \tag{3.11}$$

where,

R_{cp} = corrected hydrometer reading
R = hydrometer reading
F_t = temperature correction
F_z = hydrometer zero correction

$$\% \, Finer = \frac{(A \times R_{cp} \times 100)}{W_s} \tag{3.12}$$

where,

A = correction for specific gravity
W_s = Dry weight of soil used for hydrometer analysis
R_{cp} = corrected hydrometer reading for percent finer

3.7 REVISED UNIVERSAL SOIL LOSS EQUATION (RUSLE)

The Revised Universal Soil Loss Equation (RUSLE) was used to calculate the soil erodibility factor (K) of the tested soil and the cover management factor (C-factor) of erosion control practices. The drop size distribution data and calculations in section 3.2.1 are used along with the soil loss and rain gauge measurements for each rainfall intensity. The bare soil control test was used to calculate the K-factor for the three corresponding erosion control product tests.

3.7.1 Soil Erodibility Factor – *K*-Factor

The *K*-Factor was calculated using the rain gauge measurements and soil loss (lb.) for each 20 minute rainfall intensity segment of the bare soil control test. The rain gauge measurements were used to calculate the average rainfall in inches and the maximum 30-minute rainfall intensity (I_{30}). The total soil loss for each rainfall intensity was inserted and converted from pounds to tons. The average soil loss (*A*) in tons/acre was calculated for each intensity by dividing the soil loss (tons) by the acreage of the rainfall simulator test plot.

Following these calculations, a graph is created plotting the incremental *R*-factor vs. the incremental *A* (tons/acre). From the three points plotted on the graph, a linear trendline is used to determine the trendline equation. The slope of the trendline equation is equal to *A*/*R*. The theoretical *R*-factor is used in the trendline equation to calculate the average *A* (tons/acre) from the entire experiment. The RUSLE equation is reformatted to solve for the *K*-factor as depicted in Equation 3.13.

$$K = \frac{A}{R \times LS \times C \times P} \tag{3.13}$$

where,

K = soil erodibility factor
A = average soil loss (ton/acre)
R =rainfall erosivity factor
LS =length slope steepness factor
C = cover management factor
P = support practice factor

Since a bare soil control test was being evaluated, the *C*-factor and *P*-factor are 1.0. The *LS* value is the calculated value for the length and steepness of the test plot. Once all of the equation values are determined, the *K*-factor was calculated. This *K*-factor will be used for the three product tests it was paired with. A bare soil control test was performed for every three product experiments.

3.7.2 Cover Management Factor – *C*-Factor

The *C*-factor for a product was calculated by inserting the incremental rain gauge measurements and the incremental soil loss data into the drop size distribution data from section 3.2.1. This will calculate the incremental EI_{30} value (*R*). The incremental average soil loss (*A*) was calculated by dividing the soil loss in tons by the acreage of the test plot. Once these values were calculated, a graph was created to plot the *R*-factor vs. *A* (ton/acre). The three data points on this graph are used to create a linear trendline equation. The slope of the linear trendline equation equals *A*/*R*. The average *A* (tons/acre) for the experiment was calculated by solving the trendline equation with the theoretical *R*-value. The RUSLE equation was arranged to solve for the *C*-factor. The *C*-factor for the product was calculated using the slope of the trendline *A*/*R* and a *P*-factor of 1.0.

Once three experiments of the same product have been completed, the average *C*-factor for the product must be determined. Two separate methods were used to calculate the *C*-factor for each erosion control product. The first method plotted the incremental *C*-factor versus the incremental *R*-factor for all three of the products experiments. The 2 inch per hour (52 mm per hr) rainfall intensity data was not included because the *C*-factor was near zero resulting in a skewed trendline equation. A linear trendline equation was fit to the 4 and 6 inch per hour (102 and 152 mm per hr) data points. The resulting trendline equation was used to calculate the *C*-factor of the product by solving for the theoretical *R*-factor of 182.02.

The second method used to solve for the product *C*-factor plotted the incremental soil loss (*A*) tons/acre versus the incremental *R*-factor for each individual experiment. A trendline equation was determined for each of the graphs and used to calculate the A in tons/acre for each test that correlates with the theoretical *R*-factor of 182.02. The resulting *A*-factor was averaged for all of the experiments and used in the RUSLE equation.

3.8 SUMMARY

This chapter summarizes the procedures used for the calibration testing, validation testing, erosion control practice installation, rainfall simulator testing procedure and the soil analysis. These procedures were used to meet the requirements of ASTM D6459-19 to evaluate erosion control practices on the AU-ESCTF rainfall simulator. These procedures were used to obtain the results summarized in Chapter 4.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 INTRODUCTION

Calibration testing was performed on the AU-ESCTF rainfall simulator to verify that the simulator could produce consistent rainfall that followed the ASTM D6459 standards for intensity, uniformity, and drop size distribution. Once the calibration testing was completed, a soil analysis was performed on the soil stockpiles to verify that the soil was classified as a clay, loam, or sand. Once all of the preliminary testing was performed, bare soil and erosion control practices were analyzed through full-scale rainfall simulation testing. This chapter will present the experimental results and a statistical analysis of these results.

4.2 CALIBRATION RESULTS

The procedures described in Section 3.2 produced rainfall data, which reflects the performance of the rainfall simulator. The raw calibration data for each experiment is provided in Appendix C. The data recorded from calibration testing was used to calculate the experimental rainfall intensity, uniformity, and drop size distribution for each target rainfall intensity of 2, 4, and 6 in. per hour (51, 102, and 152 mm per hr).

4.2.1 Uniformity and Intensity

The initial rainfall simulator consisted of six risers each with four sprinklers designed to produce a 2-year, 24-hour storm event for Alabama. During the calibration process, the rainfall simulator was redesigned to have eight riser each with three sprinklers to product the 2, 4, and 6 in. per hour (51, 102, and 152 mm per hour) rainfall intensities. Calibration testing determined that the top and bottom of the test plot was not receiving the same rainfall coverage as the rest of the test plot. Therefore, two additional risers were placed at the uphill and downhill sides of the test plot. Following the placement of two additional rainfall risers, calibration tests were performed to verify that the riser placement was producing uniform rainfall throughout the test plot. Once the riser placement was finalized, a total of 30, 15 minute calibration tests were performed with 20 rain gauges installed on the test plot. A minimum of ten calibration tests were performed for each rainfall intensity. If the standard deviation between the ten tests was less than 0.1 in. per hr (0.25 cm per hr), no additional calibration testing was required. Each rainfall intensity in this experiment had a standard deviation less than 0.1 in. per hr (0.25 cm per hr) and therefore only required ten tests. During the calibration process, 6 psi (41 kPa) and 10 psi (69 kPa) pressure regulators were installed to determine which pressure resulted in the best rainfall conditions. The 6 psi (41 kPa) pressure regulator was selected for testing because it generated larger drop sizes as well as a higher rainfall uniformity. The calibration summary results are depicted in Table 4.1.

TABLE 4.1: Rainfall Intensity Results

Theoretical Rainfall Intensity	2 in. per hr	4 in. per hr	6 in. per hr
Experimental Intensity (in/hr)	2.08	4.12	6.07
Rainfall Intensity Percent Error (%)	4.00	3.00	1.17
Standard Deviation	0.04	0.06	0.07
Number of Tests	10	10	10

Note: 1 inch per hour = 25.4 millimeter per hour

The experimental rainfall intensity for each calibration test was averaged and compared to the theoretical rainfall intensity to calculate the percent error. If the percent error was greater than 5%, changes were made to the nozzle size attached to the sprinklers. Upon final calibration testing, the rainfall intensity percent error was greatest for the 2 in. per hr (51 mm per hr) rainfall intensity at 4.0% and the lowest for the 6 in. per hr (152 mm per hr) rainfall intensity at 1.17%. The standard deviation between the calibration tests for each rainfall intensity ranged from 0.043 to 0.07 in. per hr (0.11 to 0.18 cm per hr). As the rainfall depth data was recorded, the rainfall uniformity was calculated using the Christiansen Uniformity Coefficient (Equation 3.1). The results for the uniformity calculations for each rainfall intensity are depicted in Table 4.2.

TABLE 4.2: Rainfall Uniformity Results

Intensity	2 in. per hr	4 in. per hr	6 in. per hr
Experimental Intensity (in. per hr)	2.08	4.12	6.07
Christianson Uniformity Coefficient, C*u* (%)	85.67	87.49	87.51

Note: 1 inch per hour = 25.4 millimeters per hour

For the rainfall simulator to meet the ASTM D6459 requirements, the rainfall uniformity for each rainfall intensity had to be a minimum of 80%. The results of the calibration testing concluded that the average rainfall uniformity ranged between 85 to 87%. After reviewing the calibration data, it was determined that the rainfall simulator met the ASTM D6459-19 requirements for intensity and uniformity, however, an additional analysis was performed on the calibration results.

4.2.1.1 Calibration Statistical Analysis

ANOVA testing was performed on each rainfall intensity to determine if each of the ten calibration test means were equal. If the *p*-value of the ANOVA test was greater than the alpha value of 0.05, then the null hypothesis was accepted, concluding that the means were equal. The results of the three ANOVA tests is summarized in Table 4.3.

TABLE 4.3: Calibration Testing ANOVA Test Results

Rainfall Intensity	No. of Rain Gauges	Alpha Value	*P*-Value
2 in/hr	20	0.05	0.951
4 in/hr	20	0.05	0.983
6 in/hr	20	0.05	0.994

All three of the ANOVA tests resulted in *p*-values greater than the alpha value of 0.05. Therefore, the null hypothesis that the ten calibration tests for each rainfall intensity had equal means is true. This analysis concludes that the rainfall simulator was producing consistent and repeatable rainfall events for the 2, 4, and 6 in. per hour (51, 102, and 152 mm per hour) rainfall intensities.

4.2.2 Drop Size Distribution

The flour pan method was used to determine the drop size distribution for each rainfall intensity of the AU-ESCTF rainfall simulator. The procedure defined in section 3.2.1 was followed to calculate the fall velocity of the raindrops as well as the total kinetic energy from the storm event. ASTM D6459 requires the average raindrop diameter to range from 0.04 to 0.24 inches (1 to 6 mm). The average raindrop size and fall velocity retained on each sieve for each rainfall intensity are summarized in Table 4.4.

TABLE 4.4: Raindrop Fall Velocity

Particle Diameter Range (mm)	2 in/hr		4 in/hr		6 in/hr	
	Average Raindrop Size (mm)	Fall Velocity (ft/s)	Average Raindrop Size (mm)	Fall Velocity (ft/s)	Average Raindrop Size (mm)	Fall Velocity (ft/s)
4.76+	6.03	25.57	5.29	25.73	5.78	25.69
4.76-2.38	3.79	24.21	3.52	23.68	3.65	23.93
2.38-2.0	2.50	20.92	2.59	21.22	2.28	20.17
2.0-1.41	1.81	18.42	2.00	19.16	1.76	18.22
1.41-0.841	1.21	15.84	1.21	15.81	1.55	17.36
0.841-0.59	0.91	14.39	0.89	14.27	0.95	14.59

The average size of the pellets retained on each sieve was calculated by inserting the average pellet weight and the mass ratio of the pellet size into Equation 3.4. The mass ratio converts the mass of the flour pellet to the mass of a raindrop of equal size. The largest drop size was recorded for the 2 in. per hr (51 mm per hr) rainfall intensity with a diameter of 0.24 inches (6.03 mm). The fall velocities for each of the three rainfall intensities were similar for each sieve size. The average raindrop size for each sieve and the percent of rainfall by mass were plotted to get the drop size distribution for each rainfall intensity. The drop size distribution is depicted in Figure 4.1.

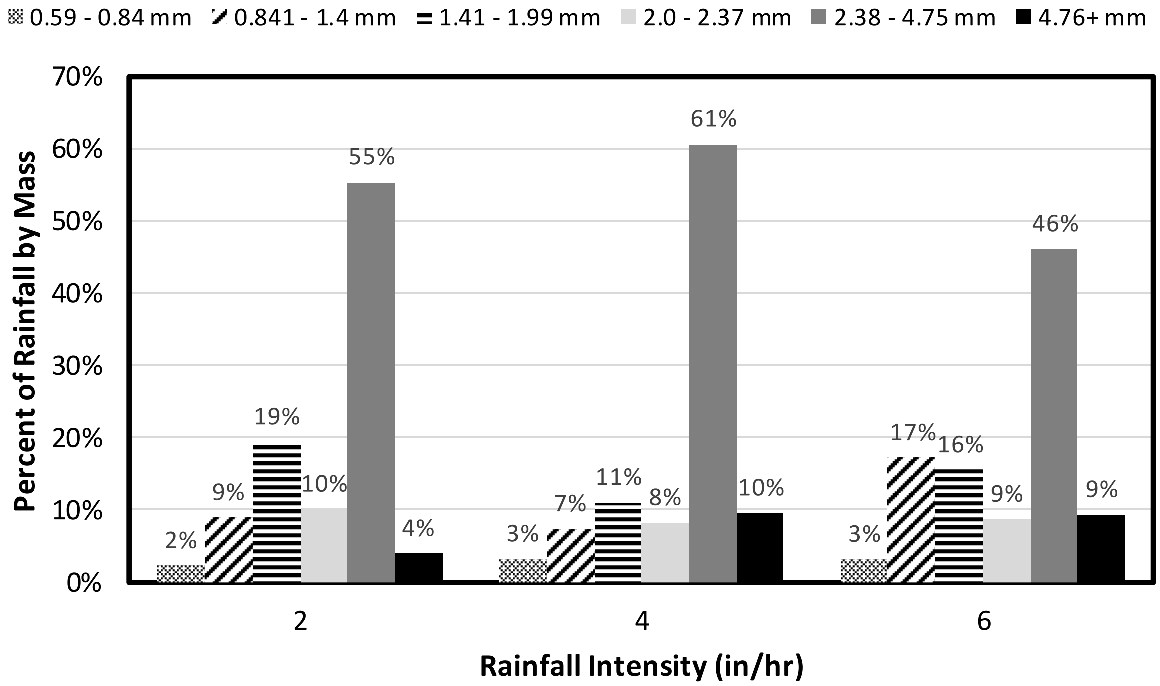


FIGURE 4.1: Drop Size Distribution by Mass.

The drop size distribution for each of the three rainfall intensities follows a similar trend. The No. 8 sieve (2.38 to 4.75 mm) retained the highest percentage of rainfall by mass produced by the rainfall simulator. The drop size distribution data and the average experimental rainfall depth for each rainfall intensity were used to calculate the total storm kinetic energy. The total energy produced by the rainfall during the one-hour experiment is depicted in Table 4.5.

TABLE 4.5: Rainfall Simulator Storm Energy

Rainfall Intensity	2 in. per hr	4 in. per hr	6 in. per hr	Total
Kinetic Energy Rainfall (ft-lbf)	8,729	17,704	24,266	50,699
Total Storm Energy, E (ft-tonf/acre)	594	1,205	1,652	3,451

Note: 1 ft-lbf = 0.138 m-kg
1 ton-ft/acre = 682 kg-m/ha

The total storm energy incrementally increases with each new rainfall intensity. The total storm energy (*E*) for the calibration test results is 3,451 ft-ton/acre (2600 m-metric ton/ha). The rainfall erosivity factor (*R*) is calculated by multiplying the E with the maximum 30-minute rainfall intensity (I_{30}). The I_{30} was calculated using the experimental rainfall intensities of 4.12 and 6.07 in. per hr (105 and 154 mm per hr). The I_{30} was calculated to be 5.42 inches (138 mm). The resulting experimental *R*-factor for the calibration test results was 187, while the theoretical *R*-factor is 182. Therefore, the rainfall simulator is generating a slightly larger *R*-factor than the theoretical storm event of ASTM D6459. The drop size distribution and total storm energy calculations are used to calculate erosion control product *C*-factors.

4.3 SOIL ANALYSIS RESULTS

Prior to erosion control product testing, the soil installed on the rainfall simulator test plot must be classified. A dry and wet sieve analysis, hydrometer test, proctor compaction test, and Atterberg test were used to classify the soil in the United States Department of Agriculture (USDA) classification system and the Unified Soil Classification System (USCS).

4.3.1 Sandy Loam Soil

The AU-ESCTF stockpile that was already on site prior to testing was used for straw mulch testing. Initially, a dry sieve analysis was performed on the soil, but the fine particles were sticking to other soil particles, which prevented an accurate particle size distribution. Therefore, a wet sieve analysis was used to accurately test the particle size distribution. To complete the particle size distribution curve, a hydrometer test was used to evaluate the soil particles passing the No. 200 sieve. The results from the wet sieve analysis and hydrometer test are depicted in Figure 4.2.

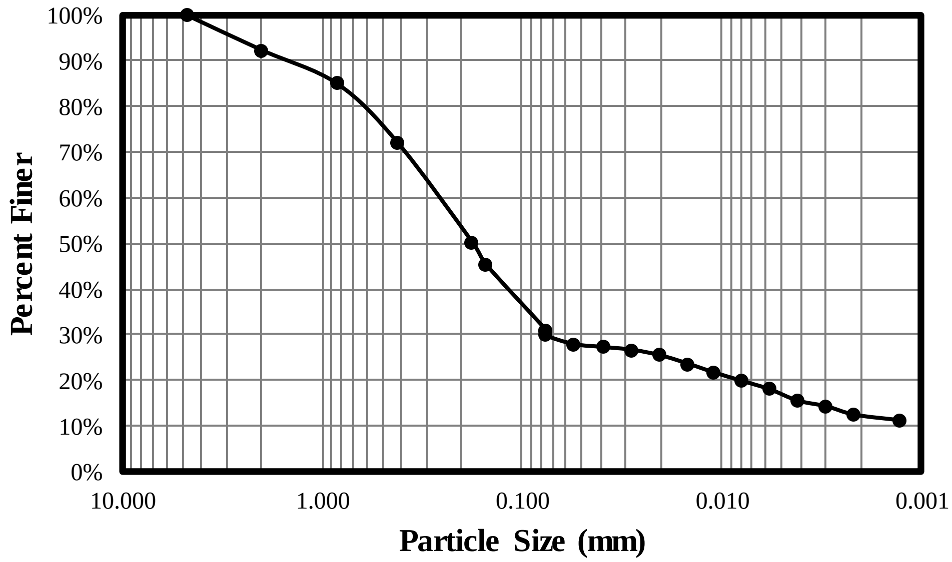


FIGURE 4.2: Sandy Loam Particle Size Distribution.

The AU-ESCTF stockpile was classified from the particle size distribution using the USDA classification system. The percentage of soil particle types were determined by measuring the percentage of sand particles ranging from 0.16 to0.002 inches (4.0 to0.05 mm), silt particles ranging from 0.002 to 0.00008 inches (0.05 to 0.002 mm), and clay particles less than 0.00008 inches (0.002 mm). The particle size distribution resulted in 73% sand, 15% silt, and 12% clay. The USDA soil texture triangle was used to classify the soil using the sieve analysis results as depicted in Figure 4.3.

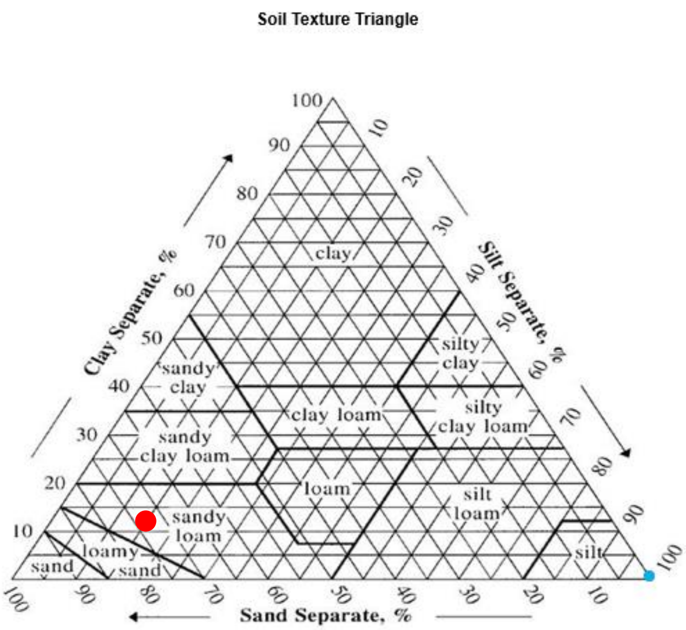


FIGURE 4.3: Sandy Loam USDA Triangle Classification.

Therefore, the soil was classified as a sandy loam. After the soil was classified for the USDA classification system, it was classified using the USCS classification system. An Atterberg test was performed to determine the liquid limit, plastic limit, and plasticity index of the soil. The results from the Atterberg test is depicted in Table 4.6.

TABLE 4.6: Atterberg Classification

Liquid Limit	27
Plastic Limit	23
Plasticity Index	4
Plasticity Chart Classification	ML or OL

The AU-stockpile had a liquid limit of 27 and a plastic limit of 23. The plastic limit was subtracted from the liquid limit to calculate a plasticity index of 4. The sand, silt, and clay percentages along with the Atterberg results were used to classify the soil. The USCS classification of the AU-stockpile was a silty sand. A proctor compaction test was also performed on the sandy loam soil to determine the maximum dry unit weight and the optimum moisture content. The results from this experiment are depicted in Figure 4.4.

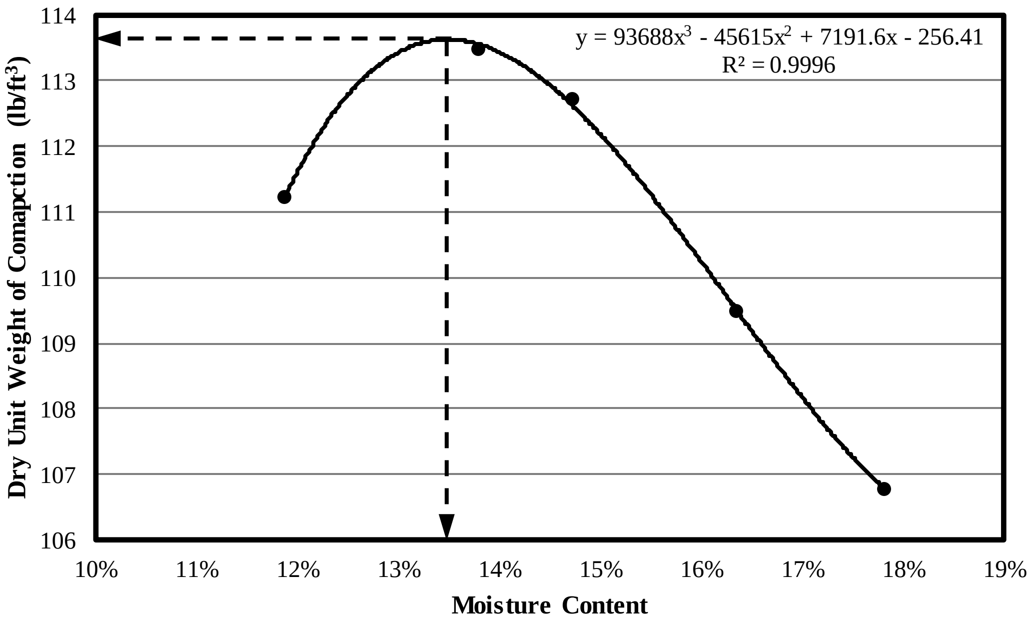


FIGURE 4.4: Sandy Loam Proctor Compaction Test Results.

The maximum dry unit weight of the AU-stockpile soil was 113.6 lb. per ft^3 (1,820 kg per m^3) with an optimum moisture content of 13.5%. These results were used to determine the percentage compaction of the test plot prior to rainfall simulation testing.

4.3.2 Loam Soil

Following the straw mulch testing it was determined that the sandy loam soil did not meet the soil requirements of ASTM D6459-19. ASTM D6459-19 specifies that the soil must be classified as a sand, loam, or clay for rainfall simulation testing. Therefore, several local soil stockpiles were evaluated using a wet sieve analysis and hydrometer test. One of the soils evaluated met the ASTM D6459-19 standards and the particle size distribution is depicted in Figure 4.5.

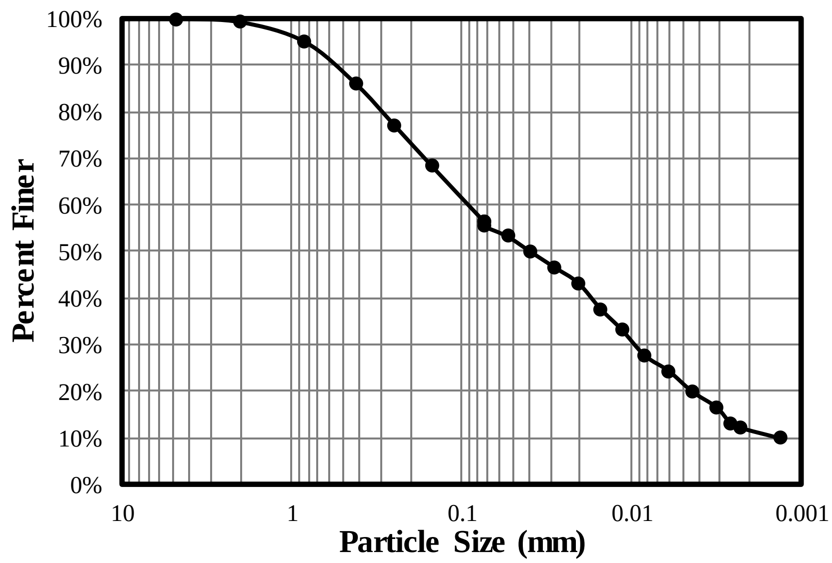


FIGURE 4.5: Loam Particle Size Distribution.

Based on the results from the particle size distribution, the soil composition was determined to be 48% sand, 41% silt, and 11% clay. The USDA soil texture triangle was used to classify the soil using the sieve analysis results as depicted in Figure 4.6.

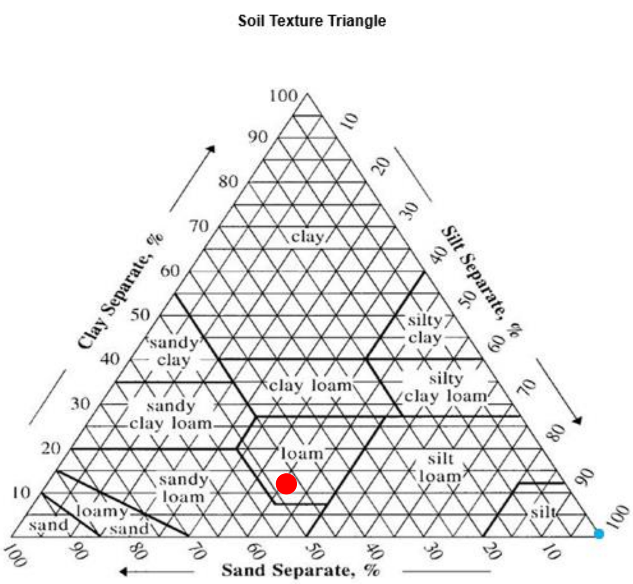


FIGURE 4.6: Loam USDA Triangle Classification.

Using the USDA classification system, the soil was classified as a loam. Once a soil that met the ASTM D6459 requirements, further soil testing was completed. An Atterberg test was performed on the loam soil to calculate the liquid limit, plastic limit, and the plasticity index. The Atterberg results are depicted in Table 4.7.

TABLE 4.7: Atterberg Soil Classification

Liquid Limit	33
Plastic Limit	28
Plasticity Index	5
Plasticity Chart Classification	ML or OL

The loam soil had a liquid limit of 33, a plastic limit of 28, and a plasticity index of 5. Using the Atterberg results, the plasticity chart classification was determined to be ML or OL. With this information and the particle size distribution, the USCS soil classification was a silty sand. A proctor compaction test was performed on the loam soil to calculate the optimum moisture content and the maximum dry unit weight. The proctor compaction test results are depicted in Figure 4.7.

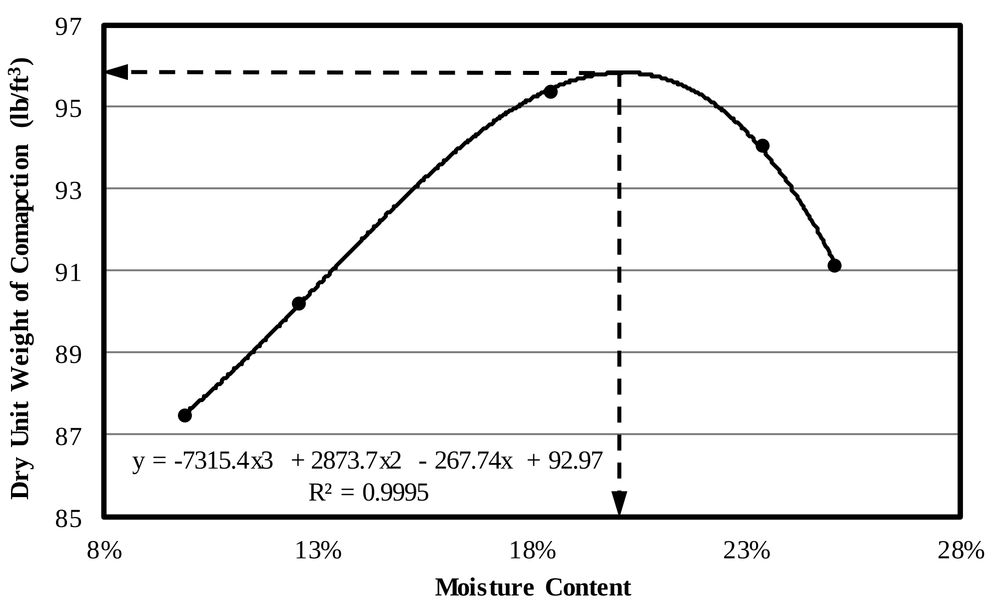


FIGURE 4.7: Loam Proctor Compaction Test.

From the compaction curve, the loams maximum dry unit weight was 96.0 lb. per ft^3 (1,538 kg per m^3) and an optimum moisture content of 20.0%. These results were used to determine the soil compaction rate prior to rainfall simulator testing.

4.3.3 Soil Summary

The two soils evaluated during this study were classified as a sandy loam and loam for the USDA classification system and both were classified as a silty sand for the USCS classification system. The soil characteristics are summarized in Table 4.8.

TABLE 4.8: Soil Analysis Summary

Soil Property	Sandy Loam	Loam
% Sand	73	48
% Silt	15	41
% Clay	12	11
Maximum Dry Unit Weight (lb./ft^3)	113.6	96.0
Optimum Moisture Content (%)	13.5	20.0

Note: 1 lb./ft^3 = 16.02 kg/m^3

The sandy loam soil had a higher percentage of soil particles than the loam soil and the loam soil had a higher percentage of silt particles. Due to these differences in soil composition, the maximum dry unit weight was much higher than the loam soil.

4.4 STRAW MULCH TESTING

The performance of straw mulch on the sandy loam soil was performed to evaluate the effectiveness of loose and anchored straw. Three types of straw applications consisting of loose straw, crimped straw, and loose straw with Tacking Agent 3 were compared to bare soil control tests to quantify the overall performance of the straw applications. The procedures for straw mulch installation, anchoring, and testing are defined in section 3.4 and 3.5.

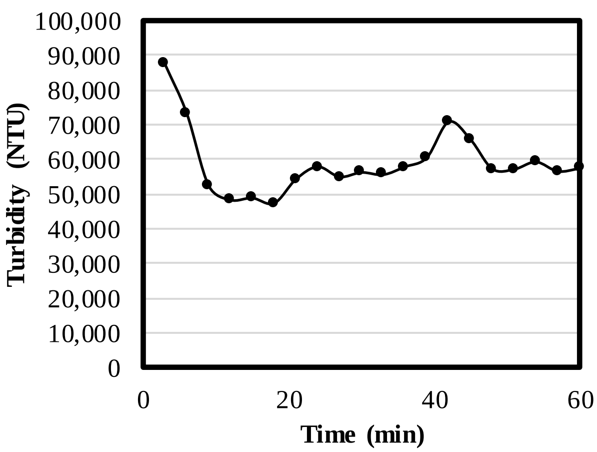
4.4.1 Bare Soil Results

Bare soil control tests were performed to evaluate the amount of erosion that occurs under the ASTM D6459-19 rainfall event. The results from these tests will be compared to erosion control practice results to evaluate the effectiveness of the practice. The data collected from four bare soil control tests is depicted in Table 4.9 and Figure 4.8.

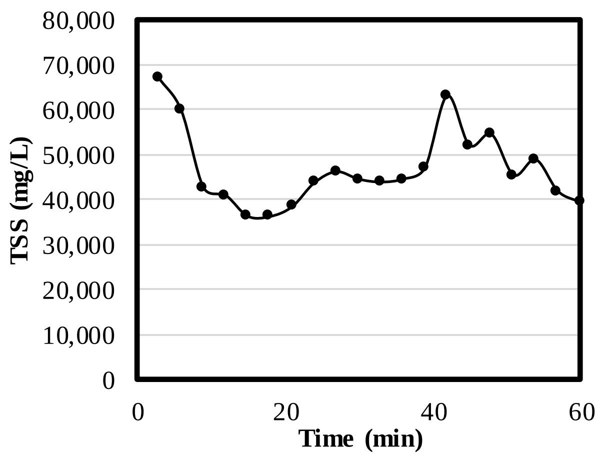
TABLE 4.9: Bare Soil Control Results for Sandy Loam Soil

Test Parameters	Test 1	Test 2	Test 3	Test 4	Average
Rainfall Depth (in.)	4.08	4.08	4.13	4.05	**4.08**
Compaction (%)	87.25	87.57	86.99	85.67	**86.87**
Moisture Content (%)	15.08	16.08	18.53	16.82	**16.63**
Total Collected Sediment (lb.)	725	711	752	764	**738**

Note: 1 inch = 25.4 millimeter
1 lb. = 0.45 kilogram



(a) Turbidity



(b) TSS

FIGURE 4.8: Bare Soil Water Quality Results for Sandy Loam Soil.

The bare soil control tests had an average percent compaction of 86.87%, an average moisture content of 16.63%, and an average experimental rainfall depth of 4.08 inches (104 mm). The turbidity and total suspended solids (TSS) water quality curves follow a similar trend. At the beginning of the experiment, there was a high initial flush resulting in high turbidity and TSS values. After the initial flush, the water quality value decreased for the remainder of the 2 in. per hr (51 mm per hr) rainfall intensity. The water quality results gradually increased in concentration throughout the remainder of the 4 and 6 in. per hr (102 and 152 mm per hr) rainfall intensities. The average soil loss for the bare soil control tests resulted in an average of 738 lb. (335 kg), which is equal to a soil loss rate of 50.2 tons per acre (112.5 metric tons per ha). The performance of the bare soil throughout the experiment is depicted in Figure 4.9.

(a) Pre-test (b) 20 minute

(c) 40 minute (d) Post-test

FIGURE 4.9: Sandy Loam Bare Soil Control Photos.

4.4.2 Loose Straw Results

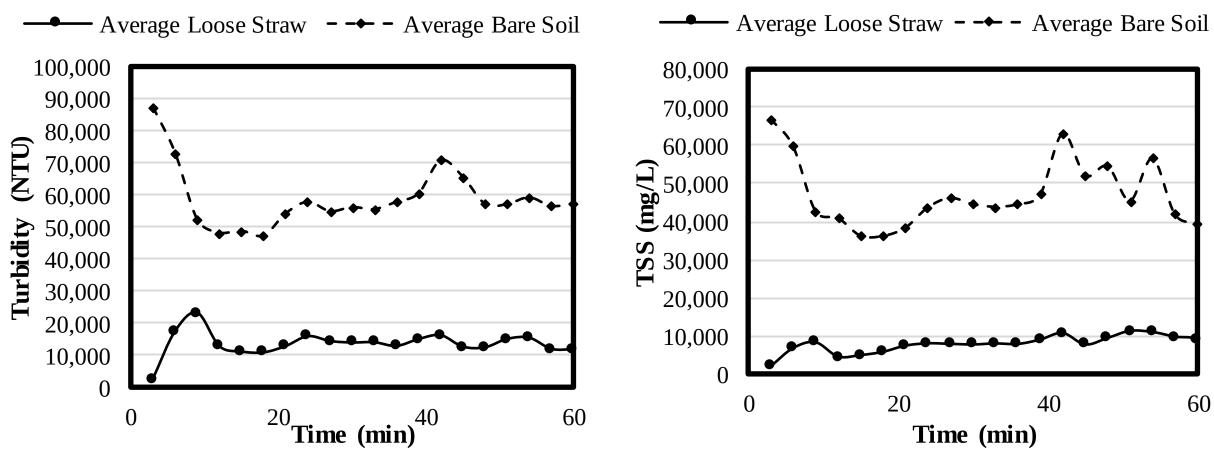
Loose wheat straw was installed to the prepared test plot to evaluate the performance of loose straw at an application rate of 2.0 tons per acre. Four initial product performance tests were completed and the results are depicted in Table 4.10.

TABLE 4.10: Loose Straw Test Results

Test Parameters	Test 1	Test 2	Test 3	Test 4	Average
Rainfall Depth (in.)	4.07	4.08	4.15	4.13	**4.11**
Compaction (%)	86.00	87.84	87.36	88.62	**87.46**
Moisture Content (%)	15.69	13.61	16.15	12.79	**14.56**
Total Collected Sediment (lb.)	113	168	129	162	**143**

Note: 1 inch = 25.4 millimeter
1 lb. = 0.45 kilogram

The four loose straw tests experienced an average rainfall depth of 4.11 in. (104 mm), an average percent compaction of 87.46%, and an average moisture content of 14.56%. The average soil loss for the loose straw was 143 lb. (64.9 kg), which is an 81% improvement from the bare soil conditions. The soil loss rate of the loose straw was 9.73 tons per acre (21.8 t/ha). The average water quality results for the loose straw are depicted in Figure 4.10.



(a) Turbidity (b) TSS

FIGURE 4.10: Loose Straw Water Quality Results.

The turbidity and TSS results were reduced from the bare soil results. The turbidity and TSS were gradually increased throughout the experiment. A small initial flush occurred, but was not as large as the initial flush occurring under bare soil conditions. The bare soil had an initial flush that quickly decreased 35,000 NTU while the loose straw had an initial flush that quickly decreased only 10,438 NTU. The performance of the loose straw is depicted in Figure 4.11.


(a) Pre-test


(b) 20 minute


(c) 40 minute


(d) Post-test

FIGURE 4.11: Loose Straw Test Photos.

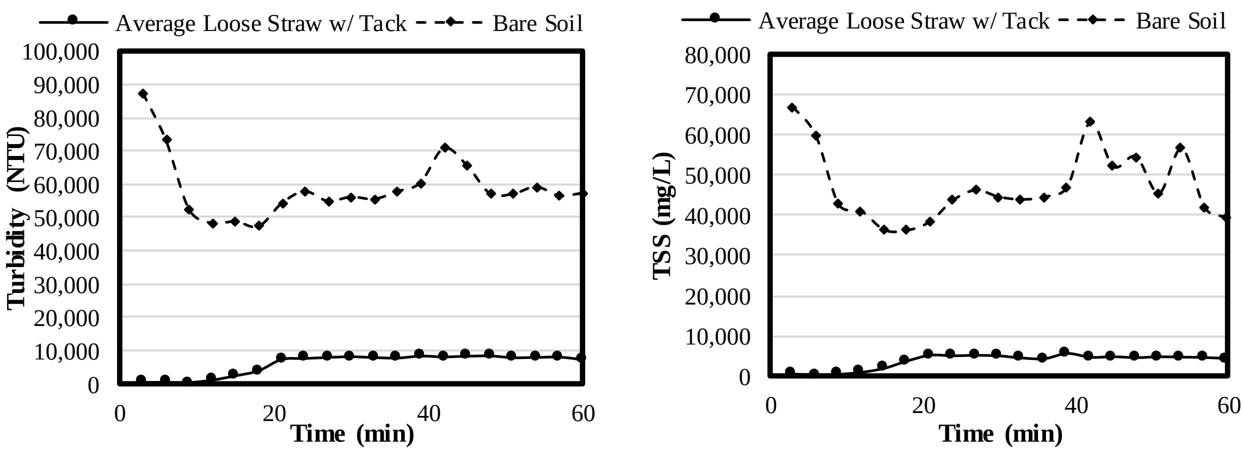
4.4.3 Loose Straw with Tacking Agent 3

Wheat straw was installed by hand to the test plot at an application rate of 2 tons per acre (4.5 t/ha). Once the straw was installed, Tacking Agent 3 was sprayed onto the straw at an application rate of 50 lb. per acre (56 kg per ha). The results from the three loose straw with tackifier experiments are depicted in Table 4.11 and Figure 4.12.

TABLE 4.11: Loose Straw with Tacking Agent 3 Results

Test Parameters	Test 1	Test 2	Test 3	Average
Rainfall Depth (in.)	4.07	4.05	4.08	**4.07**
Compaction (%)	88.12	87.25	86.96	**87.44**
Moisture Content (%)	16.48	16.61	16.16	**16.42**
Total Collected Sediment (lb.)	91.29	105.46	94.16	**96.97**

Note: 1 inch = 25.4 millimeter
1 lb. = 0.45 kilogram



(a) Turbidity (b) TSS

FIGURE 4.12: Loose Straw with Tacking Agent 3 Water Quality Results.

The three loose straw with Tacking Agent 3 tests had an average rainfall depth of 4.07 in. (103 mm), percent compaction of 87.44%, and moisture content of 16.42%. The average total soil loss for the loose straw with Tacking Agent 3 was 97 lb. (44 kg), which is an 87% improvement from the bare soil results. The soil loss rate for this erosion control practice is 6.60 tons per acre (14.8 t/ha). The turbidity and TSS for the loose straw with Tacking Agent 3 started near zero and gradually increased during the 2 in. per hr (51 mm per hr) rainfall intensity. During the 4 and 6 in. per hr (102 and 152 mm per hr) rainfall intensities, the water quality results remained relatively constant. The performance of the loose straw with Tacking Agent 3 is depicted in Figure 4.13.

(a) Pre-test

(b) 20 minute

(c) 40 minute

(d) Post-test

FIGURE 4.13: Loose Straw with Tacking Agent 3 Test Photos.

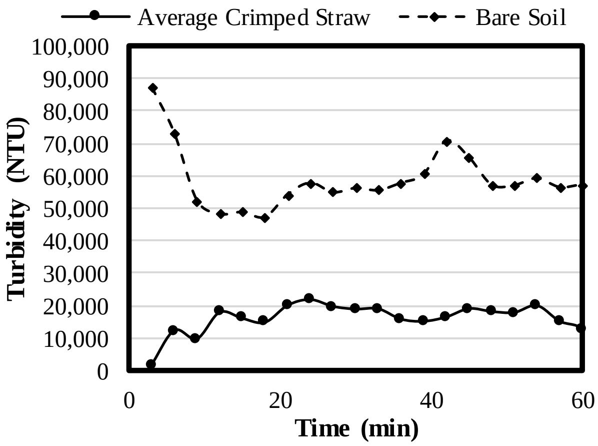
4.4.4 Crimped Straw

Wheat straw was installed on the test plot at an application rate of 2 tons per acre (4.5 t/ha). Following this application, the straw was imbedded into the soil a minimum of 2 in. (5.1 cm) with a crimper. The straw was crimped every 8 in. (20.3 cm) perpendicular to the direction of flow. The results of the crimped straw is depicted in Table 4.12 and Figure 4.14.

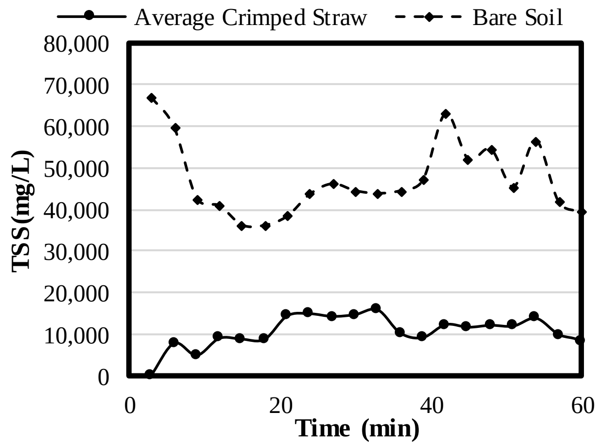
TABLE 4.12: Crimped Straw Test Results

Test Parameters	Test 1	Test 2	Test 3	Average
Rainfall Depth (in.)	4.05	4.05	4.13	**4.08**
Compaction (%)	88.40	89.36	87.35	**88.37**
Moisture Content (%)	14.65	14.89	11.57	**13.70**
Total Collected Sediment (lb.)	187	175	142	**168**

Note: 1 inch = 25.4 millimeter
1 lb. = 0.45 kilogram



(a) Turbidity



(b) TSS

FIGURE 4.14: Crimped Straw Water Quality Results.

The crimped straw tests resulted in an average rainfall depth of 4.08 in. (104 mm), an average percent compaction of 88.37%, and an average moisture content of 13.70%. The average soil loss for the three crimped straw tests was 168 lb. (76.2 kg), which is a 77% improvement from the bare soil results. The crimped straw had a soil loss rate of 11.43 ton per acre (25.6 t/ha). The turbidity and TSS results for the crimped straw quickly increased at the beginning of the experiment to a consistent value throughout the remainder of the experiment. The crimped straw had the worst water quality performance out of the three straw mulch applications under initial product testing. This was most likely due to the process of imbedding the straw into the soil. When imbedding the straw, the soil is disturbed resulting in loose soil on the test plot surface and voids along the crimped straw. The performance of the crimped straw is depicted in Figure 4.15.

(a) Pre-test

(b) 20 minute

(c) 40 minute

(d) Post-test

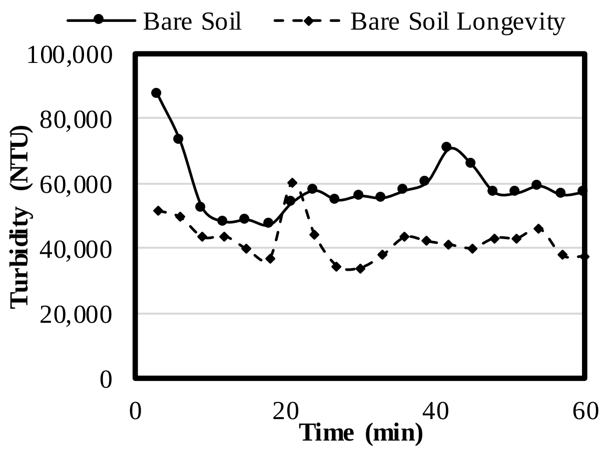
FIGURE 4.15: Crimped Straw Test Photos.

4.4.5 Straw Mulch Longevity Testing

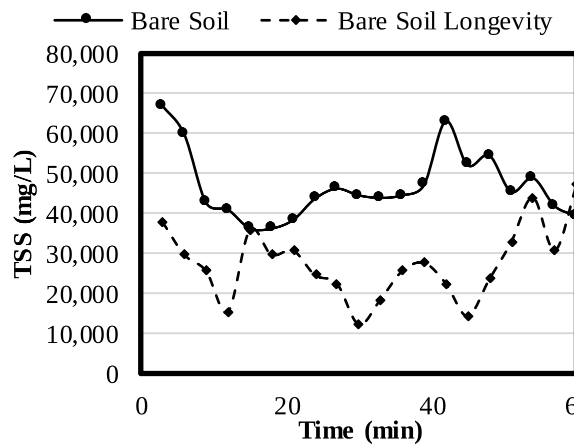
Following the completion of the initial product performance tests, a longevity test was performed on one of each of the straw mulch treatments to evaluate how well the straw mulch practices will perform under multiple rainfall events. Between the initial and longevity experiments, the test slope was not altered, the catch basin was cleaned out, and the water quality samples were tested.

4.4.5.1 Bare Soil Longevity

Following the initial bare soil control test, a longevity experiment was performed on the test plot to evaluate the performance of the bare soil under an additional rainfall event. There was a two-day break between the initial and longevity experiments to allow for the completion of data collection. The longevity bare soil had a rainfall depth of 4.12 in. (105 mm) and a total soil loss of 611 lb. (277 kg). The longevity experiment experience a reduction in soil loss of 17% from the initial bare soil control test. The water quality results of the experiment are depicted in Figure 4.16.



(a) Turbidity



(b) TSS

FIGURE 4.16: Bare Soil Longevity Water Quality Results.

The turbidity and TSS water quality curves for the longevity experiment resulted in lower concentrations throughout the experiment than the initial bare soil control test. The testing results of the bare soil longevity experiment is depicted in Figure 4.17.


(a) Pre-test


(b) Post-test

FIGURE 4.17: Bare Soil Longevity Results.

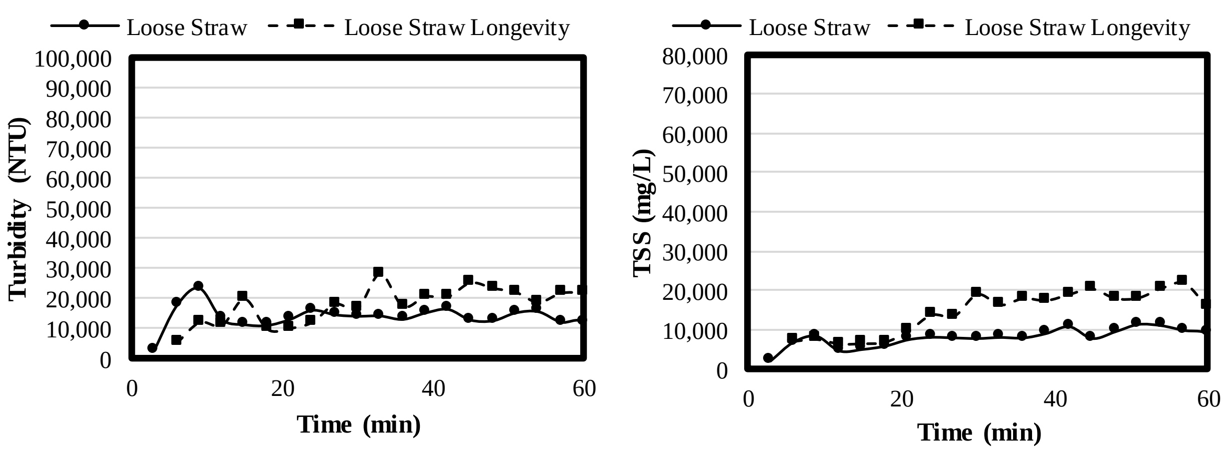
4.4.5.2 Loose Straw Longevity

Following the initial loose straw test and data collection, a longevity experiment was performed on the loose straw application. The longevity experiment was used to evaluate the performance of the straw mulch when exposed to an additional rainfall event. The loose straw longevity experiment had a rainfall depth of 4.13 in. (105 mm). The soil loss and water quality from the bare soil control test is depicted in Table 4.13 and Figure 4.18. Table 4.13 shows the percent improvement for the initial and longevity loose straw experiments as compared to the corresponding initial and longevity bare soil control soil loss results.

TABLE 4.13: Loose Straw Longevity Soil Loss Results

Product	Soil Loss (lb)	Soil Loss Ratio	% Improvement
Bare Soil Control	738	-	-
Bare Soil Longevity	611	-	-
Loose Straw	143	0.19	81%
Loose Straw Longevity	287	0.47	53%

Note: 1 lb. = 0.45 kilograms



(a) Turbidity (b) TSS

FIGURE 4.18: Loose Straw Longevity Water Quality Results.

The loose straw longevity test had a soil loss of 287 lb. (130 kg), which is double the soil loss of the initial loose straw test of 143 lb. (64.9 kg). The longevity test resulted in a percent improvement from the bare soil longevity test of 53%. The turbidity and TSS water quality concentrations gradually increased throughout the rainfall experiment, while the initial loose straw test resulted in more constant values throughout most of the experiment. The loose straw was washed from the test plot causing a larger amount of erosion to occur during the longevity test. The loose straw longevity test plot conditions are depicted in Figure 4.19.

(a) Pre-Test (b) Post-Test

FIGURE 4.19: Loose Straw Longevity Photos.

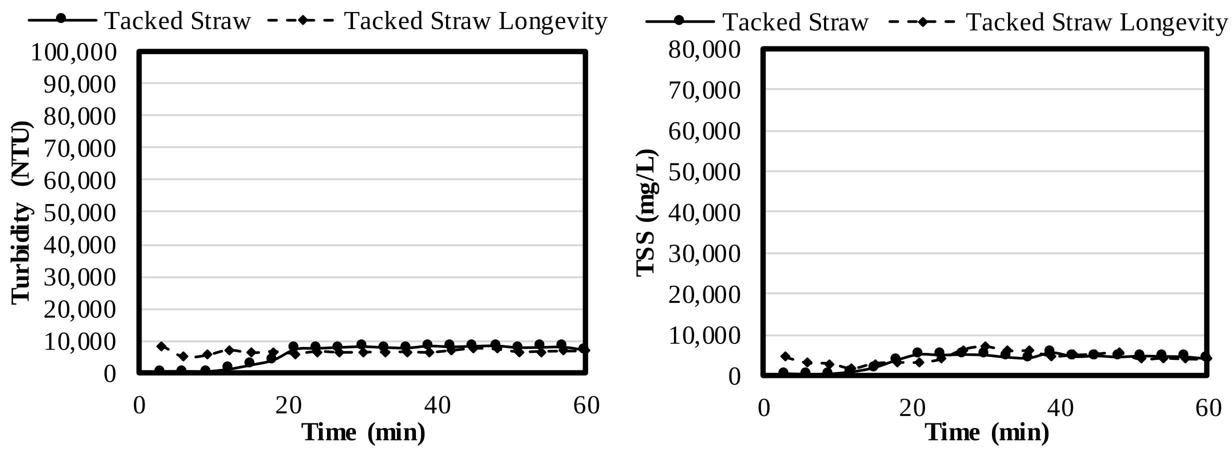
4.4.5.3 Loose Straw with Tacking Agent 3

Following the initial test of the loose straw with Tacking Agent 3, a longevity test was performed to determine the effectiveness of the straw anchoring application under an additional rainfall event. The loose straw with Tacking Agent 3 longevity test had a rainfall depth of 4.12 in. (105 mm). The soil loss from the initial and longevity test as well as the water quality results are depicted in Table 4.14 and Figure 4.20.

TABLE 4.14: Loose Straw with Tacking Agent 3 Longevity Results

Product	Soil Loss (lb.)	Soil Loss	% Improvement
Bare Soil Control	738	-	-
Bare Soil Longevity	611	-	-
Loose Straw with Tackifier	97	0.13	87%
Loose Straw w/ Tackifier Longevity	131	0.21	79%

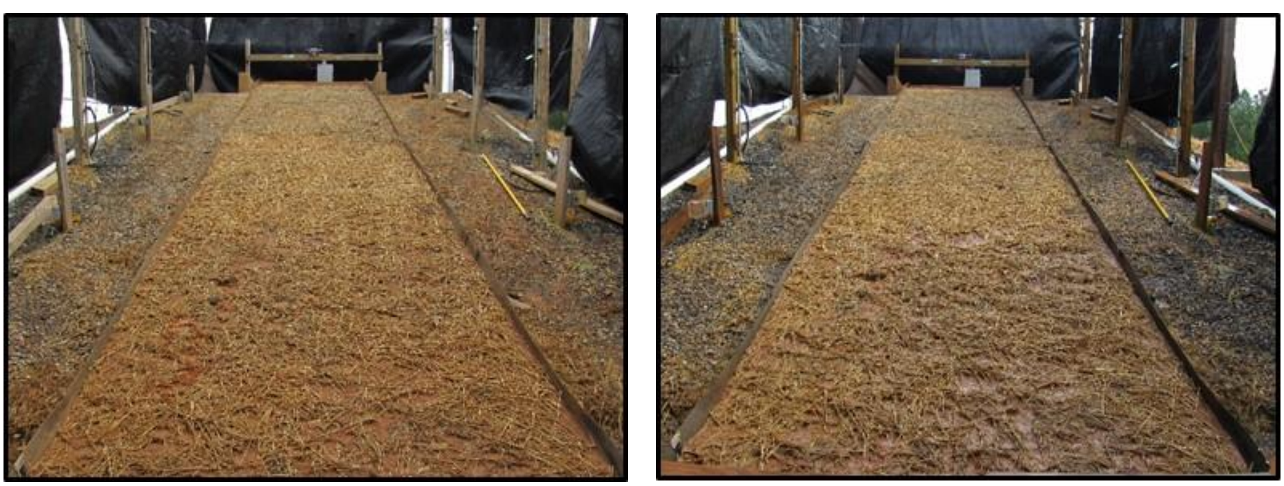
Note: 1 lb. = 0.45 kilograms



(a) Turbidity (b) TSS

FIGURE 4.20: Loose Straw with Tacking Agent 3 Longevity Water Quality Results.

The loose straw with Tacking Agent 3 longevity experiment resulted in a total soil loss of 131 lb. (59.4 kg), while the initial test had a soil loss of 97 lb. (44 kg). The longevity test had a percent improvement from bare soil conditions of 79%. The increase in soil loss is possibly due to the tackifier washing from the test plot along with the straw cover. The turbidity and TSS water quality concentrations were slightly better than the initial test. The turbidity values were consistent throughout the entire experiment while the TSS values gradually increased during the 2 in. per hr (51 mm per hr) rainfall intensity and became relatively constant for the remainder of the experiment. The loose straw with Tacking Agent 3 performance is depicted in Figure 4.21.



(a) Pre-test (b) Post-test

FIGURE 4.21: Loose Straw with Tacking Agent 3 Longevity Photos.

4.4.5.4 Crimped Straw Longevity

Following the completion of the initial crimped straw test, longevity testing was performed on the crimped straw to determine the installations effectiveness under an additional rainfall event. The crimped straw longevity test had a total rainfall depth of 4.07 in. (103 mm). The total soil loss and water quality curves from the crimped straw longevity test are depicted in Table 4.15 and Figure 4.22.

TABLE 4.15: Crimped Straw Longevity Results

Product	Soil Loss (lb.)	Soil Loss	% Improvement
Bare Soil Control	738	-	-
Bare Soil Longevity	611	-	-
Crimped Straw	169	0.23	77%
Crimped Straw Longevity	82	0.13	87%

Note: 1 lb. = 0.45 kilograms

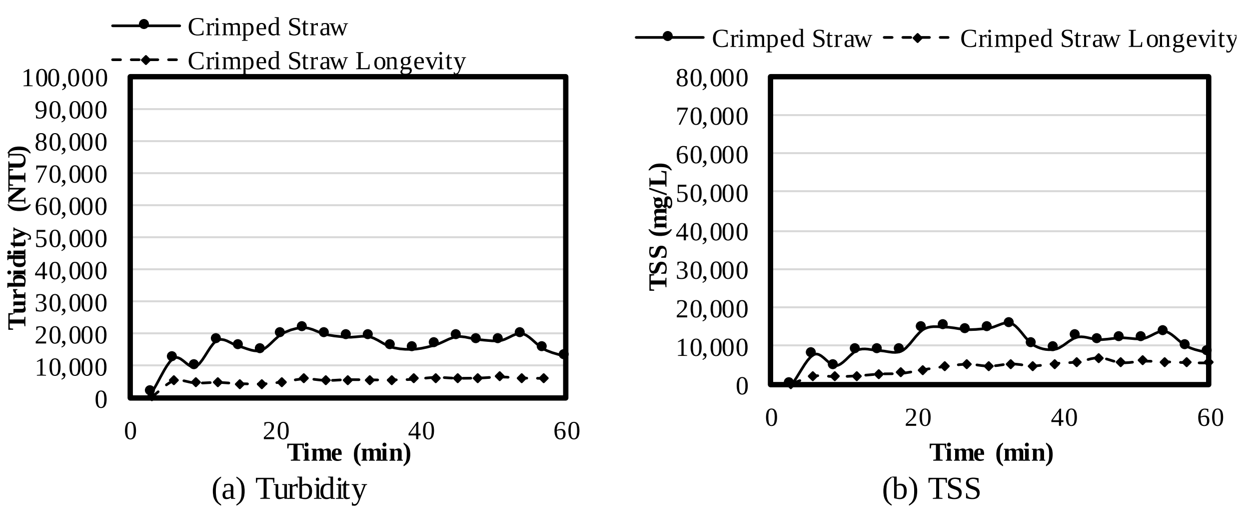


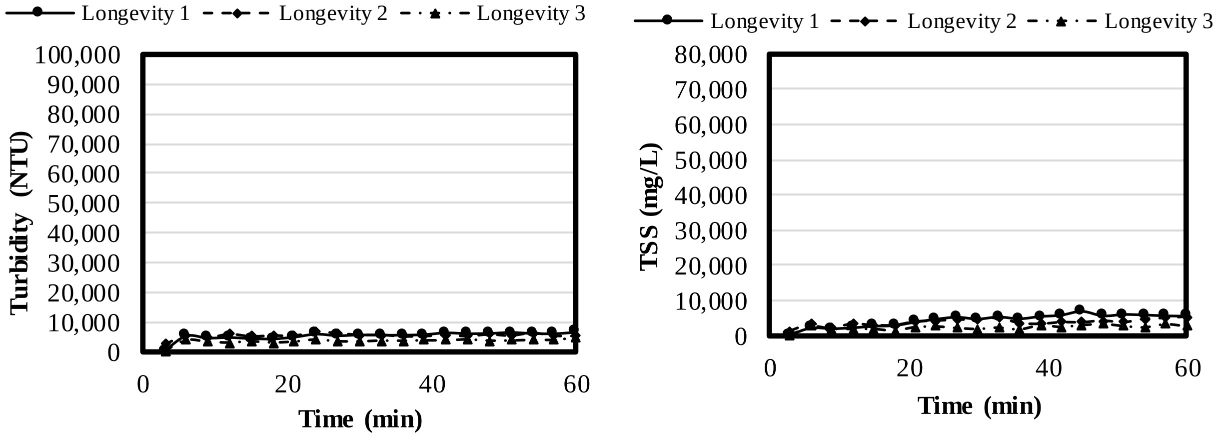
FIGURE 4.22: Crimped Straw Longevity Water Quality Results.

The crimped straw longevity experiment had a total soil loss of 82 lb. (37.2 kg), while the initial crimped straw test had a total soil loss of 169 lb. (77 kg). The longevity crimped straw had an 87% improvement from the longevity bare soil results. The turbidity and TSS concentration curves were greatly reduced from the initial crimped straw test. The turbidity and TSS values were consistent throughout the entire rainfall event even though the rainfall intensity was increasing. The substantial improvement from the initial to longevity testing is likely caused by the removal of the disturbed soil during the first rainfall event caused by crimping the soil and filling the voids around the crimped straw. As the longevity test continued, a tier system formed between the crimped sections of straw. The tiers slowed down the flow of the runoff, which also reduced the impact of the raindrops. The performance of the crimped straw during longevity experiments is depicted in Figure 4.23.

(a) Pre-test (b) Post-test

FIGURE 4.23: Crimped Straw Longevity Photos.

Due to the substantial improvement between the initial and longevity tests of the crimped straw, additional longevity tests were performed. The second longevity test had a total rainfall depth of 4.07 in. (103 mm) with a total soil loss of 78 lb. (35.4 kg). The third longevity experiment had a total rainfall depth of 4.02 in. (102 mm) with a total soil loss of 83 lb. (37.6 kg). The turbidity and TSS water quality curves for the longevity experiments are depicted in Figure 4.24.



(a) Turbidity (b) TSS

FIGURE 4.24: Crimped Straw Longevity Results.

The first and second longevity experiments followed similar turbidity and TSS concentration curves while the third longevity experiment showed an improvement in water quality results. The improvement in performance was potentially caused by the formation of a tier system between the rows of crimped straw. The tier formation occurring with the crimped straw is depicted in Figure 4.25. Another potential cause of improvement was that the three prior rainfall events had removed a majority of the fine, easily erodible surface soils causing a reduction in the amount of soil eroding from the slope. All three of the longevity experiments had a near zero initial turbidity concentrations and quickly increased to a concertation that was relatively constant for the remainder of the experiment.

FIGURE 4.25: Crimped straw tier formation

4.4.6 Straw Mulch Statistical Analysis

A statistical analysis was performed on the initial straw mulch results to determine if any of the straw mulch applications had statistically similar soil loss results. An ANOVA test was performed to determine if the means of all three straw mulch applications soil loss results were equal. If the *p*-value resulting from the ANOVA test was less than the alpha value of 0.05, then the null hypothesis that all three means were equal would be rejected. The results from the ANOVA test are summarized in Table 4.16.

TABLE 4.16: Straw Mulch ANOVA Results

Degrees of Freedom	Alpha Value	*F*-value	*p*-value
9	0.05	8.444	0.014

The ANOVA test resulted in a *p*-value less than the alpha value of 0.05. Therefore, the null hypothesis that all three of the means was equal was rejected. At least one of the straw mulch soil loss means was statistically different from the others. Three hypothesis tests was performed to compare the loose versus tackifier, loose versus crimped, and the tackifier versus crimped straw to determine which means were equal. The hypothesis tested for this statistical analysis is depicted in Equation 4.1 and 4.2. The null hypothesis of this experiment was that the two sample means were statistically equal, while the alternative hypothesis was that the means were not equal. If the

p-value resulting from the hypothesis test is less than 0.05, then the alternative hypothesis is true. The results from the three hypothesis tests is summarized in Table 4.17.

$$H_0: \mu_1 = \mu_2 \quad (4.1)$$

where,

H_0 = null hypothesis
μ_1 = variable one mean
μ_2 = variable two mean

$$H_1: \mu_1 \neq \mu_2 \quad (4.2)$$

where,

H_1 = alternative hypothesis
μ_1 = variable one mean
μ_2 = variable two mean

TABLE 4.17: Straw Mulch Hypothesis Test

Hypothesis Test	**Application 1 Mean (lb.)**	**Application 2 Mean**	**Alpha Value**	***p*-value**
Loose vs. Tackifier	143	97	0.05	0.042
Loose vs. Crimped	143	168	0.05	0.185
Tackifier vs. Crimped	97	168	0.05	0.002

Note: 1 lb. = 0.45 kilograms

The loose versus tackifier and the tackifier versus crimped straw hypothesis tests resulted in p-values that were less than the alpha value of 0.05. Therefore, the null hypothesis was rejected, resulting in the means between the two initial straw applications soil loss results not being equal. The loose versus crimped straw hypothesis test resulted in a p-value greater than 0.05. Therefore, the means between these two initial straw applications soil loss results was equal. The straw with tackifier soil loss for the initial product test was statistically different from the other two straw mulch applications under initial product testing.

4.4.7 Straw Summary

Three straw mulching applications were evaluated under the AU-ESCTF rainfall simulator to compare the erosion control practice performance to bare soil control tests on a sandy loam soil. The straw mulch was installed as a loose straw, loose straw with Tacking Agent 3, and crimped straw. The turbidity of the test plot runoff is summarized for each straw mulch application and the bare soil control tests in Figure 4.26 and the soil loss for each application is summarized Table 4.18.

TABLE 4.18: Straw Mulch Soil Loss Results

Product	Soil Loss (lb.)	Soil Loss Ratio	% Improvement
Bare Soil Control	738	-	-
Loose Straw	143	0.19	81%
Loose Straw with Tacking Agent 3	97	0.13	87%
Crimped Straw	169	0.23	77%

Note: 1 lb. = 0.45 kilograms

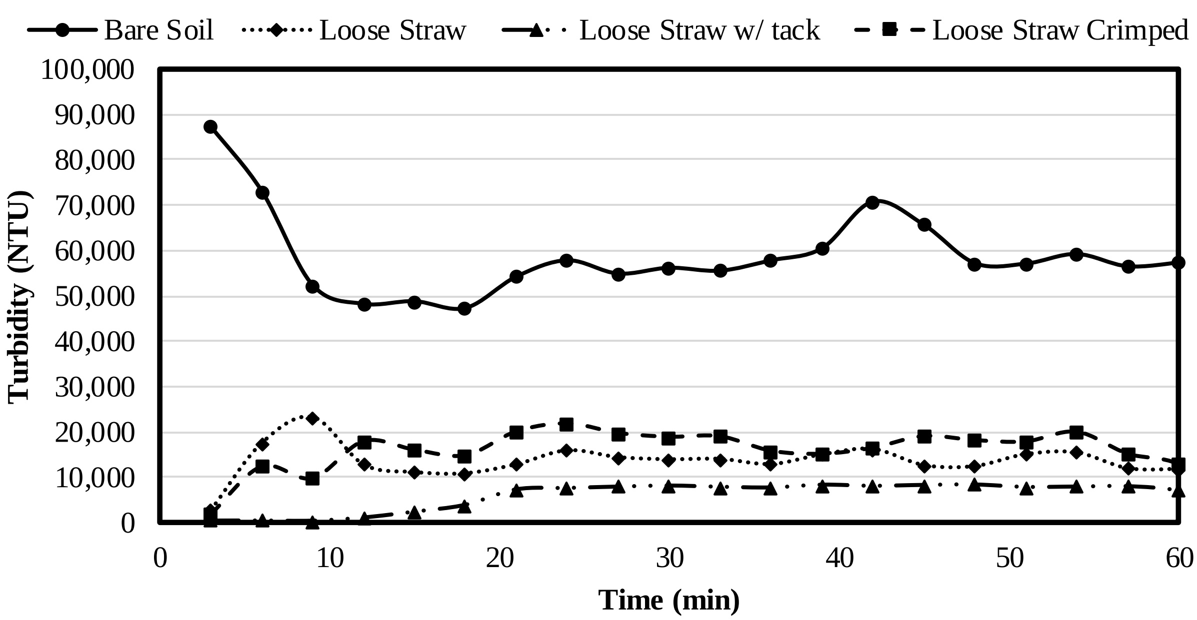


FIGURE 4.26: Straw Mulch Turbidity Summary.

All three of the straw applications showed substantial reduction in turbidity throughout the entire experiment. The best performing straw application under initial performance testing was the loose straw with Tacking Agent 3 with a total soil loss of 97 lb. (44 kg), which was an 87% improvement from bare soil conditions. The crimped straw was the worst performing straw mulch application under initial product performance testing. The crimped straw had a total soil loss of 169 lb. (76.6 kg), which was a 77% improvement from bare soil conditions. The test plot conditions following the initial product test is depicted in Figure 4.27.

(a) Bare soil

(b) Loose straw

(c) Loose straw with Tacking Agent 3

(d) Crimped straw

FIGURE 4.27: Straw Mulch Product Results.

The straw mulch applications and bare soil were exposed to a second rainfall event to evaluate the longevity performance of the erosion control applications. The soil loss results for the second rainfall event and the water quality curves are depicted in Table 4.19 and Figure 4.28.

TABLE 4.19: Straw Mulch Longevity Soil Loss

Product	Soil Loss (lb.)	Soil Loss Ratio	% Improvement
Bare Soil Control	611	-	-
Loose Straw	287	0.47	53%
Loose Straw with Tacking Agent 3	131	0.21	79%
Crimped Straw	82	0.13	87%

Note: 1 pound = 0.45 kilograms

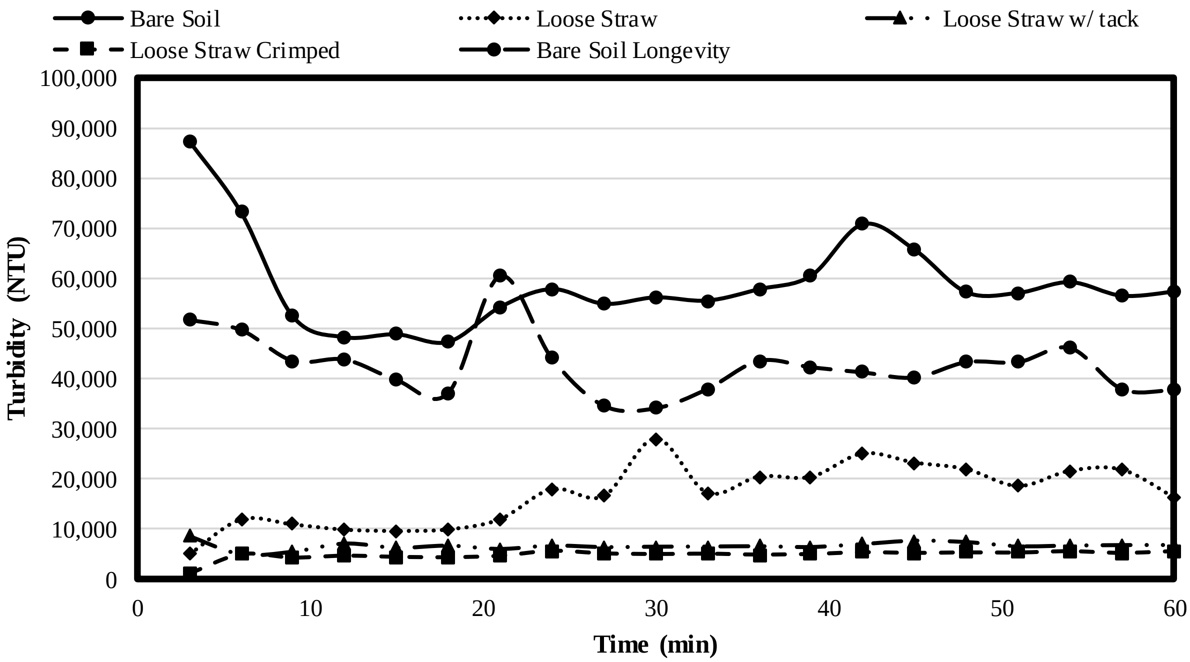


FIGURE 4.28: Straw Mulch Longevity Water Quality Results.

The longevity testing of the straw mulch applications resulted in different results from the initial product testing. Unlike in the initial test, the crimped straw was the best performing straw mulch application with a total soil loss of 82 lb. (37.2 kg), which is an 87% improvement from the longevity bare soil results. The crimped straw and the loose straw with Tacking Agent 3 had similar turbidity measurements throughout the duration of the longevity experiments. The loose straw was the worst performing straw mulch application with a total soil loss of 287 lb. (130.2 kg), which is a 53% improvement from bare soil conditions. The loose straw with Tacking Agent 3 did not perform as well under longevity testing as under initial product testing. The total soil loss for the loose straw with tackifier under longevity testing was 131 lb. (59.4 kg), which is a 79% improvement from the bare soil conditions. The reason for the drop off in performance of the loose straw with tackifier is likely caused by the tackifier being washed from the test plot. The crimped straw had an increased performance because the loose soil that was disturbed by the crimping process had been washed form the site and the voids caused by the crimper had been filled with sediment.

The initial and longevity soil loss results were combined to determine the overall effectiveness of each straw mulch application. The soil loss data for the combined results is depicted in Table 4.20.

TABLE 4.20: Combined Straw Mulch Results

Straw Application	Combined Soil Loss (lb.)	Soil Loss Ratio	% Improvement
Bare Soil	1,349	-	-
Loose Straw	430	0.32	68%
Loose Straw w/ Tackifier	228	0.17	83%
Crimped Straw	251	0.19	81%

Note: 1 lb. = 0.45 kilograms

The combination of the initial and longevity results shows that anchoring straw reduces the amount of erosion. The loose straw with Tacking Agent 3 was the best performing straw mulch practice with an 83% improvement from the bare soil conditions. The crimped straw was the second best straw application with an 81% improvement from bare soil conditions. The crimped straw and loose straw with Tacking Agent 3 were similar in performance with only a 23 lb. (10.4 kg) difference in combined soil loss. The loose straw application resulted in a 68% improvement from bare soil conditions. The results found in this study prove that anchored straw applications provided the greatest erosion reduction occurring on steep slopes.

4.5 HYDRAULIC MULCH RESULTS

At the conclusion of straw mulch testing, the rainfall simulator slope was rebuilt and a new loam soil was used for constructing the slope to meet ASTM D6459-19. The loam soil was then used to determine the performance of three hydraulic mulch products as compared to bare soil control tests. The three types of hydraulic mulches were Eco-Fibre plus Tackifier, Soil Cover Wood Fiber with Tack, and Terra-Wood with Tacking Agent 3. The data collected for each product was used to calculate the cover-factor (*C*-factor) of the product. The test procedures used for application and testing of the hydraulic mulches are defined in section 3.4 and 3.5.

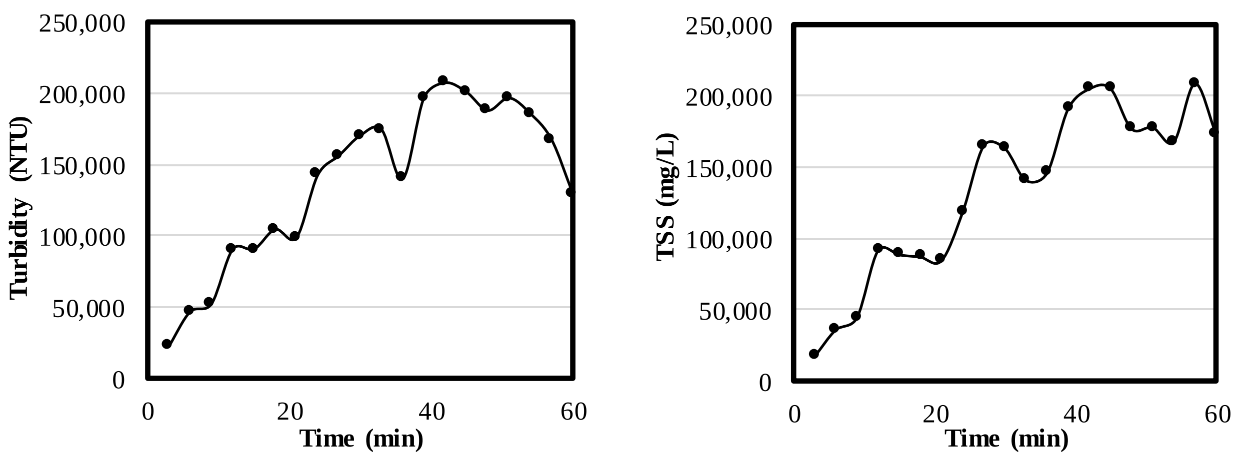
4.5.1 Loam Bare Soil Control

A bare soil control test was performed for every three hydraulic mulch tests to determine the RUSLE K-factor of the soil as well as to evaluate the effectiveness of the erosion control products. The three hydraulic mulch tests performed for the hydraulic mulches are summarized in Table 4.21 and Figure 4.29.

TABLE 4.21: Loam Bare Soil Control Results

Test Parameters	Test 1	Test 2	Test 3	Average
Rainfall Depth (in.)	4.05	4.07	4.03	4.05
Compaction (%)	89.61	89.27	86.83	88.40
Moisture Content (%)	23.86	20.01	19.33	21.07
2 in. per hr Soil Loss (lb.)	54	11.1	65	43.4
4 in. per hr Soil Loss (lb.)	683	704	938	775
6 in. per hr Soil Loss (lb.)	1,509	1,689	1,347	1,515
Total Collected Sediment (lb.)	**2,246**	**2,404**	**2,350**	**2,333**

Note: 1 inch = 25.4 millimeters
1 pound = 0.45 kilograms



(a) Turbidity (b) TSS

FIGURE 4.29: Average Bare Soil Water Quality Results.

All three of the bare soil control tests had similar results. The average soil loss for the 2 in. per hr (51 mm per hr) rainfall intensity was 43 lb. (19.5 kg), while the 4 in. per hr (102 mm per hr) rainfall intensity had an average soil loss of 775 lb. (352 kg). There was a large increase in soil loss between the 2 and 4 in. per hr (51 and 102 mm per hr) rainfall intensities. This is evident when reviewing the turbidity and TSS data. The 2 in. per hr (51 mm per hr) rainfall intensity water quality measurements gradually increases, but when the 4 in. per hr (102 mm per hr) rainfall intensity started, the turbidity and TSS values increased quickly. The average total soil loss for the loam soil was 2,333 lb. (1,058 kg), which is substantially more soil loss than the sandy loam soil. The performance of the loam soil under bare soil control conditions is depicted in Figure 4.30.

(a) Pre-test (b) 20 minute

(c) 40 minute (d) Post-test

FIGURE 4.30: Loam Bare Soil Test Results.

4.5.1.1 *K-factor Results*

The bare soil control results were used to calculate the *K*-factor for the loam soil. The soil loss and the rainfall depth following each twenty-minute testing segment was used to calculate the *K*-factor. The *K*-factor was later used to determine the *C*-factor for each erosion control product. The RUSLE values used to determine the *K*-factor for the three bare soil control tests are summarized in Table 4.22.

TABLE 4.22: Bare Soil RUSLE Data

Bare Soil Control Test for each Product	Rainfall Intensity (in. per hr)	Cumulative *R*	Cumulative *A* (ton per acre)
Eco Fiber - Plus	2	12.01	3.66
	4	60.41	50.14
	6	188.88	152.85
Soil Cover	2	13.20	0.75
	4	64.23	47.88
	6	184.62	162.89
Terra-Wood	2	13.20	4.42
	4	61.54	68.25
	6	182.11	159.96

Note: 1 inch per hour = 25.4 millimeters per hour

This data was used to plot the soil loss (*A*) versus the *R*-factor. A linear equation was fitted to the data set and the equation was used to calculate the soil loss for the theoretical *R*-factor value of 182.02. The theoretical *R*-factor was calculated using the drop size distribution data collected using the flour pan method in section 3.2.1. The linear trend line and equation are depicted in Figure 4.31.

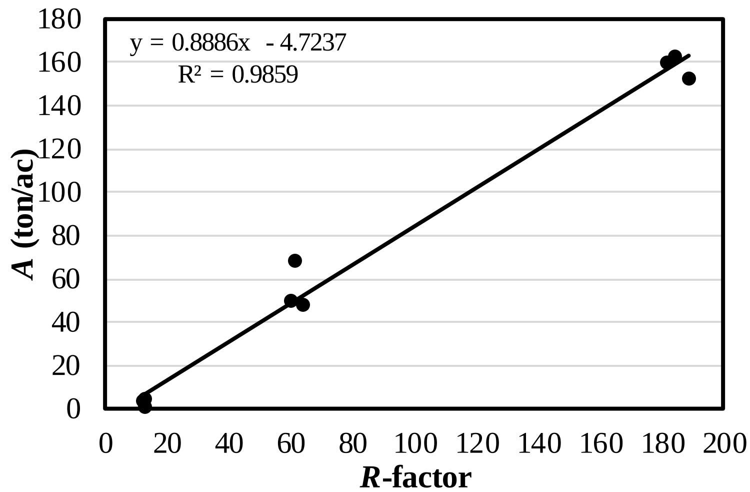


FIGURE 4.31: *K*-Factor Regression Equation.

The soil loss value that coordinates with the theoretical *R*-factor of 182.02 on the linear regression equation was 159.21 ton per acre (357 t/ha). The RUSLE equation was used to quantify the *K*-factor using the data shown in Table 4.23.

TABLE 4.23: *K*-factor Calculations

A =	159.21
Theoretical *R* =	182.02
LS =	2.86
C =	1.0
P =	1.0
***K* =**	**0.311**

Since the test plot is bare soil, the *C*-factor and *P*-factor are 1.0. The *K*-factor of the loam soil determined for the hydraulic mulch bare soil control tests was 0.31.

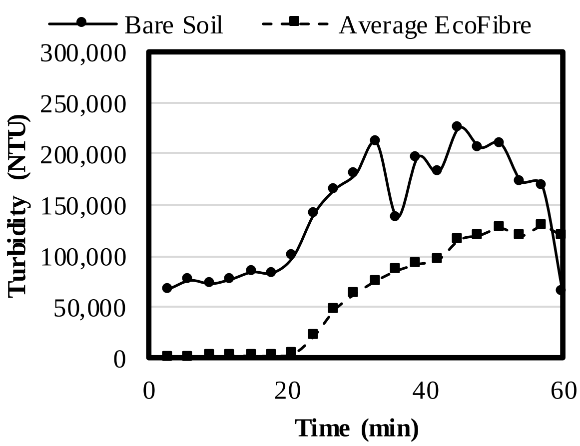
4.5.2 Eco-Fibre plus Tackifier

Profile Products Eco-Fibre plus Tackifier (Eco-Fibre) is a hydraulic mulch product consisting of 85% thermally refined wood fibers, 3% polymer based tackifier, and 12% moisture content. Eco-Fibre's manufacturer data sheet can be found in Appendix B. The product was installed on the test slope at an application rate of 2,500 lb. per acre (2,802 kg per ha). Eco-Fibre was evaluated three times under rainfall simulation and compared to a bare soil control test. The test results for the Eco-Fibre hydraulic mulch is summarized in Table 4.24 and Figure 4.32.

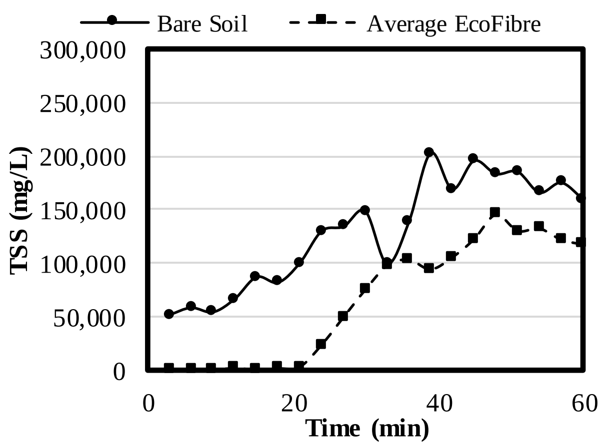
TABLE 4.24: Eco-Fibre plus Tackifier Test Results

Test Parameters	Bare Soil Control	Test 1	Test 2	Test 3	Average
Rainfall Depth (in.)	4.05	4.10	4.04	3.97	4.04
Compaction (%)	89.61	85.81	87.97	88.17	87.32
Moisture Content (%)	23.86	26.07	16.65	22.75	21.82
2 in. per hr Soil Loss (lb.)	54	2.43	3.57	4.36	3.45
4 in. per hr Soil Loss (lb.)	683	356	377	279	337
6 in. per hr Soil Loss (lb.)	1,509	734	1,220*	700	717
Total Collected Sediment (lb.)	**2,246**	**1,092**	**1,601***	**984**	**1,038**

Note: *A storm event occurred following the test removing the slope cover and washing additional soil into the catch basin affecting the 6 in. per hr (152 mm per hr) soil loss.
1 inch = 25.4 millimeters
1 pound = 0.45 kilograms



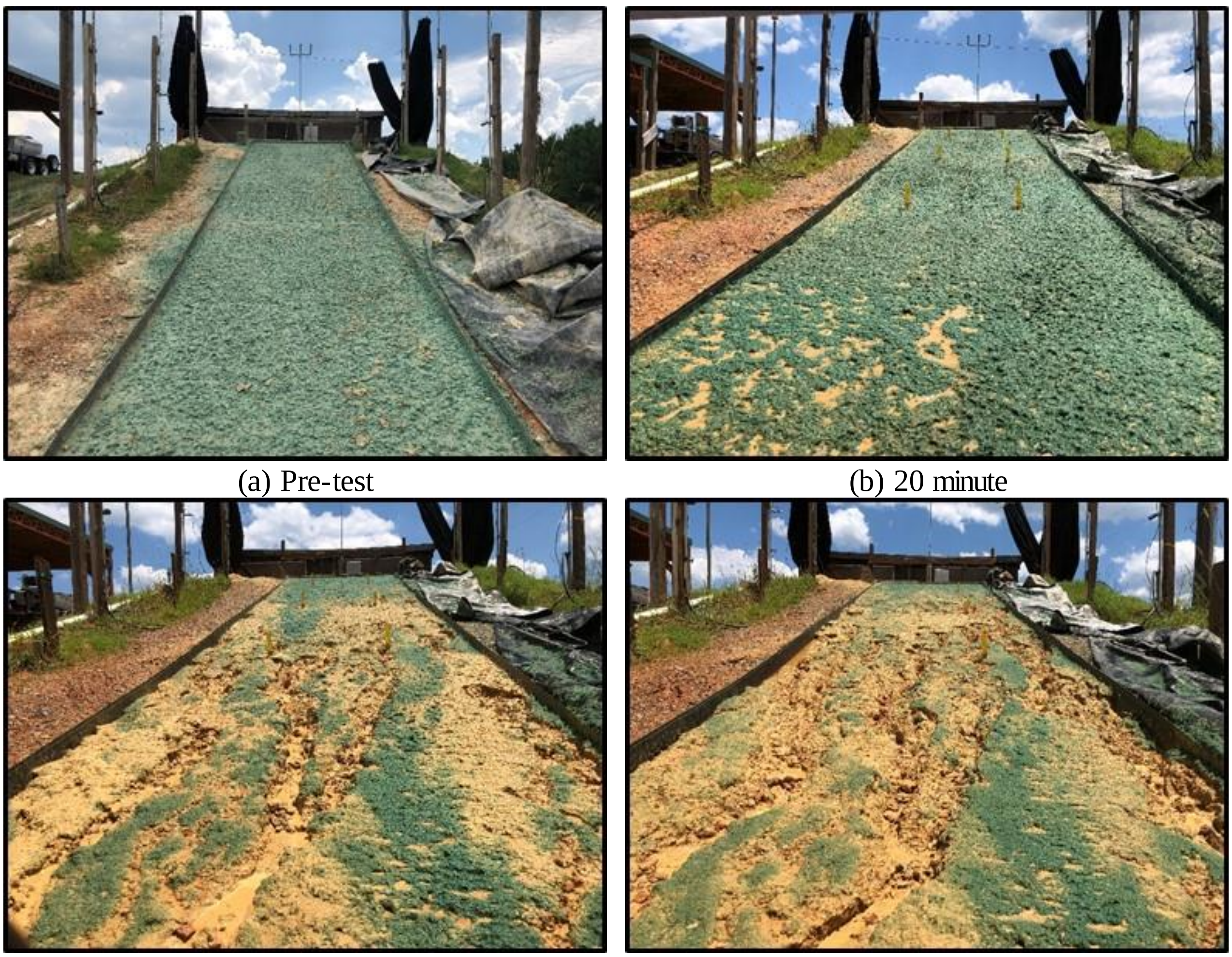
(a) Turbidity



(b) TSS

FIGURE 4.32: Eco-Fibre plus Tackifier Water Quality Results.

The Eco-Fiber plus Tackifier had an average soil loss of 1,038 lbs. (471 kg), while the bare soil control test had a total soil loss of 2,246 lb. (1,019 kg). The installation of the hydraulic mulch resulted in a 54% improvement from the bare soil conditions. The hydraulic mulch was effective during the 2 in. per hr (51 mm per hr) rainfall intensity. The turbidity and TSS measurements were near zero for the first 20 minutes of the experiment, but soon after the 4 in. per hr (102 mm per hr) rainfall intensity started, the hydraulic mulch began to wash from the test slope. Therefore, the turbidity and TSS measurements substantially increased. Even though a large portion of the hydraulic mulch was washed from the test plot, the turbidity and TSS measurements were still less than the corresponding bare soil conditions. Following Eco-Fibre test 2, a natural rainfall event occurred, removing the test plot cover and causing erosion. The 6 in. per hr (152 mm per hr) soil loss data was effected by the erosion that occurred from the post-test rainfall event. The performance of the hydraulic mulch is depicted in Figure 4.33.



(a) Pre-test (b) 20 minute (c) 40 minute (d) Post-test

FIGURE 4.33: Eco-Fibre plus Tackifier Test Photos.

4.5.2.1 Eco-Fibre plus Tackifier C-factor

Following the completion of the three Eco-Fibre plus Tackifier, tests and a bare soil control test, the *C*-factor for the product was calculated using the soil loss, rain gauge measurements, and the drop size distribution data. Before the *C*-factor could be calculated, the *K*-factor for the corresponding bare soil control test must be determined. The soil loss (*A*) and *R*-factor for each rainfall intensity were plotted to determine a linear equation. The K-factor calculation of the bare soil control is depicted in Figure 4.34.

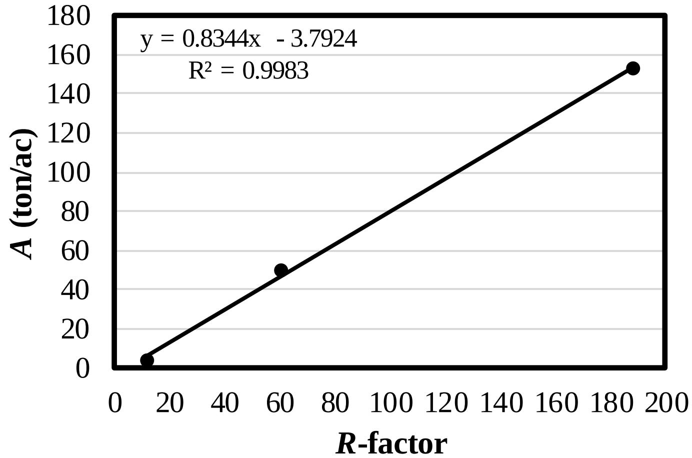


FIGURE 4.34: Eco-Fibre *K*-Factor Trendline Equation from Bare Soil Control Test.

The three data points were the resulting values from the 2, 4, and 6 in. per hr (52, 102, and 152 mm per hr) rainfall intensities for *A* and *R*-factor. The linear equation that best fits the three data points was used to determine the soil loss that corresponds with the theoretical *R*-factor. The RUSLE equation was solved for the *K*-factor. Since the bare soil control test was used to calculate the *K*-factor, the *C*-factor and *P*-factor were both 1.0 and an *LS*-factor of 2.86. The *A*-factor calculated from the regression equation was 148.08 tons per acre (332 t/ha) for a theoretical *R*-factor of 182.02. The resulting *K*-factor for the Eco-Fibre plus Tackifier tests was 0.29.

Once the *K*-factor for the Eco-Fibre test group was calculated, the product *C*-factor was determined. The rainfall depth and soil loss data collected for each rainfall intensity was used to calculate the *A*-factor for each product test that corresponds with the theoretical *R*-factor of 182.02. The Eco-Fibre tests resulted in *A*-factors of 74.34, 180.95, and 66.96 tons per acre (166.64, 405.63, and 150.10 t/ha). The *C*-factor for the product was calculated using two different procedures. The first method plotted the incremental *C*-factor from actual soil loss versus the incremental *R*-factor, which is depicted in Figure 4.35.

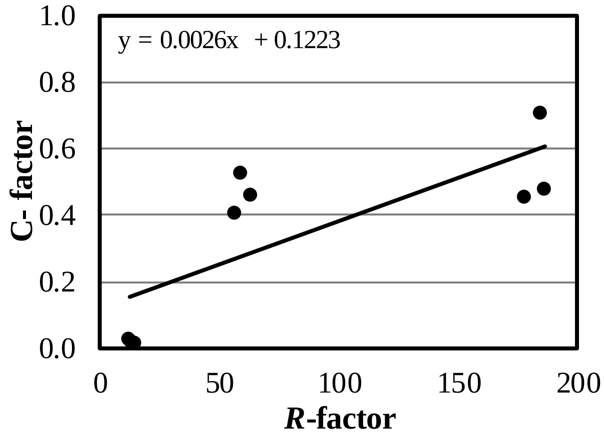


FIGURE 4.35: Eco-Fibre *C*-factor Equation.

A linear trendline was fit to the data points from the 2, 4, and 6 in. per hr (51, 102, and 152 mm per hr) rainfall intensities. The *C*-factor corresponding with the theoretical *R*-factor of 182.02 was calculated using the trendline equation. The resulting *C*-factor for this method was 0.596. Since the 2 in. per hr (51 mm per hr) *C*-factor was much smaller than the 4 and 6 in. per hr (102 and 152 mm per hr) *C*-factors, a statistical analysis was performed to determine if the mean of the *C*-factors were equal. Hypothesis tests were performed on the *C*-factor data for each rainfall intensity for the Eco-Fibre test results in section 4.5.2.2. Since the means of the 2-4 in. per hr (51-102 mm per hr) and 2-6 in. per hr (51-152 mm per hr) hypothesis tests were not equal, the 2 in. per hr (51 mm per hr) *C*-factor value was not used in this method to determine the product *C*-factor. The 2 in. per hr (51 mm per hr) *C*-factor was negligible compared to the 4 and 6 in. per hr (102 and 152 mm per hr) *C*-factors and therefore was biasing in the regression equation. The *C*-factor calculations without the 2 in. per hr (51 mm per hr) data is depicted in Figure 4.36.

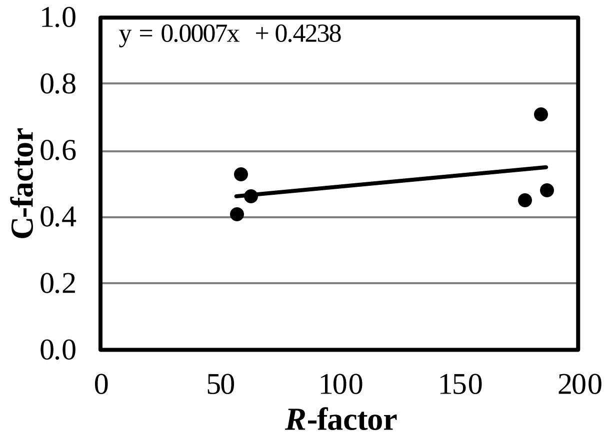


FIGURE 4.36: Eco-Fibre *C*-factor Equation without 2 in. per hr Data.

Since the slope of the trendline is nearly zero, then the *C*-factor between the 4 and 6 in. per hr (102 and 152 mm per hr) rainfall events provide a more uniform *C*-factor between storm events, which should be achieved since *C*-factor is not considered storm dependent. The regression equation was used to calculate average *C*-factor for all three experiments using the theoretical *R*-factor of 182.02. The *C*-factor using the first method was 0.551. The second method averaged the *A*-factors from the three Eco-Fibre experiments and inserted the average *A*-factor into the RUSLE equation. The *C*-factor calculation for the second method is depicted in Table 4.25.

TABLE 4.25: Eco-Fibre RUSLE Calculations

A =	83.42
Theoretical *R* =	182.02
LS=	2.86
K =	0.29
P =	1.0
C =	**0.5493**

The resulting *C*-factor from the second method was 0.549. Therefore, the two *C*-factor calculation procedures used resulted in *C*-factor values of 0.551 and 0.549 for the Eco-Fibre with Tackifier hydraulic mulch. When using the 2 in. per hr (51 mm per hr) *C*-factor data for the first method, the resulting *C*-factor was 0.596. When the 2 in. per hr (51 mm per hr) *C*-factor data was not included, the *C*-factor value was nearly equal to the second method. Therefore, the 2 in. per hr (51 mm per hr) *C*-factor data skews the data resulting in inaccurate results.

4.5.2.2 Eco-Fibre plus Tackifier Statistical Analysis

Three hypothesis tests were performed on the incremental *C*-factor calculated for the three Eco-Fibre plus Tackifier experiments. The three hypothesis tests compared the 2-4 in. per hr (51-102 mm per hr), 2-6 in. per hr (51-152 mm per hr), and the 4-6 in. per hr (102-152 mm per hr) rainfall intensity *C*-factor results to determine if the means of the resulting *C*-factors were equal. If the two-tail *p*-value was less than the alpha value of 0.05, then the null hypothesis was rejected, concluding that the means of the two rainfall intensity *C*-factors are not equal. The hypothesis used to evaluate whether the 2, 4, and 6 in. per hr (51, 102, and 152 mm per hr) *C*-factors were equal for all of the erosion control practices is depicted in Equation 4.3 and 4.4. The null hypothesis of this experiment was that the two sample means were statistically equal, while the alternative hypothesis was that the means were not equal. If the hypothesis test resulted in a *p*-value less than 0.05, then the null hypothesis was rejected. The results from the three hypothesis tests for the Eco-Fibre plus Tackifier are depicted in Table 4.26.

$$H_0: \mu_1 = \mu_2 \tag{4.3}$$

where,

H_0 = null hypothesis
μ_1 = variable one mean
μ_2 = variable two mean

$$H_1: \mu_1 \neq \mu_2 \tag{4.4}$$

where,

H_1 = alternative hypothesis
μ_1 = variable one mean
μ_2 = variable two mean

TABLE 4.26: Eco-Fibre plus Tackifier Hypothesis Test Results

Hypothesis Test	Intensity 1 Mean	Intensity 2 Mean	Alpha	*p* (two-tail)
2-4 in. per hr	0.0213	0.4655	0.05	0.006
2-6 in. per hr	0.0213	0.5456	0.05	0.023
4-6 in. per hr	0.4655	0.5456	0.05	0.432

The 2-4 in. per hr (51-102 mm per hr) and 2-6 in. per hr (51-152 mm per hr) hypothesis tests resulted in *p*-values less than the alpha value of 0.05. Therefore, the null hypothesis was rejected, concluding that the means, which represent the RUSLE *C*-values calculated for each intensity, are not equal. The 4-6 in. per hr (102-152 mm per hr) hypothesis test resulted in a *p*-value greater than 0.05, concluding that the null hypothesis was accepted and that the means are equal.

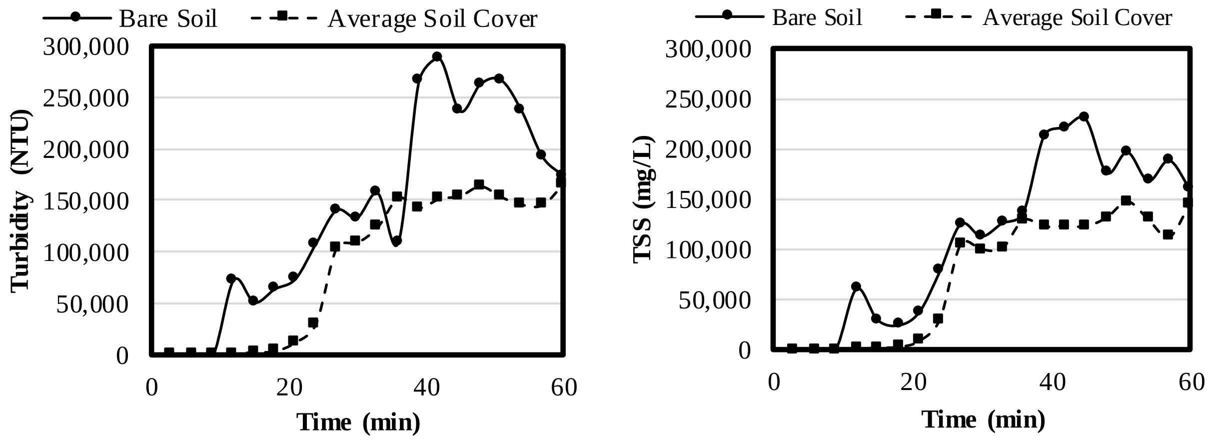
4.5.3 Soil Cover Wood Fiber with Tack

Soil Cover Wood Fiber with Tack (Soil Cover) is a hydraulic mulch consisting of 85% thermally refined wood fibers, 3% polymer based tackifier, and 12% moisture content. Soil Covers manufacturer data sheet can be found in Appendix B. Soil Cover was evaluated three times at an application rate of 2,500 lb. per acre (2,802 kg per ha). All three of the hydraulic mulch experiments were compared to a bare soil control test. The Soil Cover test results are summarized in Table 4.27 and Figure 4.37.

TABLE 4.27: Soil Cover Wood Fiber with Tack Test Results

Test Parameters	Bare Soil Control	Test 1	Test 2	Test 3	Average
Rainfall Depth (in.)	4.07	4.01	4.05	4.07	4.04
Compaction (%)	89.27	86.29	88.39	87.98	87.55
Moisture Content (%)	20.01	18.18	21.27	21.73	20.39
2 in. per hr Soil Loss (lb.)	11.1	0	6.60	1.40	2.67
4 in. per hr Soil Loss (lb.)	704	304	410	433	382
6 in. per hr Soil Loss (lb.)	1,689	841	634	861	779
Total Collected Sediment (lb.)	**2,405**	**1,145**	**1,051**	**1,296**	**1,164**

1 inch = 25.4 millimeters
1 pound = 0.45 kilograms



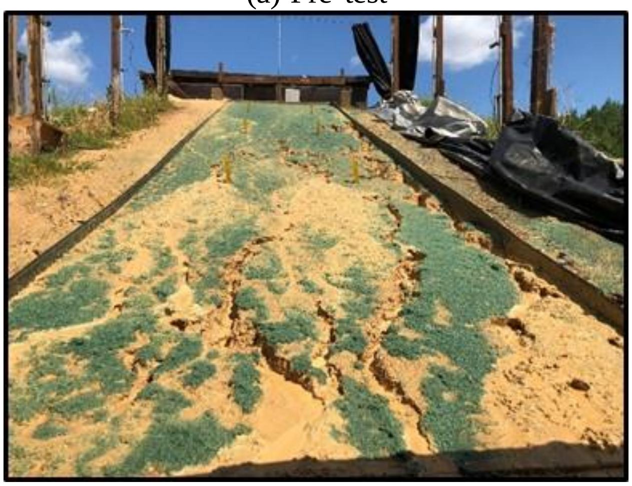
(a) Turbidity (b) TSS

FIGURE 4.37: Soil Cover Wood Fiber with Tack Water Quality Results.

Soil Cover had an average total soil loss of 1,164 lb. (528 kg), while the bare soil control test had an average soil loss of 2,405 lb. (1,091 kg). The hydraulic mulch had a 52% reduction in soil loss from the bare soil conditions. Soil Cover was most effective during the 2 in. per hr (51 mm per hr) rainfall event with an average soil loss of 2.67 lb. (1.21 kg) and low turbidity and TSS measurements. However, soon after the 4 in. per hr (102 mm per hr) rainfall intensity started, the hydraulic mulch began to wash off the test plot. The turbidity and TSS measurements substantially increased during the beginning of the 4 in. per hr (102 mm per hr) rainfall intensity as the hydraulic mulch was washed from the test plot. Once some of the hydraulic mulch had washed off the test plot, the soil loss greatly increased from 2.67 lb. (1.21 kg) during the 2 in. per hr (51 mm per hr) test segment to an average of 382 lb. (173 kg) of soil loss during the 4 in. per hr (102 mm per hr) test segment. The performance of the Soil Cover Wood Fiber with Tack is depicted in Figure 4.38.

(a) Pre-test

(b) 20 minute



(c) 40 minute

(d) Post-test

FIGURE 4.38: Soil Cover Wood Fiber with Tack Test Photos.

4.5.3.1 Soil Cover Wood Fiber with Tack C-factor

Once the three Soil Cover tests and the bare soil control test data had been collected, the soil loss, rainfall depth, and drop size distribution data were used to calculate the *C*-factor of the hydraulic mulch. Prior to calculating the Soil Cover *C*-factor, the *K*-factor for the corresponding bare soil control test was determined. The *K*-factor was calculated by plotting the *A*-factor in tons/acre vs. the *R*-factor as depicted in Figure 4.39.

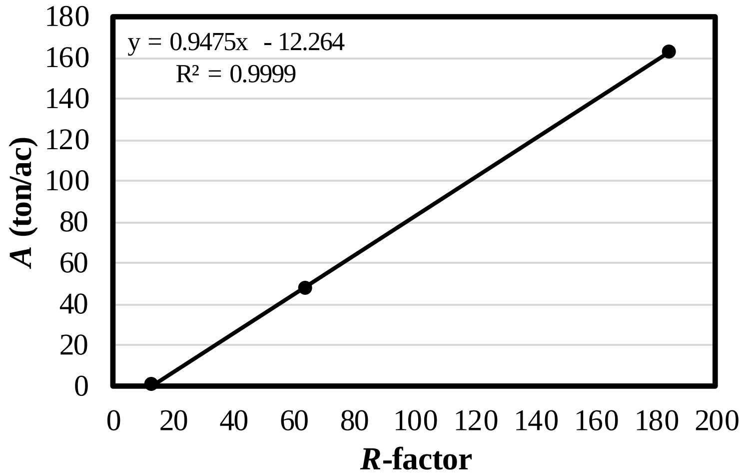
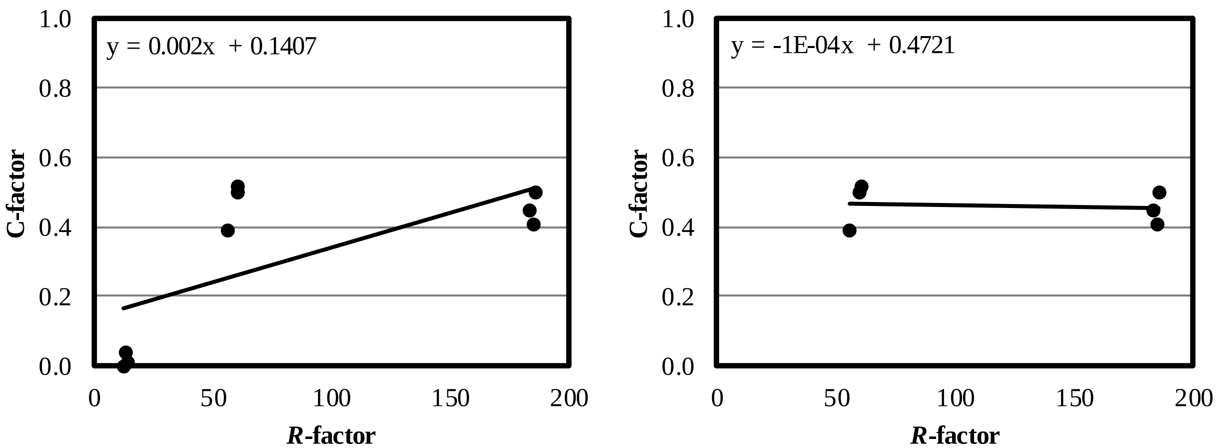


FIGURE 4.39: Soil Cover *K*-factor Trendline Equation.

The linear trendline equation was fitted to the three data points. The *A*-factor that corresponds with the theoretical *R*-factor was equal to 160.21 tons per acre (359 t per ha). The RUSLE Equation was used to calculate the *K*-factor using the theoretical *R*-factor, an *LS*-factor of 2.86, *C*-factor of 1.0, and the *P*-factor of 1.0. The resulting *K*-factor for the Soil Cover tests is 0.33.

The cumulative *A*-factor for each of the three Soil Cover rainfall experiments was 77.93, 71.50, and 88.18 tons per acre (174.7, 160.3, and 197.7 metric t/ha). There were two methods used to calculate the *C*-factor of the Soil Cover hydraulic mulch. The first method plotted the incremental *C*-factor calculated using the actual soil loss for each rainfall intensity versus the incremental *R*-factor and is depicted in Figure 4.40. Three hypothesis tests were performed on the *C*-factor data to determine if the *C*-factor means were equal in section 4.5.3.2. The hypothesis tests concluded that the means were not equal for all three intensities. Since the 4-6 in. per hr (102-152 mm per hr) *C*-factor means were equal, but the 2 in. per hr (51 mm per hr) *C*-factor mean was not equal to the 4 or 6 in. per hr (102 or 152 mm per hr) *C*-factors. Since the 2 in. per hr (51 mm per hr) *C*-factor mean was not equal, the data was excluded from Figure 4.39 because it would skew the results of the trend line equation.



(a) Full test *C*-factor (b) Without 2 in. per hr *C*-factor

FIGURE 4.40: Soil Cover *C*-factor Equation.

The regression equation from Figure 4.40(b) was used to calculate the *C*-factor that corresponded with the theoretical *R*-factor of 182.02. The *C*-factor calculated for the Soil Cover hydraulic mulch was 0.454.

The second method used to calculate the *C*-factor for the Soil Cover hydraulic mulch averaged the cumulative *A*-factor for each rainfall experiment. The average A-factor along with the RUSLE variables were used to calculate the *C*-factor as depicted in Table 4.28.

TABLE 4.28: Soil Cover RUSLE Equation

A =	79.21
Theoretical *R* =	182.02
LS =	2.86
K =	0.33
P =	1.0
***C* =**	**0.4592**

The *C*-factor calculated using the second method was 0.459. Therefore, the two methods to calculate the *C*-factor of the Soil Cover Wood Fiber with Tack was 0.454 and 0.459.

4.5.3.2 Soil Cover Wood Fiber with Tack Statistical Analysis

Three hypothesis tests were performed on the incremental *C*-factors calculated for the three Soil Cover experiments. The three hypothesis tests compared the 2-4 in. per hr (51-102 mm per hr), 2-6 in. per hr (51-152 mm per hr), and 4-6 in. per hr (102-152 mm per hr) rainfall intensity *C*-factors to determine if the means of the each intensities *C*-factors were equal. If the two-tail *p*-value was less than the alpha value of 0.05, then the null hypothesis was rejected, concluding that the means of the two rainfall intensity *C*-factors are not equal. The results from the three hypothesis tests for the Soil Cover experiments is depicted in Table 4.29.

TABLE 4.29: Soil Cover Hypothesis Test Results

Hypothesis Test	Intensity 1 Mean	Intensity 2 Mean	Alpha	*p* (two-tail)
2-4 in. per hr	0.0144	0.4673	0.05	0.008
2-6 in. per hr	0.0144	0.4528	0.05	0.001
4-6 in. per hr	0.4673	0.4528	0.05	0.773

The 2 to 4 in. per hr (51 to 102 mm per hr) and 2 to 6 in. per hr (51 to152 mm per hr) hypothesis tests resulted in *p*-values less than the alpha value of 0.05. Therefore, the null hypothesis was rejected, concluding that the means are not equal. The 4 to 6 in. per hr (102 to 152 mm per hr) hypothesis test resulted in a *p*-value greater than 0.05, concluding that the null hypothesis was accepted and that the means are equal. The 2 in. per hr (51 mm per hr) *C*-factors were much smaller than the 4 and 6 in. per hr (102 and 152 mm per hr) *C*-factors, which corresponds with the results of the hypothesis tests.

4.5.4 Terra-Wood with Tacking Agent 3

Terra-Wood with Tacking Agent 3 (Terra Wood) is a hydraulic mulch composed of 97% thermally processed wood fibers and 3% polymer based tackifier. Terra-Woods manufacturer data sheet can be found in Appendix B. The hydraulic mulch was installed at an application rate of 2,500 lb. per acre (2,802 kg per ha) and allowed to cure for a minimum of 24 hours prior to rainfall simulation testing. The hydraulic mulch was evaluated with three rainfall simulation tests and compared to the performance of a bare soil control test. The test results for the hydraulic mulch is depicted in Table 4.30 and Figure 4.41.

TABLE 4.30: Terra-Wood with Tacking Agent 3 Test Results

Test Parameters	Bare Soil Control	Test 1	Test 2	Test 3	Average
Rainfall Depth (in.)	4.03	4.07	4.07	4.03	4.06
Compaction (%)	86.83	88.36	87.00	87.04	87.47
Moisture Content (%)	19.33	21.22	19.79	17.64	19.55
2 in. per hr Soil Loss (lb.)	65	3.98	3.85	14.8	8.54
4 in. per hr Soil Loss (lb.)	938	296	686	483	491
6 in. per hr Soil Loss (lb.)	1,347	679	881	832	832
Total Collected Sediment (lb.)	**2,350**	**979**	**1,574**	**1,330**	**1,294**

Note: 1 inch = 25.4 millimeters
1 lb. = 0.45 kilograms

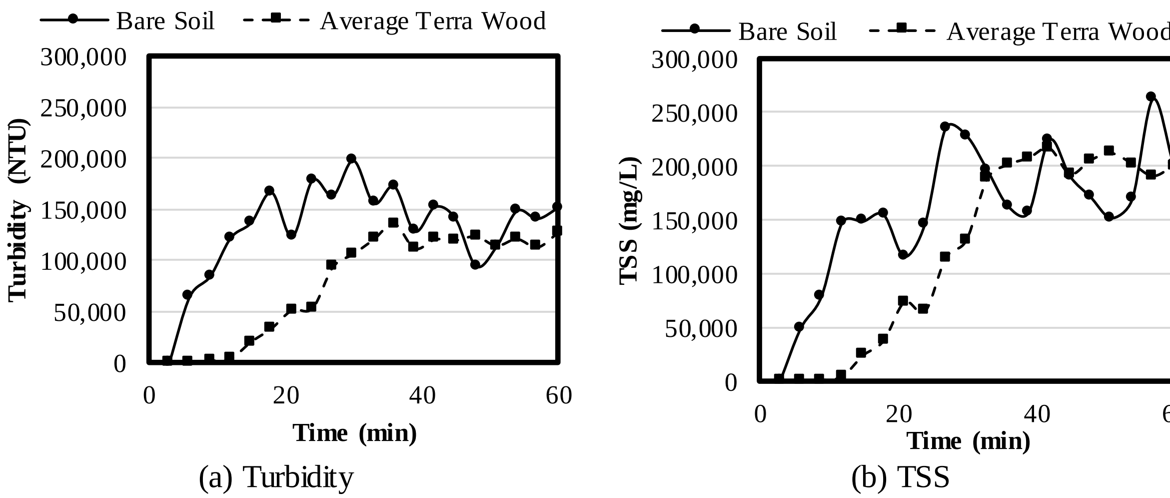
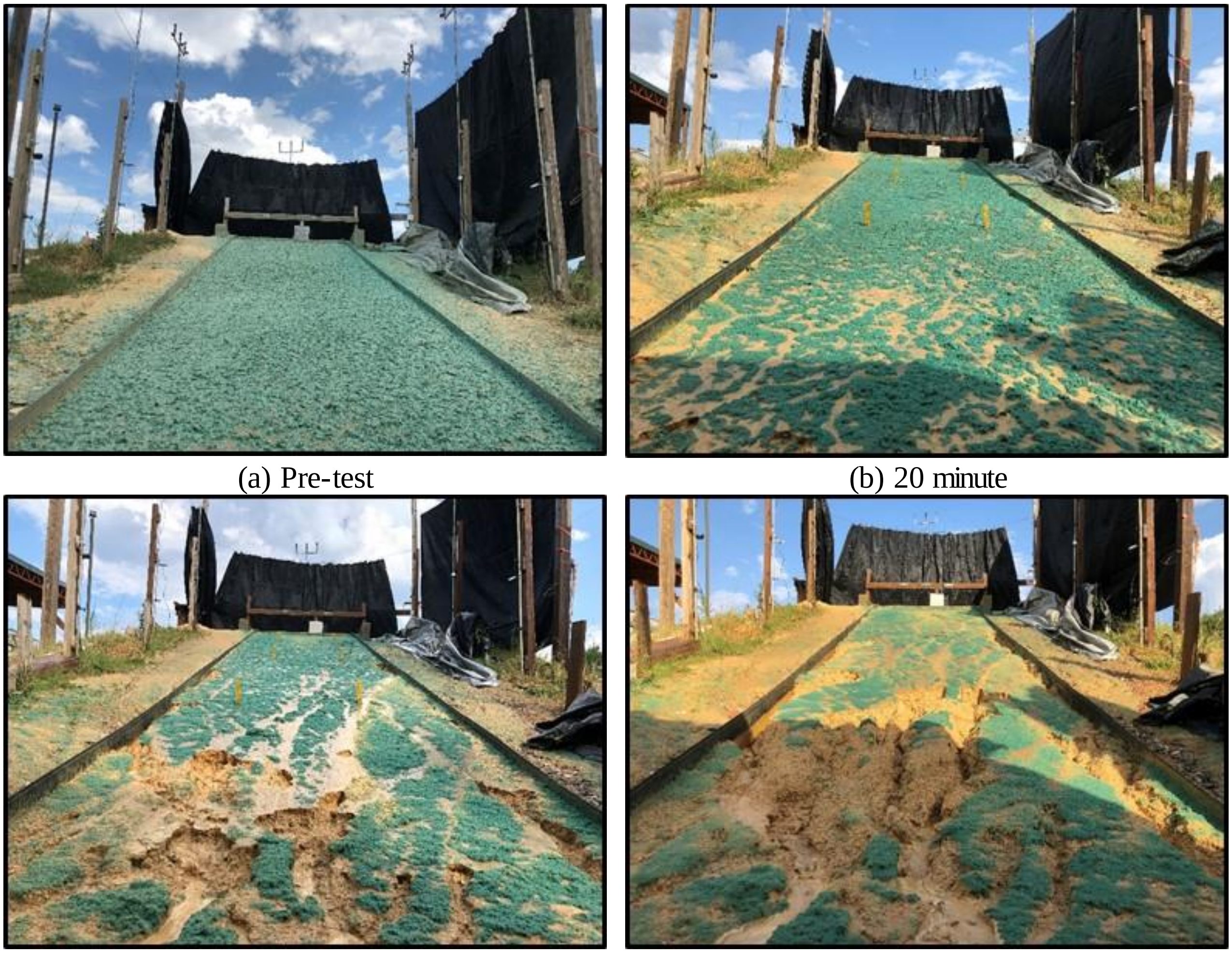


FIGURE 4.41: Terra-Wood with Tacking Agent 3 Water Quality Results.

Terra-Wood had an average soil loss of 1,294 lb. (587 kg), while the bare soil control test had a total soil loss of 2,350 lb. (1,066 kg). The hydraulic mulch reduced the amount of erosion occurring during the experiment by 45%. Similar to the other hydraulic mulches, Terra-Wood was effective during the 2 in. per hr (51 mm per hr) rainfall intensity with an average soil loss of 8.54 lb. (3.87 kg). However, once the rainfall intensity was increased to 4 in. per hr (102 mm per hr), the hydraulic mulch began to wash from the test plot. The soil loss increased from 8.54 lb. (3.87 kg) during the 2 in. per hr (51 mm per hr) rainfall intensity to 491 lb. (222.7 kg) during the 4 in. per hr (102 mm per hr) rainfall intensity. The turbidity and TSS measurements show that the concentration of the runoff substantially increased during the 4 in. per hr (102 mm per hr) rainfall intensity. The performance of the hydraulic mulch is depicted in Figure 4.42.



(a) Pre-test (b) 20 minute

(c) 40 minute (d) Post-test

FIGURE 4.42: Terra-Wood Test Photos.

4.5.4.1 Terra-Wood with Tacking Agent 3 C-factor

Following the completion of three Terra-Wood rainfall experiments and a bare soil control test, the *C*-factor for the hydraulic mulch was calculated. The rainfall depth following each rainfall intensity and the soil loss for each rainfall intensity was used to calculate the *K*-factor and *C*-factor of the hydraulic mulch. Prior to *C*-factor calculations, the *K*-factor was determined for the bare soil control test paired with the Terra-Wood product. The *K*-factor was calculated by plotting the incremental *A*-factor in tons/acre versus the incremental *R*-factor for the bare soil control test, which is depicted in Figure 4.43.

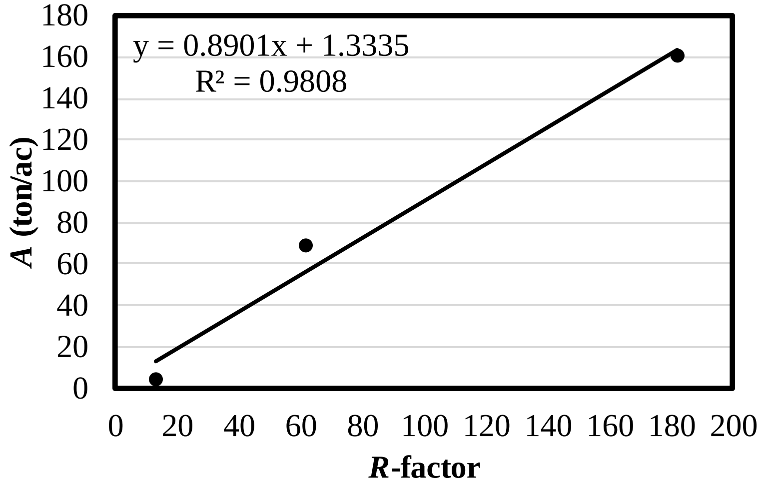
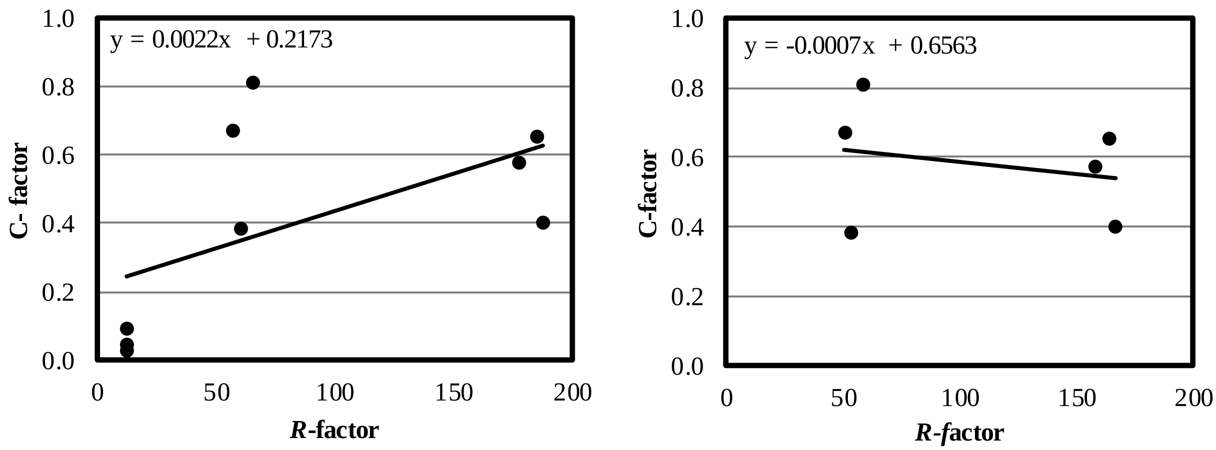


FIGURE 4.43: Terra-Wood with Tacking Agent 3 *K*-factor Equation.

A linear trendline was used to generate an equation that best fits the data points. The trendline equation used the theoretical *R*-factor to determine the corresponding A-factor in tons/acre. The *A*-factor was calculated to equal 163.35 tons per acre (366.2 t per ha). The *K*-factor was calculated using the RUSLE equation with the theoretical *R*-factor, *LS*-factor of 2.86, *C*-factor of 1.0, and *P*-factor of 1.0. The *K*-factor calculated for the Terra-Wood hydraulic mulch was 0.31.

Once the *K*-factor was calculated for the Terra-Wood experiments, the *C*-factor was calculated. The cumulative *A*-factor was determined for each of the three Terra-Wood experiments to be 66.64, 107.15, and 90.49 tons per acre (149.4, 240.2, and 202.9 t/ha). The first method used to calculate the Terra-Wood *C*-factor plotted the incremental *C*-factor vs. the incremental *R*-factor for each experiment as depicted in Figure 4.43. A statistical analysis was performed on the Terra-Wood *C*-factor data to determine if the *C*-factor means for all three-rainfall intensities were equal in section 4.5.4.2. Hypothesis tests concluded that the 2 in. per hr (51 mm per hr) *C*-factors were not equal to the 4 or 6 in. per hr (102 or 152 mm per hr) *C*-factors. Therefore, the 2 in. per hr (51 mm per hr) *C*-factor data was not included in Figure 4.44 because the data would skew the trendline equation and product *C*-factor results.



(a) Full test *C*-factor (b) Without 2 in. per hr *C*-factor

FIGURE 4.44: Terra-Wood *C*-factor Equation.

The 2 in. per hr (51 mm per hr) *C*-factor data was statistically different from the 4 and 6 in. per hr (102 and 152 mm per hr) *C*-factors. Therefore, the linear trendline from Figure 4.44(b) was best fit to the data set to create a trendline equation. The theoretical *R*-factor was used to determine the corresponding *C*-factor of the Terra-Wood results. The resulting *C*-factor for the Terra-Wood hydraulic mulch was 0.529.

The second method used to calculate the product *C*-factor used the average *A*-factor from all three Terra-Wood experiments in the RUSLE Equation. The data used to calculate the *C*-factor is depicted in Table 4.31.

TABLE 4.31: Terra-Wood RUSLE Equation

A =	88.09
Theoretical *R* =	182.02
LS =	2.86
K =	0.31
P =	1.0
***C* =**	**0.544**

The *C*-factor calculated using the RUSLE equation was 0.544. Therefore, the two separate calculation methods produced *C*-factors of 0.523 and 0.544 for the Terra-Wood with Tacking Agent 3.

4.5.4.2 Terra-Wood with Tacking Agent 3

Three hypothesis test were performed on the Terra-Wood with Tacking Agent 3 on the 2-4 in. per hr (51-102 mm per hr), 2-6 in. per hr (51-152 mm per hr), and the 4-6 in. per hr (102-152 mm per hr) rainfall intensity *C*-factors. The hypothesis test was used to determine if the means between all three of the rainfall intensity combinations were equal. If the *p*-value resulting from the hypothesis test was less than 0.05, then the null hypothesis was rejected resulting in the means not being equal. The results from the three hypothesis tests for the Terra-Wood experiments is depicted in Table 4.32.

TABLE 4.32: Terra-Wood Hypothesis Test Results

Hypothesis Test	Intensity 1 Mean	Intensity 2 Mean	Alpha	*p* (two-tail)
2-4 in. per hr	0.0520	0.6189	0.05	0.0468
2-6 in. per hr	0.0520	0.5410	0.05	0.0240
4-6 in. per hr	0.6189	0.5410	0.05	0.631

The 2 to 4 in. per hr (51-102 mm per hr) and 2 to 6 in. per hr (51 to 152 mm per hr) hypothesis tests resulted in *p*-values less than the alpha value of 0.05, concluding that the means for both tests were not equal. The 4 to 6 in. per hr (102 to 152 mm per hr) hypothesis test resulted in a *p*-value greater than the alpha value of 0.05, concluding that the means of the 4 in. per hr (102 mm per hr) and 6 in. per hr (152 mm per hr) *C*-factors are equal.

4.5.5 Hydraulic Mulch Summary

Three hydraulic mulch products were evaluated under the AU-ESCTF rainfall simulator on a loam soil. Each hydraulic mulch was paired with a bare soil control test to aid in the analysis of the product's *C*-factor. The three hydraulic mulches tested during this experiment was (1) Eco-

Fiber plus Tackifier, (2) Soil Cover Wood Fiber with Tack, and (3) Terra-Wood with Tacking Agent 3. Three initial product performance tests were completed for each product. The average soil loss results for each product is summarized in Table 4.33.

TABLE 4.33: Hydraulic Mulch Soil Loss Results

Product	Soil Loss (lb.)
Bare Soil Control	2,333
Eco-Fiber	1,038
Soil Cover	1,164
Terra-Wood	1,294

Note: 1 lb. = 0.45 kilograms

The Eco-Fiber hydraulic mulch resulted in the lowest average soil loss of 1,038 lb. (471 kg). The Terra-Wood hydraulic mulch experiments resulted in the highest average soil loss of 1,294 lb. (587 kg). The average turbidity curves for each product is depicted in Figure 4.45.

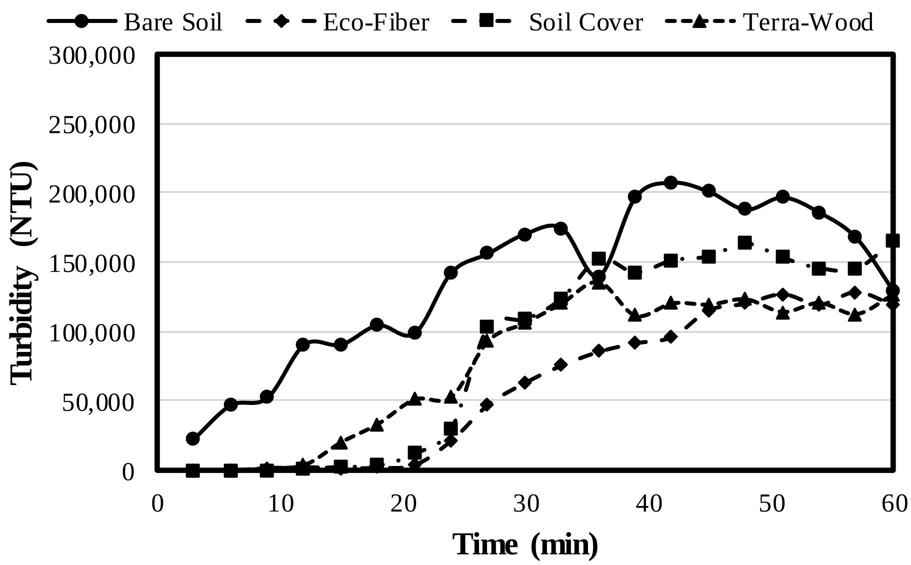


FIGURE 4.45: Hydraulic Mulch Turbidity Summary.

All three of the hydraulic mulches started with near zero turbidity measurements for the duration of the 2 in. per hr (51 mm per hr) rainfall intensity. The Terra-Wood hydraulic mulch began to have increased turbidity measurements around 15 minutes into the 2 in. per hr (51 mm per hr) rainfall intensity. All three of the hydraulic mulches substantially increased during the 4 in. per hr (102 mm per hr) rainfall intensity as the hydraulic mulch began to wash from the soil surface. The turbidity measurements leveled off at the end of the 4 in. per hr (102 mm per hr) rainfall intensity and continued throughout the 6 in. per hr (152 mm per hr) rainfall intensity. The Eco-Fiber product had the lowest turbidity measurements throughout the entirety of the experiment. Each of the products resulted in decreased turbidity measurements from the bare soil results; however, the turbidity measurements were still very high.

The *C*-factor for each hydraulic mulch was determined from the test specific soil loss and total rainfall depth. The resulting *C*-factor for each product is summarized in Table 4.34.

TABLE 4.34: Hydraulic Mulch *C*-Factor Results

Product	*K*-factor	Regression Method	RUSLE Method
Eco-Fiber	0.29	0.5512	0.5493
Soil Cover	0.33	0.4539	0.4592
Terra-Wood	0.31	0.5289	0.5437

The hydraulic mulch that resulted in the highest *C*-factor was the Soil Cover with a *C*-factor of 0.45. The worst performing hydraulic mulch was the Eco-Fiber mulch with a *C*-factor of 0.55. However, one of the Eco-Fiber experiments was exposed to excess rainfall due to the covers being blown off the test plot. Eco-Fibre had the lowest average soil loss between the three hydraulic mulch products, but resulted in the highest *C*-factor. The high *C*-factor was caused by the second Eco-Fibre test, which was exposed to excess rainfall. The exposure to excess rainfall resulted in around 900 lb. (408 kg) more soil loss than the other two Eco-Fibre experiments. If the second experiment was removed from the *C*-factor calculations, the Eco-Fibre *C*-factor would be 0.472 for the regression method and 0.465 for the RUSLE method. Another reason that caused the Eco-Fibre mulch to have the highest *C*-factor was that the bare soil control test paired with the product had the lowest soil loss and lowest *K*-factor.

4.6 EROSION CONTROL BLANKETS

Rainfall simulation testing at the AU-ESCTF was performed on the loam soil to evaluate the effectiveness of three erosion control blankets (ECB). Each ECB was compared to a bare soil control test to quantify the product effectiveness and to determine the product *C*-factor. The three ECBs tested were the American Excelsior Curlex I, North American Green S150, and East Coast Erosion ECX-2. The test procedures followed for the application and testing for the ECB are defined in section 3.4.5 and 3.5. The manufacturer product data sheets for the blankets is depicted in Appendix B.

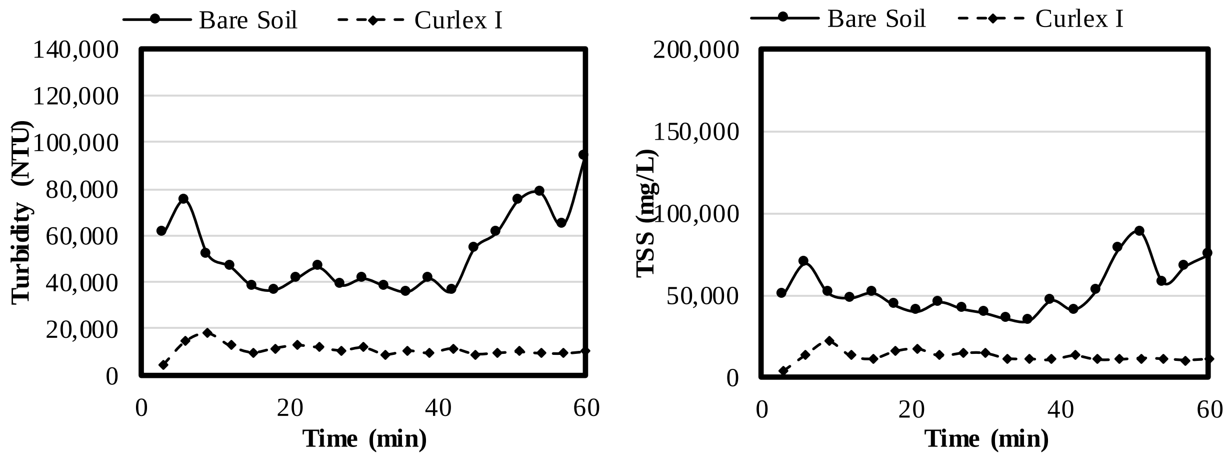
4.6.1 Curlex I

Three rainfall simulation experiments were performed on American Excelsior's Curlex I blanket. Curlex I is a single net excelsior blanket with a functional longevity of 12 months. The blanket has a photodegradable netting installed on the top of the blanket. Curlex I was installed following the manufacturer installation guidelines for trenching and anchoring. The ECB test results were compared to a bare soil control test, which are depicted in Table 4.35 and Figure 4.46.

TABLE 4.35: Curlex I Test Results

Test Parameters	Bare Soil Control	Test 1	Test 2	Test 3	Average
Rainfall Depth (in.)	4.08	4.05	4.07	4.12	4.08
Compaction (%)	89.54	89.22	89.95	88.23	89.13
Moisture Content (%)	21.33	18.39	17.73	19.80	18.64
2 in. per hr Soil Loss (lb.)	28.65	1.70	4.49	3.21	3.13
4 in. per hr Soil Loss (lb.)	651	15.84	25.16	18.25	19.75
6 in. per hr Soil Loss (lb.)	1,193	68.62	67.25	65.53	67.13
Total Collected Sediment (lb.)	**1,873**	**86.17**	**96.91**	**86.99**	**90.02**

Note: 1 inch = 25.4 millimeters
1 lb. = 0.45 kilograms



(a) Turbidity (b) TSS

FIGURE 4.46: Curlex I Water Quality Results.

The three Curlex I blanket experiments resulted in an average rainfall depth of 4.08 in. (104 mm), an average slope compaction rate of 89.13%, and average moisture content of 18.64%. The bare soil control test paired with the Curlex I blanket had a soil loss of 28.65 lb. (13 kg) during the 2 in. per hr (51 mm per hr) rainfall intensity while the excelsior blanket only allowed an average of 3.13 lb. (1.42 kg) of soil loss. The total soil loss for the bare soil control test was 1,873 lb. (849.6 kg) while the Curlex I blanket had an average total soil loss of 90 lb. (40.8 kg). Therefore, the blanket resulted in a 95% reduction in soil loss. Similar to the soil loss data, the turbidity and TSS results were significantly less than the bare soil control test. The turbidity and TSS measurements had an initial flush, but then leveled out for the remainder of the experiment even though the rainfall intensity increased. The Curlex I blanket test performance is depicted in Figure 4.47.

(a) Pre-test (b) 20 minute

(c) 40 minute (d) Post-test

FIGURE 4.47: Curlex I Test Photos.

4.6.1.1 Curlex I C-factor

Following the completion of the three Curlex I product experiments and a bare soil control test, the rainfall depth and soil loss data from each experiment was used to calculate the product *C*-factor. The bare soil control experiment was used to calculate the *K*-factor associated with the three product experiments. The *K*-factor was calculated by plotting the soil loss in tons/acre vs. the *R*-factor for the 2, 4, and 6 in. per hr (51, 102, 152 mm per hr) rainfall intensities as depicted in Figure 4.48.

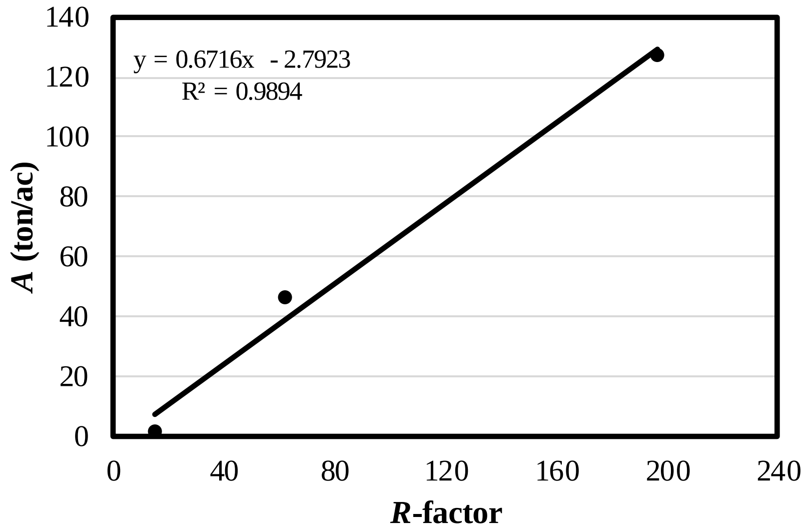
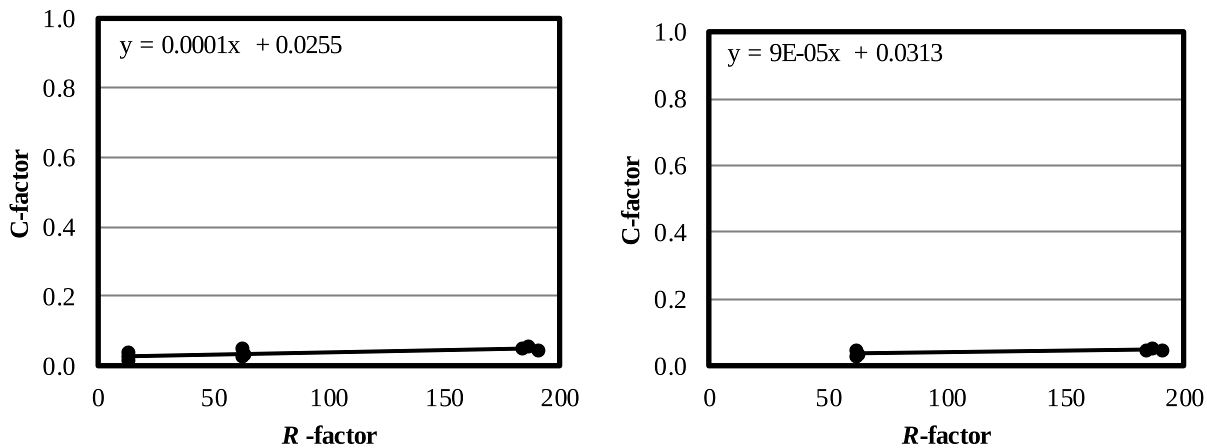


FIGURE 4.48: Curlex I *K*-factor Equation.

The linear equation from the trend line was used to calculate the corresponding A-factor with the theoretical *R*-factor of 182.02. The corresponding *A*-factor was 119.45 tons per acre (267.8 t/ha). The calculated *A*-factor was used in the RUSLE equation to calculate the soil erodibility factor (*K*-factor). The resulting *K*-factor for the Curlex I experiment was 0.23.

Once the *K*-factor was calculated, the *C*-factor for the Curlex I blanket was determined using two separate methods. The first method plotted the incremental *C*-factor vs. the incremental *R*-factor for the three blanket experiments. The data for all three-rainfall intensities was used in the graph because the means for all three rainfall intensity *C*-factors was equal the statistical analysis in section 4.6.1.2. The *C*-factor plot is depicted in Figure 4.49.



(a) Full test *C*-factor (b) Without 2 in. per hr *C*-factor

FIGURE 4.49: Curlex I *C*-factor Equation.

The 2, 4, and 6 in. per hr (51, 102, and 152 mm per hr) *C*-factors were statistically similar means. Therefore, the linear trend line equation from Figure 4.49(a) was used to calculate the *C*-factor corresponding with the theoretical *R*-factor of 182.02. The resulting *C*-factor for this method was 0.049. The second method used to calculate the *C*-factor used the average *A*-factor for each of the three product experiments was the RUSLE equation. The variables used to calculate the *C*-factor are depicted in Table 4.36.

TABLE 4.36: Curlex I RUSLE Equation

A =	6.13
Theoretical *R* =	182.02
LS =	2.86
K =	0.23
P =	1.0
***C* =**	**0.0501**

The resulting *C*-factor using the RUSLE equation was 0.050. Therefore, the two separate calculation methods resulted in *C*-factor of 0.049 and 0.050.

4.6.1.2 Curlex I Statistical Analysis

Three hypothesis tests were performed on the incremental *C*-factors for the three Curlex I blanket experiments. The three hypothesis tests compared the 2 to 4 in. per hr (51 to 102 mm per hr), 2 to 6 in. per hr (51 to 152 mm per hr), and 4 to 6 in. per hr (102 to 152 mm per hr) *C*-factor results to determine if the means of the resulting *C*-factors were equal. A hypothesis test was performed on the incremental *C*-factors of the three S150 blankets evaluated under rainfall simulation. If the two-tail *p*-value is less than the alpha value of 0.05 then the null hypothesis was rejected and the means are not equal. The results from the three hypothesis tests are summarized in Table 4.37.

TABLE 4.37: Curlex I Hypothesis Test Results

Hypothesis Test	Intensity 1 Mean	Intensity 2 Mean	*p* (two-tail)
2-4 in. per hr	0.0246	0.0371	0.228
2-6 in. per hr	0.0246	0.0488	0.074
4-6 in. per hr	0.0371	0.0488	0.197

The three hypothesis tests all resulted in *p*-values greater than the alpha value of 0.05. Therefore, the means for all three combinations were equal and the null hypothesis was not rejected.

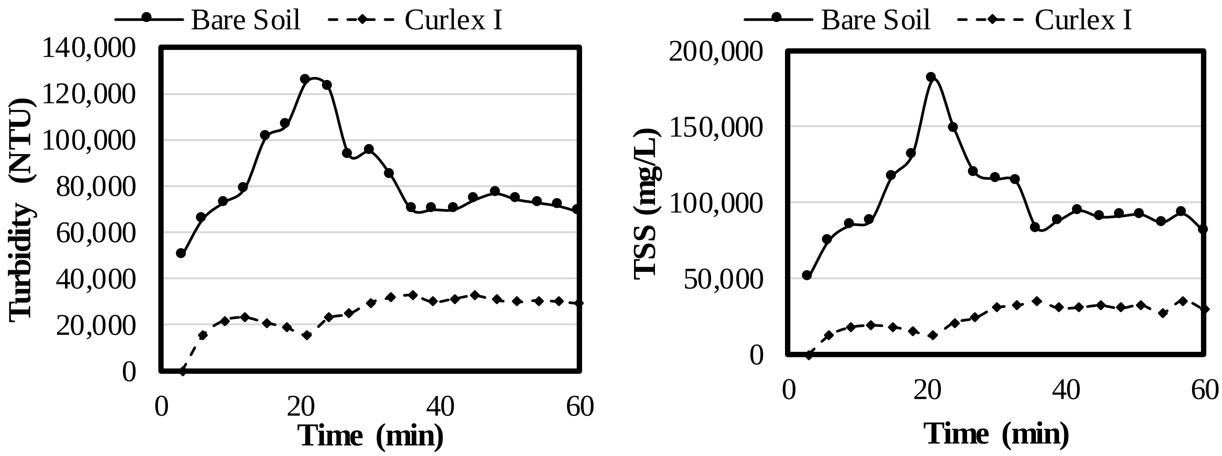
4.6.2 S150

Three rainfall simulation tests were performed on North American Greens S150 ECB. The S150 blanket is a double net straw fiber blanket with a functional longevity of 12 months. The netting is a lightweight photodegradable netting located on the top and bottom of the blanket. The S150 product specifications are depicted in Appendix B. The ECB was installed following the manufacturers installation recommendations for trenching and anchoring. The S150 average water quality measurements and soil loss results were compared to the performance of a bare soil control test which is depicted in Table 4.38 and Figure 4.50.

TABLE 4.38: S150 Test Results

Test Parameters	Bare Soil Control	Test 1	Test 2	Test 3	Average
Rainfall Depth (in.)	4.05	4.02	4.10	4.08	4.07
Compaction (%)	87.26	88.98	89.49	86.68	88.38
Moisture Content (%)	19.61	18.86	17.09	18.66	18.20
2 in. per hr Soil Loss (lb.)	97.58	13.59	2.77	5.55	7.30
4 in. per hr Soil Loss (lb.)	752	60.89	51.80	86.84	66.51
6 in. per hr Soil Loss (lb.)	1,245	230	223	200	218
Total Collected Sediment (lb.)	**2,094**	**304**	**278**	**293**	**292**

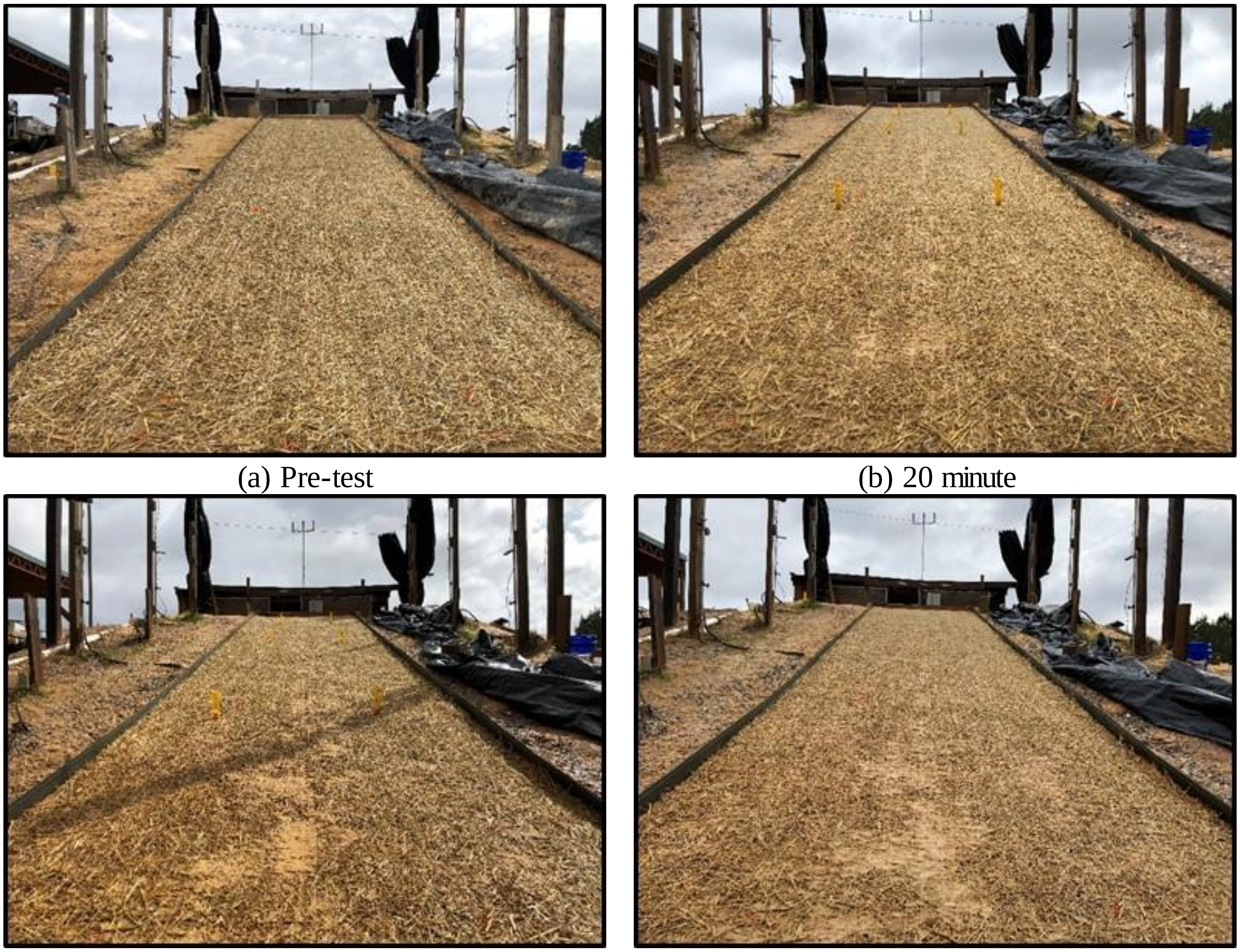
Note: 1 inch = 25.4 millimeters
1 lb. = 0.45 kilograms



(a) Turbidity (b) TSS

FIGURE 4.50: S150 Water Quality Results.

The three rainfall experiments performed on the S150 ECB resulted with an average rainfall depth of 4.07 in. (103 mm), percent compaction of 88.38%, and an average moisture content of 18.20%. The S150 blanket resulted in an average total soil loss of 292 lb. (132 kg). The blanket resulted in an average soil loss of 7.30 lb. (3.3 kg) during the 2 in. per hr (51 mm per hr) rainfall intensity and 66.5 lb. (30.2 kg) during the 4 in. per hr (102 mm per hr) rainfall intensity. However, the 6 in. per hr (152 mm per hr) rainfall intensity resulted in a higher soil loss of 218 lb. (98.9 kg). The S115 ECB resulted in lower turbidity and TSS values than the corresponding bare soil control test. The water quality measurements quickly increased to around 20,000 NTU during the 2 in. per hr (51 mm per hr) rainfall period and gradually increased for the remainder of the experiment. The performance of the S150 ECB is depicted in Figure 4.51.



(a) Pre-test (b) 20 minute

(c) 40 minute (d) Post-test

FIGURE 4.51: S150 Test Photos.

4.6.2.1 S150 C-factor

Following the completion of the three S150 blanket experiments and a bare soil control test, the rainfall depth, and soil loss data from each experiment was used to calculate the product *C*-factor. The bare soil control resulted were used to calculate a *K*-factor for the three S150 experiments. The *K*-factor was calculated by plotting the soil loss in tons/acre versus the *R*-factor for the 2, 4, and 6 in. per hr (51, 102, and 152 mm per hr) rainfall intensities as depicted in Figure 4.52.

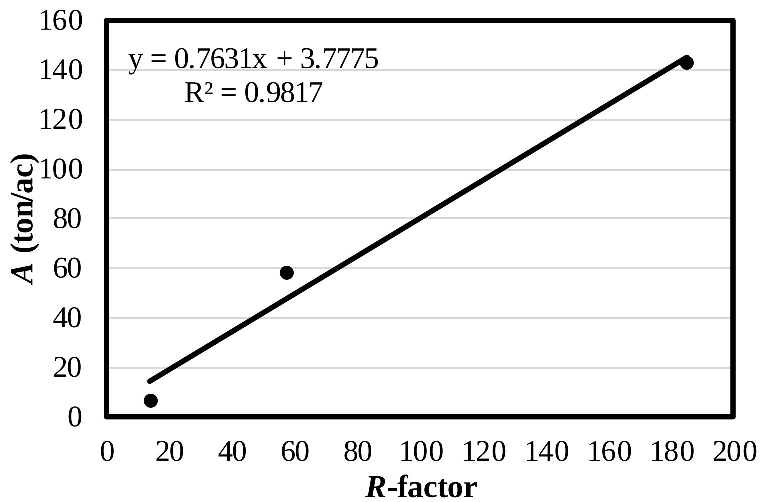
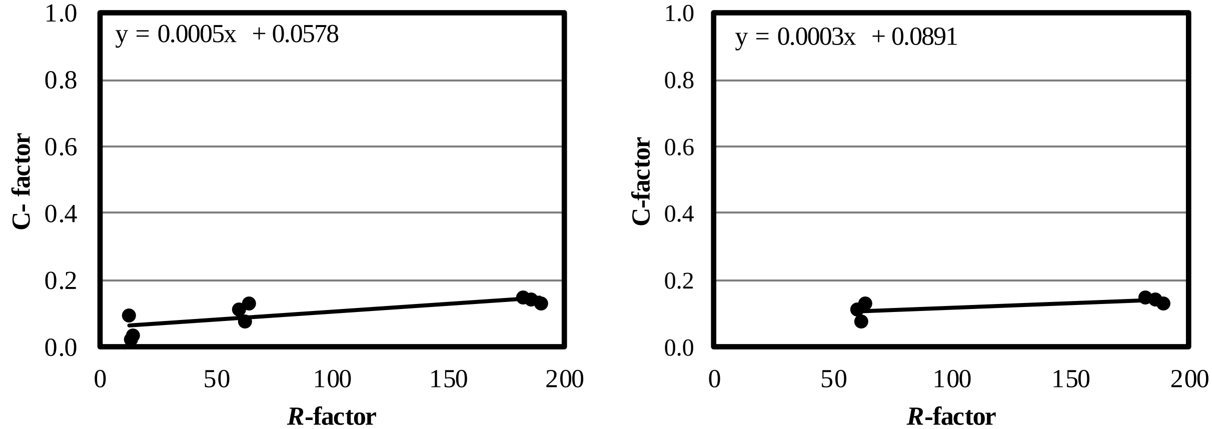


FIGURE 4.52: S150 *K*-factor Equation.

The linear trendline equation was used to calculate the corresponding *A*-factor with the theoretical *R*-factor of 182.02. The *A*-factor resulting from the calculation was 142.68 tons per acre (63.64 t/ha). The calculated *A*-factor was used in the RUSLE equation to calculate the *K*-factor. The resulting *K*-factor for the S150 experiment is 0.27.

Once the *K*-factor was calculated, the *C*-factor for the S150 blanket was determined using two separate methods. The first method plotted the incremental *C*-factor versus the incremental *R*-factor the three blanket experiments. Since the means for all three hypothesis tests were equal in section 4.6.2.2, the 2, 4, and 6 in. per hr (51, 102, and 152 mm per hr) rainfall data was used in the *C*-factor graph which is depicted in Figure 4.53.



(a) Full test *C*-factor (b) Without 2 in. per hr *C*-factor

FIGURE 4.53: S150 *C*-factor Equation.

The 2, 4, and 6 in. per hr (51, 102, and 152 mm per hr) *C*-factors had statistically equal means. Therefore, the linear trendline equation to calculate the *C*-factor corresponding with the theoretical *R*-factor of 182.02. The calculated *C*-factor for this method was 0.144. The second method used to calculate the *C*-factor used the average *A*-factor for each of the three S150 experiments with the RUSLE equation. The variables used to calculate the *C*-factor are depicted in Table 4.39.

TABLE 4.39: S150 RUSLE Equation

A =	19.84
Theoretical *R* =	182.02
LS=	2.86
K =	0.27
P =	1.0
***C* =**	**0.143**

The *C*-factor calculated using the average A-factor for each product experiment in the RUSLE equation was 0.143. Therefore, the two separate methods calculated a *C*-factors of 0.144 and 0.143.

4.6.2.2 S150 Statistical Analysis

Three hypothesis tests were performed on the incremental *C*-factors for the three S150 blanket experiments. The three hypothesis tests compared the 2-4 in. per hr (51-102 mm per hr), 2-6 in. per hr (51-152 mm per hr), and 4-6 in. per hr (102-152 mm per hr) *C*-factor results to determine if the means of the resulting *C*-factors were equal. If the two-tail *p*-value is less than the alpha value of 0.05 then the null hypothesis was rejected and the means are not equal. The results from the three hypothesis tests are summarized in Table 4.40.

TABLE 4.40: S150 Hypothesis Test Results

Hypothesis Test	Intensity 1 Mean	Intensity 2 Mean	Degrees of Freedom	P (two-tail)
2-4 in/hr	0.0502	0.1060	3	0.1381
2-6 in/hr	0.0502	0.1402	3	0.0650
4-6 in/hr	0.1060	0.1402	3	0.1179

The hypothesis tests resulted in a *p*-value greater than the alpha value of 0.05. Therefore, the null hypothesis that the means are equal was true for all three experiments.

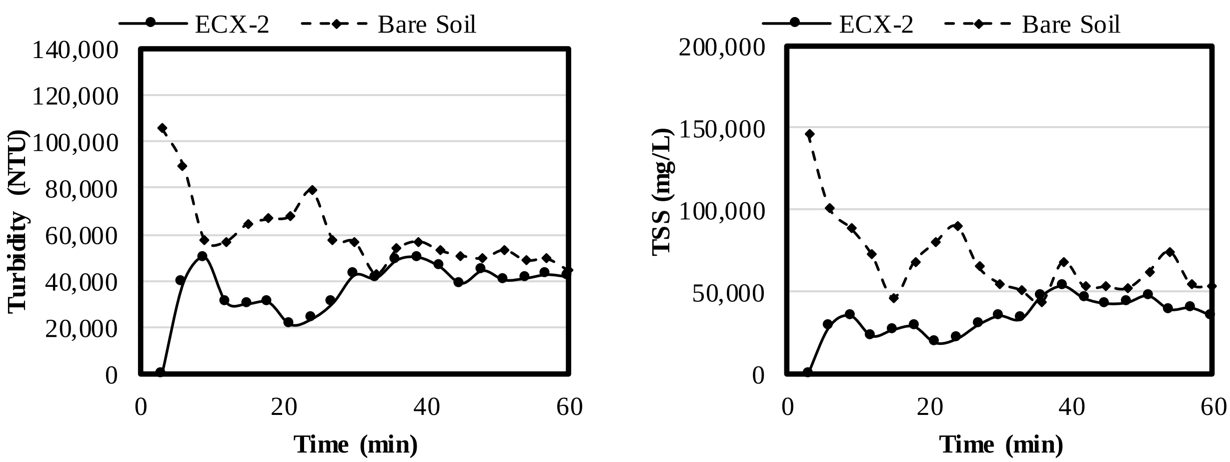
4.6.3 ECX-2

Three rainfall simulation experiments were performed on the East Coast Erosion's ECX-2 (ECX-2) blanket. ECX-2 is a double net excelsior blanket with a functional longevity of 24 months. The netting is a photodegradable polypropylene netting installed on the top and bottom of the excelsior fiber. The blanket was installed following the manufacturers recommendations for trenching and anchoring. The blanket soil loss and water quality results were compared to a bare soil control test which is depicted in Table 4.41 and Figure 4.54.

TABLE 4.41: ECX-2 Test Results

Test Parameters	Bare Soil Control	Test 1	Test 2	Test 3	Average
Rainfall Depth (in.)	4.08	4.10	3.97	3.98	4.02
Compaction (%)	90.20	89.73	90.46	88.79	89.66
Moisture Content (%)	19.99	18.72	19.51	21.28	19.84
2 in. per hr Soil Loss (lb.)	104.70	0.98	3.23	5.08	3.10
4 in. per hr Soil Loss (lb.)	676.52	63.64	50.93	55.82	56.80
6 in. per hr Soil Loss (lb.)	1,174	202.43	121.31	159.55	161.10
Total Collected Sediment (lb.)	**1,955**	**267**	**205**	**221**	**231**

Note: 1 inch = 25.4 millimeters
1 pound = 0.45 kilograms



(a) Turbidity (b) TSS

FIGURE 4.54: ECX-2 Water Quality Results.

ECX-2 had an average total soil loss of 231 lb. (105 kg), rainfall depth of 4.02 in. (102 mm), and 89.66% compaction. The bare soil control test paired with the ECX-2 blanket had a total soil loss of 1,955 lb. (886.8 kg), which means the blanket resulted in an 88% reduction in soil loss. The blanket resulted in a low initial soil loss during the 2 in. per hr (51 mm per hr) rainfall intensity and gradually increased as the rainfall intensity increased to 4 and 6 in. per hr (102 and 152 mm per hr). The turbidity measurements resulted in a high initial flush, but slowly reduced for the remainder of the 2 in. per hr (51 mm per hr) rainfall intensity. Similar to the soil loss data, the turbidity and TSS values gradually increased as the rainfall intensities increased. The excelsior blankets test performance throughout the rainfall experiment is depicted in Figure 4.55.


(a) Pre-test


(b) 20 minute


(c) 40 minute


(d) Post-test

FIGURE 4.55: ECX-2 Test Photos.

ECX-2 significantly reduced the water quality and soil loss results. However, there were some areas in the installed blankets that were not filled with excelsior fiber, which did not provide a protective cover for that area of the slope. Due to the lack of coverage, there was increased erosion in those areas causing higher values of water quality and soil loss. The lack of excelsior cover is depicted in Figure 4.56(a).

(a) Pre-test blanket conditions (b) Post-test conditions

FIGURE 4.56: ECX-2 Coverage Problems.

4.6.3.1 ECX-2 C-factor

Following the completion of the three ECX-2 blanket tests and a bare soil control test, the incremental rainfall depth and soil loss data were used to calculate the product *C*-factor. The bare soil control test was used to determine the loam *K*-factor. This *K*-factor will be used to calculate the *C*-factor of the ECX-2 blankets. The *K*-factor was determined by plotting the *A*-factor vs. *R*-factor for the 2, 4, and 6 in. per hr (51, 102, and 152 mm per hr) rainfall intensities and is depicted in Figure 4.57.

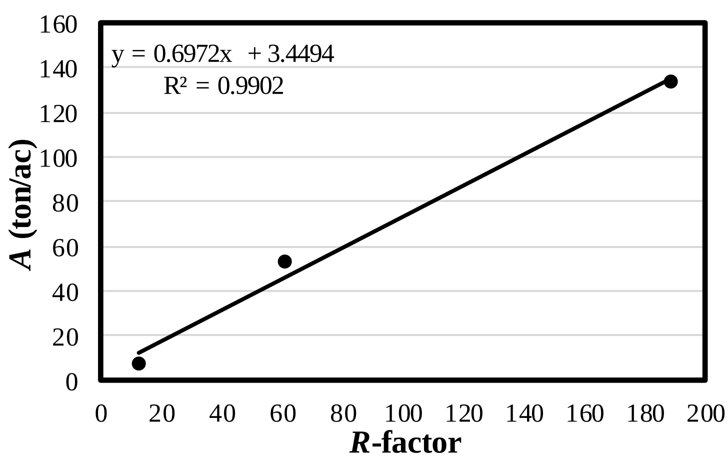
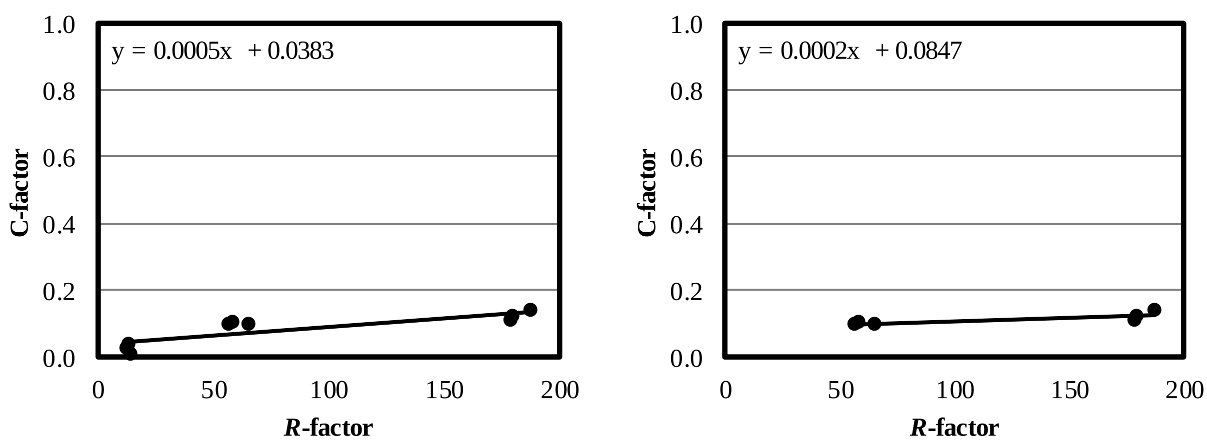


FIGURE 4.57: ECX-2 *K*-factor Equation.

A linear trendline was used to determine a linear equation that best fits the data points. The trendline equation was used to calculate the *A*-factor that corresponds with the theoretical *R*-factor of 182.02. The *A*-factor calculated by this equation was 130.35 tons per acre (292.2 t/ha). This *A*-factor was used in the RUSLE equation along with a *LS*-factor of 2.86, *C*-factor of 1.0, and *P*-factor of 1.0. The resulting *K*-factor for this test group was 0.24.

Following the *K*-factor calculation, the *C*-factor for ECX-2 was determine following two different methods. The first method plotted the incremental *C*-factor vs. the incremental *R*-factor for the three ECX-2 experiments, which is depicted in Figure 4.57. The statistical analysis performed in section 4.6.3.2 determined that the 2 in. per hr (51 mm per hr) *C*-factor mean was not equal to the 4 or 6 in. per hr (102 or 152 mm per hr) means. Therefore, the 2 in. per hr (51 mm per hr) data point was not used in this method because the resulting trend line was skewed due to the small amount of erosion resulting in an inaccurate *C*-factor.



(a) Full test *C*-factor (b) Without 2 in. per hr *C*-factor

FIGURE 4.58: ECX-2 *C*-factor Equation.

The 2 in. per hr (51 mm per hr) *C*-factor mean was statistically different from the 4 and 6 in. per hr (102 and 152 mm per hr) *C*-factor means. Therefore, the linear trend line from Figure 4.58(b) was used to best fit the incremental data points. The *C*-factor was determined by solving the linear equation for the theoretical *R*-factor of 182.02. The *C*-factor calculated for the ECX-2 using the first method was 0.121.

The second method used to calculate the ECX-2 *C*-factor plotted the incremental *A*-factor versus the incremental *R*-factor for each of the three product experiments. A linear trendline was used to calculate the *A*-factor that corresponds with the theoretical *R*-factor. All three of the *A*-factors were averaged together to get the *A*-factor of 15.71 tons per acre (32.2 t per ha) for the ECX-2 blanket. The data used to calculate the product *C*-factor is depicted in Table 4.42.

TABLE 4.42: ECX-2 RUSLE Equation

A =	15.71
Theoretical *R* =	182.02
LS =	2.86
K =	0.24
P =	1.0
***C* =**	**0.1238**

The *C*-factor calculated using the RUSLE equation was 0.124. The first and second methods used to calculate the *C*-factor resulted in values of 0.121 and 0.124 for the ECX-2 blankets.

4.6.3.2 ECX-2 Statistical Analysis

Three hypothesis tests were performed on the incremental *C*-factor calculated for the three ECX-2 blanket experiments. The three hypothesis tests compared the 2 to 4 in. per hr (51 to 102 mm per hr), 2 to 6 in. per hr (51 to 152 mm per hr), and 4 to 6 in. per hr (102 to 152 mm per hr) *C*-factor results to determine if the means of the resulting *C*-factors were equal. If the two-tail *p*-value was less than the alpha value of 0.05 then the null hypothesis was rejected, concluding that the means are not equal. The results from the three hypothesis tests for the ECX-2 blanket are summarized in Table 4.43.

TABLE 4.43: ECX-2 Hypothesis Testing Results

Hypothesis Test	Intensity 1 Mean	Intensity 2 Mean	Alpha	*p* (two-tail)
2-4 in. per hr	0.0242	0.0979	0.05	0.017
2-6 in. per hr	0.0242	0.1238	0.05	0.001
4-6 in. per hr	0.0979	0.1238	0.05	0.093

The three hypothesis tests performed on the ECX-2 blanket had varying results. The 2 to 4 in. per hr (51 to 102 mm per hr) and 2 to 6 in. per hr (51 to 152 mm per hr) hypothesis tests resulted in *p*-values less than the alpha value of 0.05. Therefore, the null hypothesis was rejected, concluding that the means are not equal. The 4 to 6 in. per hr (102 to 152 mm per hr) hypothesis test resulted in a *p*-value greater than 0.05, concluding that the null hypothesis is true and that the means are equal.

4.6.4 Erosion Control Blankets Summary

Three erosion control blankets were evaluated under large-scale rainfall simulation consisting of American Excelsior's Curlex I, North American Green's S150, and East Coast Erosion's ECX-2. Three initial product performance tests were completed for each product and each product was paired with a bare soil control test. The average soil loss results for the products are depicted in Table 4.44.

TABLE 4.44: Erosion Control Blanket Soil Loss Summary

Product	Soil Loss (lb.)
Bare Soil	1,974
Curlex I	90
S150	292
ECX-2	231

Note: 1 lb. = 0.45 kilograms

Curlex I resulted in the lowest total soil loss of 90 lb. (40.8 kg), which was 141 lb. (64 kg) less than the second best blanket. The S150 blanket was the worst performing blanket with an average soil loss of 292 lb. (132.4 kg). The average turbidity measurements for each product is depicted in Figure 4.59.

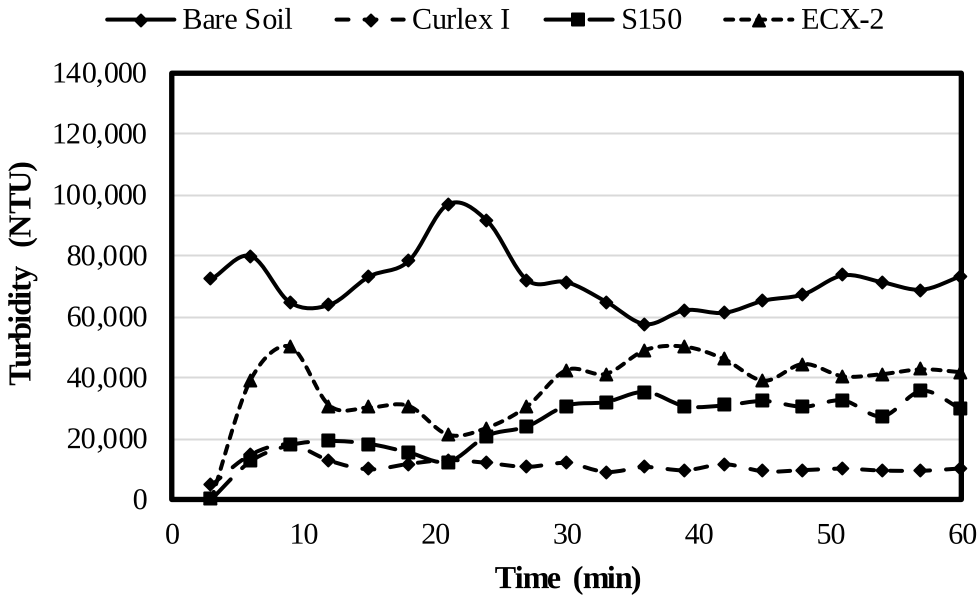


FIGURE 4.59: ECB Turbidity Results.

All three of the blankets had an initial flush, but were followed by different results for the remainder of the experiment. ECX-2 had the highest initial flush of 50,000 NTU and resulted in the highest turbidity measurements throughout the remainder of the experiment. Curlex I had an initial flush of only 18,000 NTU and then stabilized at roughly 10,000 NTU for the remainder of the experiment. The rainfall depth and soil loss data for each blanket was used to calculate the product *C*-factor. The *C*-factor was calculated using the regression and the RUSLE method, which is depicted in Table 4.45.

TABLE 4.45: ECB *C*-factor Results

Product	K-factor	Regression Method	RUSLE Method
Curlex I	0.23	0.049	0.050
S150	0.27	0.144	0.143
ECX-2	0.24	0.121	0.124

All three ECBs resulted in lower *C*-factors than the hydraulic mulches. Curlex I, which had the lowest soil loss results, had the lowest *C*-factor of 0.05. S150, which had the highest average soil loss, had the highest *C*-factor of 0.14. The S150 and ECX-2 blankets both had bare spots within the blanket where there was minimal to no product. The lack of soil coverage in these areas resulted in higher amounts of erosion. The Curlex I blanket did not have any bare spots resulting in a better product performance than the other two blankets. If the bare spots in the ECX-2 and S150 blankets were filled, the blanket performance would likely increase resulting in lower *C*-factors.

4.6.5 Summary

In this study, erosion control practice performance was evaluated by the AU-ESCTF rainfall simulator, which is designed to follow the ASTM D6459-19 rainfall event. Three initial product performance tests were completed on each erosion control practice and compared to bare soil control results. The soil loss ratio (*SLR*) was calculated for the straw mulch practices under initial and longevity testing on the sandy loam soil. The erosion control product *C*-factor was calculated on the loam soil for the products initial performance. The average soil loss from initial product testing and the straw mulch longevity testing is summarized in Table 4.46.

TABLE 4.46: Rainfall Simulation Average Soil Loss Summary

Soil Type	Erosion Control Practice	Average Initial Soil Loss (lb.)	*SLR* or *C*-factor	Longevity Soil Loss (lb.)	Longevity *SLR*
Sandy Loam	Bare Soil	738	-	611	-
	Loose Straw	143	0.19	287	0.47
	Loose Straw with Tacking Agent 3	97	0.13	131	0.21
	Crimped Straw	169	0.23	82	0.13
Loam	Bare Soil	2,154	-	-	-
	Eco-Fibre plus Tackifier	1,038	0.55	-	-
	Soil Cover Wood Fiber plus Tack	1,164	0.46	-	-
	Terra-Wood with Tacking Agent 3	1,294	0.53	-	-
	Curlex I	90	0.05	-	-
	S150	292	0.14	-	-
	ECX-2	231	0.12	-	-

The top performing erosion control practice tested in this study was American Excelsior's Curlex I, which had a product *C*-factor of 0.05. The erosion control blankets were on average the best performing erosion control practice tested for initial product performance. However, the loose straw with Tacking Agent 3 evaluated on the sandy loam soil resulted in a *SLR* of 0.13, which is comparable to North American Green's S150 blanket with a *C*-factor of 0.14 and East Coast Erosion's ECX-2 blanket with a *C*-factor of 0.12. Longevity testing was only performed on the sandy loam soil. For the initial product performance test, the crimped straw was the worst performing straw mulch practice with a *SLR* of 0.23. However, when the crimped straw was evaluated under longevity testing, the crimped straw had a *SLR* of 0.13, which is comparable to the performance of two of the erosion control blankets. Three thermally processed wood with tackifier hydraulic mulches were evaluated in this project. The hydraulic mulches experienced high amounts of soil loss with a minimal *C*-factor of 0.46.

CHAPTER 5: CONCLUSION

5.1 INTRODUCTION

The purpose of this research study was to re-design the existing rainfall simulator at the AU-ESCTF to follow the ASTM D6459-19 (ASTM 2019) testing standards. A literature review was performed to aid in the design of the rainfall simulator, the installation of erosion control practices, and the rainfall simulator testing procedure. The rainfall simulator was calibrated for rainfall intensity, uniformity, and drop size distribution. Following the calibration testing, rainfall simulation testing was performed on bare soil and erosion control practices.

The first aspect of this research was to calibrate the rainfall simulator to produce 2, 4, and 6 in. per hr (51, 102, and 152 mm per hr) rainfall intensities. The existing rainfall simulator was designed to produce the Alabama 2-yr, 24-hour storm event. There were six rainfall risers that each had four sprinklers. The re-design of the rainfall simulator consisted of altering the configuration of each riser to have three sprinklers each and to add four additional risers surrounding the test plot to maximize rainfall uniformity. The optimal riser locations were determined during the calibration testing. A calibration test consisted of a 15-minute rainfall event for each rainfall intensity to determine the intensity and uniformity of the rainfall simulator. Once the required rainfall intensity and uniformity were met, the drop size distribution was determined using the flour pan method. Following the calibration testing, test plot preparation, testing, and data collection procedures were developed. Rainfall simulation testing was performed to evaluate the performance of erosion control practices as compared to bare soil conditions.

5.2 CALIBRATION TESTING

The rainfall simulator was designed to generate theoretical rainfall intensities of 2, 4, and 6 in. per hr (51, 102, and 152 mm per hr). Thirty, 15 minute calibration tests were conducted on the rainfall simulator with 20 rain gauges installed on the test plot. Following each 15 minute calibration test, rainfall depths were recorded for each rain gauge and used to calculate the rainfall intensity and uniformity of the rainfall simulator. Ten calibration tests were conducted on each rainfall intensity. A 5% difference from the theoretical rainfall depth was allowed for the experimental rainfall depth. The uniformity of the rainfall was calculated using the Christiansen Uniformity Coefficient with a minimum uniformity of 80% was required for each rainfall intensity. The experimental rainfall intensities resulting from calibration testing was 2.08, 4.12, and 6.07 in. per hour (53, 105, 154 mm per hr). An ANOVA test was performed on each of the three rainfall intensity calibration results to determine if the means between each of the calibration tests resulted in equal means. The statistical analysis concluded that the calibration tests resulted in equal means for the ten tests performed on the 2, 4, and 6 in. per hr (51, 102, and 152 mm per hr) rainfall intensities. The uniformity coefficient calculated for each rainfall intensity ranged between 85.5-87.5%. Since the rainfall depth and uniformity met the testing requirements, the drop size distribution of the rainfall simulator was determined using the flour pan method. Three flour pan tests were conducted for each rainfall intensity to accurately represent the drop sizes for the entire test plot. The drop size distribution is depicted in Figure 4.1.

5.3 SANDY LOAM TESTING

Rainfall simulation testing was first performed on the sandy loam soil. Prior to the start of rainfall simulation testing, a test plot preparation procedure was created to reach the desired compaction rate of 86±6% and a moisture content within 5% of the testing soils optimum moisture content. A test and data collection procedure were created to collect water samples for TSS and turbidity measurements, total soil loss, rainfall depth, and discharge over time. Once these procedures were completed, four bare soil control tests were conducted to determine the water quality results throughout the experiment and the total soil loss of the experiment. The average soil loss for the bare soil control test was 738 lb. (335 kg).

Following the bare soil control tests, three straw mulch applications were evaluated including loose straw, loose straw with Tacking Agent 3, and crimped straw. The straw mulch was installed at an application rate of two tons per acre for all three straw mulch applications. The Tacking Agent 3 was sprayed on the loose straw at an application rate of 50 lb. per acre (56 kg per ha). The straw was crimped a minimum of two inches into the soil in the perpendicular direction to flow per the Alabama Handbook requirements. The rows of crimped straw were spaced a maximum of eight inches with ¼ inch flat edged coulter blades. The straw applications had an average total soil loss of 143 lb. (65 kg) for loose straw, 97 lb. (44 kg) for loose straw with Tacking Agent 3, and 168 lb. (76 kg) for crimped straw. An ANOVA test was performed on the straw mulch test results to determine if the soil loss between the three applications were equal. The statistical analysis concluded that at least one of the means was not equal to the others. In order to determine which means were equal, three hypothesis tests were performed to compare the loose versus tackifier, loose versus crimped, and tackifier versus crimped straw applications. The statistical analysis concluded that the loose straw and crimped straw had equal means and the straw with tackifier was not equal to the crimped or loose straw applications. Under initial performance testing, the loose straw with Tacking Agent 3 had the lowest water quality measurements and lowest total soil loss. The tackifier was highly effective at the beginning of the experiment, but the effect wore off over time. The crimped straw application had the highest soil loss and the worst resulting water quality measurements. The poor performance by the crimped straw was due to the disturbance of the soil as the straw was imbedded in the slopes surface.

Following the initial product testing for the straw mulch applications, a longevity test was performed on each installation. The longevity tests had a total soil loss of 287 lb. (130 kg) for loose straw, 131 lb. (59.4 kg) for loose straw with Tacking Agent 3, and 82 lb. (37.2 kg) for crimped straw. The additional rainfall event resulted in significant improvement in the effectiveness of the crimped straw. The crimped straw improved from having the highest soil loss under initial product testing to having the lowest soil loss for longevity testing. The loose straw resulted in the highest soil loss and water quality measurements under longevity testing. The decrease of loose straw performance was due to the straw washing from the test plot, which reduced the amount of soil cover. The loose straw with Tacking Agent 3 resulted in similar water quality measurements as the crimped straw but had a higher total soil loss. The evaluation of the three straw mulch applications on a 3*H*:1*V* slope proved that anchoring straw mulches provides longer lasting coverage and reduces the amount of erosion.

5.4 LOAM SOIL TESTING

Following the straw mulch testing on the sandy loam soil, testing transitioned to a soil type that better aligned to the ASTM D6459-19 soil requirements of a clay, loam, or sand. Therefore, a soil analysis was performed on local soil stockpiles until a soil met the standard requirements. Following the soil analysis, 12 in. (30.5 cm) of the sandy loam soil was excavated from the test plot and replaced with 12 in. (30.5 cm) of loam soil. Once the test plot was reconstructed, rainfall simulation testing was continued to evaluate the performance of bare soil, hydraulic mulches, and erosion control blankets (ECB).

The testing procedure was performed differently for the loam soil experiments so that the RUSLE *C*-factor could be calculated for each erosion control product. The rainfall simulator was stopped between each 20 minute rainfall intensity interval to measure the rainfall depth and to separate the soil loss into separate containers.

5.4.1 Hydraulic Mulches

Rainfall simulator testing was performed on three hydraulic mulches consisting of Eco-Fibre plus Tackifier, Soil Cover Wood Fiber with Tack, and Terra-Wood with Tacking Agent 3. All three of the hydraulic mulches were installed following the manufacturer recommendations at an application rate of 2,500 lb. per acre (2,802 kg per ha). The hydraulic mulches were allowed to cure for a minimum of 24 hours prior to rainfall simulation testing. The bare soil control experiments paired with the hydraulic mulch products resulted in an average soil loss of 2,333 lb. (1,058 kg). The total soil loss for the hydraulic mulches was 1,038 lb. (471 kg) for the Eco-Fiber, 1,164 lb. (528 kg) for the Soil Cover, and 1,294 lb. (587 kg) for the Terra-Wood. During the 2 in. per hr (51 mm per hr) rainfall intensity the soil loss for each of the products was 3.45 lb. (1.56 kg) for the Eco-Fiber, 2.67 lb. (1.21 kg) for the Soil Cover, and 8.54 lb. (3.87 kg) for the Terra-Wood. The hydraulic mulch performed well during the 2 in. per hr (51 mm per hr) rainfall intensity. However, as the rainfall intensity increased to 4 in. per hr (102 mm per hr), the hydraulic mulches experienced greater soil losses of 337 lb. (153 kg) for Eco-Fibre, 382 lb. (173 kg) for Soil Cover, and 491 lb. (223 kg) for Terra-Wood. The increase in soil loss between the 2 and 4 in. per hr (51 and 102 mm per hr) rainfall intensities was caused by the mulch washing from the test plot. Once the hydraulic mulch had washed from the test plot, there were large areas of exposed soil resulting in substantial rill formation and high water quality measurements and soil loss.

Following the completion of the hydraulic mulch testing, a procedure for calculating the product *C*-factor was created using the drop size distribution, incremental soil loss, and the incremental rainfall depth for each experiment. Two separate procedures were used to calculate the product *C*-factors, which is referenced in section 3.7.2. Three hypothesis tests were performed on the incremental soil loss results for each hydraulic mulch to determine if the *C*-factors between the 2 to 4, 2 to 6, and 4 to 6 in. per hr (51 to 102, 51 to 152, and 102 to 152 mm per hr) rainfall intensities had equal means. All three of the hydraulic mulches resulted in the 4 to 6 in. per hr (102 to 152 mm per hr) rainfall intensities to have *C*-factors with equal means. The 2 to 4 and 2 to 6 in. per hr (51 to 102 and 51 to 152 mm per hr) rainfall intensities mean *C*-factors were not equal. The results from this statistical analysis were used to calculate the product *C*-factor in the regression method. The 2 in. per hr (51 mm per hr) *C*-factor was not included in the *C*-factor versus *R*-factor graph because its mean was not equal to the 4 or 6 in. per hr (102 or 152 mm per hr) *C*-factors. The resulting *C*-factors for the hydraulic mulches was 0.55 for Eco-Fibre, 0.46 for Soil Cover, and 0.54 for Terra-Wood. The Soil Cover hydraulic mulch had the highest *C*-factor of 0.46. The Eco-Fibre hydraulic mulch had a higher *C*-factor because one of the experiments was exposed to excess rainfall from a storm that occurred prior to the collection of the 6 in. per hr (152 mm per hr) soil loss data. All three of the hydraulic mulches had relatively high *C*-factors. Other erosion control practices should be used to reduce the amount of erosion occurring on the test plot.

5.4.2 Erosion Control Blankets

Three erosion control blankets were evaluated under rainfall simulation testing consisting of American Excelsior's Curlex I, North American Green's S150, and East Coast Erosion's ECX-2. The installation of the ECBs followed manufacturer recommendations for trenching and anchoring. The bare soil control experiments paired with the three ECBs resulted in an average total soil loss of 1,974 lb. (895 kg). The total soil loss for the ECBs was 90 lb. (40.8 kg) for Curlex I, 292 lb. (132 kg) for S150, and 231 lb. (105 kg) for ECX-2. All three of the blankets had an increase in soil loss as the rainfall intensity increased. The 2 in. per hr soil loss for the ECBs was 3.13 lb. (1.42 kg) for Curlex I, 7.30 lb. (3.31 kg) for S150, and 3.10 lb. (1.41 kg) for ECX-2. The ECBs soil loss during the 4 in. per hr (102 mm per hr) rainfall intensity was 19.75 pounds (8.95 kg) for Curlex I, 66.51 lb. (30.2 kg) for S150, and 56.8 lb. (25.7 kg) for ECX-2. All three blankets had similar soil loss results during the 2 in. per hr (51 mm per hr) rainfall intensity. During the 4 and 6 in. per hr (102 and 152 mm per hr) rainfall intensities, the soil loss for the S150 and ECX-2 blankets increased at a higher rate than the 2 in. per hr (51 mm per hr) rainfall intensity. The S150 and ECX-2 blankets had bare spots where no blanket filler was located, resulting in little to no cover for those areas. The lack of cover caused the erosive forces of the rainfall to increase the amount of erosion occurring at those bare spots. If the S150 and ECX-2 blankets covered the test plot like the Curlex I blanket, then the soil loss results would be reduced.

Following the completion of product testing, the *C*-factors for each ECB was calculated using the incremental soil loss and the rainfall depth. The bare soil control results paired with each ECB was used to calculate the *K*-factor associated with each blanket test. Three hypothesis tests were performed on the incremental soil loss results for each ECB to determine if the *C*-factors between the 2 to 4, 2 to 6, and 4 to 6 in. per hr (51 to 102, 51 to 152, and 102 to 152 mm per hr) rainfall intensities had equal means. The Curlex I and S150 blankets resulted in equal *C*-factor means for all three rainfall intensity combinations. Therefore, all three rainfall intensities *C*-factor data was used in the regression method to aid in the product *C*-factor calculation. The ECX-2 blanket resulted in the 2 to 4 and 2 to 6 in. per hr (51 to 102 and 51 to 152 mm per hr) rainfall intensities mean *C*-factors not being equal. The 2 in. per hr (51 mm per hr) *C*-factor data was not included in the *C*-factor versus *R*-factor graph because its mean was not equal to the 4 or 6 in. per hr (102 or 152 mm per hr) *C*-factors. The results from this statistical analysis were used to calculate the product *C*-factor in the regression method. The *C*-factors calculated for each product was 0.05 for Curlex I, 0.14 for S150, and 0.12 for ECX-2. If the S150 and ECX-2 blankets did not have the bare spots with no filler, the product *C*-factors could have been closer to the Curlex I *C*-factor.

All three of the blankets resulted in lower *C*-factors than the hydraulic mulches. The hydraulic mulches washing from the test plot caused the difference in performance between the hydraulic mulches and ECBs. The hydraulic mulches and ECBs resulted in similar soil loss results for the 2 in. per hr (51 mm per hr) rainfall intensity. However, when the rainfall intensity increased to 4 in. per hr (102 mm per hr), the hydraulic mulch would wash from the test plot causing a lack of coverage while the blankets remained anchored in place for the full duration of the experiment.

5.5 SUMMARY

This research study had four primary objectives that were addressed throughout this project. Based on the research performed in this study, the objectives were addressed as follows.

1. The AU-ESCTF rainfall simulator was redesigned from the existing rainfall simulator to follow the ASTM D6459-19 design requirements. This rainfall simulator was designed and calibrated to produce 2, 4, and 6 in. per hr (51, 102, and 152 mm per hr) rainfall intensities. Ten calibration tests were performed on each rainfall intensity to measure the experimental rainfall intensity and uniformity. The experimental rainfall intensities resulting from calibration testing was 2.08, 4.12, and 6.07 in. per hour (53, 105, 154 mm per hr) and had rainfall uniformities ranging from 85-87%. The drop size distribution of the rainfall simulator was

determined by using the flour pan method. The drop size distribution results are summarized in section 4.2.2.

2. The test procedures used in this study followed the ASTM D6459-19 specifications for test plot preparation and data collection. The test plot was tilled, raked, and compacted with a turf roller in preparation for each rainfall experiment. The compaction rate and moisture content of the test slope were evaluated through the drive cylinder compaction test. Test procedures were created to collect water samples at three-minute intervals, measure rainfall depth, collect soil loss, and measure discharge over time. Following a rainfall experiment, procedures were established for the measurement of total soil loss and the water sample results for TSS and turbidity. Following the straw mulch testing, test procedures were updated to allow for product *C*-factor calculations by separating each rainfall intensities soil loss and measuring rainfall depth for each rainfall intensity.
3. This study evaluated erosion control practices listed on ALDOT's preferred products List II-11 and II-20. Throughout this project, three straw mulch applications, hydraulic mulches, and erosion control blankets from ALDOT's preferred products lists were evaluated. The straw mulch practices evaluated in this study were loose straw, loose straw with Tacking Agent 3, crimped straw. The hydraulic mulches evaluated in this study were Profile Products Eco-Fibre plus Tackifier, Profile Products Soil Cover Wood Fiber with Tack, and Profile Products Terra-Wood with Tacking Agent 3. The three erosion control blankets tested in this study were American Excelsior's Curlex I, North American Green's S150, and East Coast Erosion's ECX-2.

4. During this project, a procedure was developed to calculate the erosion control practice *C*-factor using the RUSLE equation. The procedure uses the drop size distribution data, incremental rainfall depth, and the incremental soil loss for each experiment. A bare soil control test was paired with each erosion control practice to calculate the soils *K*-factor, which was used for the product *C*-factor calculation. The data collected from the three erosion control practice tests were used to calculate the product *C*-factor. Two separate *C*-factor calculation procedures were created during this project, which are compared in this study.

5.6 RECOMMENDATIONS FOR FURTURE RESEARCH

The research presented in this study shows that the AU-ESCTF rainfall simulator is capable of consistently simulating the ASTM D6459-19 rainfall event. The test procedures and rainfall simulation results found in this study should be used to pursue accreditation for ASTM D6459-19 testing through the Geosynthetic Accreditation Institute (GAI). As rainfall simulation testing continues, additional erosion control practices should be tested to better understand product performance on a 3*H*:1*V* slope. In this study, anchored straw mulch was evaluated on the sandy loam soil. Future research should evaluate the performance of the same anchored straw applications on the loam soil. Additional mulching applications (pine straw, peanut hulls, and wood chips) should be tested to compare the performance of straw mulches with other mulching practices. In this study, hydraulic mulches were only effective during the 2 in. per hr (51 mm per hr) rainfall intensity and resulted in large amounts of erosion. Since the wood with tack hydraulic mulches were ineffective under the ASTM D6459-19 rainfall event, future testing should evaluate higher strength hydraulic erosion control products (HECPs) such as ProMatrix Engineered Fiber Matrix and Flexterra Flexible Growth Medium. Profile Products representatives recommended using the ProMatrix and Flexterra products for the ASTM D6459 testing parameters. ProMatrix and Flexterra are designed to withstand higher shear stresses and flow velocities than ordinary wood with tack hydraulic mulches. These two products use crimped biodegradable interlocking fibers and micro pore granules to increase the strength of the product. Unlike the wood with tack hydraulic mulches tested in this study, the ProMatrix mulch is designed to withstand a 3*H*:1*V* slope length of 50 ft (15.2 m) without slope interrupters while Flexterra is designed to withstand 100 ft (30.5 m) slope length. The hydraulic mulches in this study were installed on a smooth slope, which affected the performance of the products. Future testing should compare the hydraulic mulch effectiveness with and without tracking. All three of the hydraulic mulches evaluated in this study are designed for slopes less than 30 ft (9.1 m.) long. Future research should install slope interrupters on the slope to evaluate the performance of the hydraulic mulches with and without slope interrupters. ECBs were the most effective erosion control practice evaluated in this study. Future research should be performed on ECBs with varying fillers such as straw, excelsior, straw/ coconut, and coconut and varying biodegradable netting options such as woven jute and coir nettings. In addition to these ECBs, a polymer-enhance soft armoring system (PAM and jute), which has been evaluated under small-scale rainfall simulation at the AU-ESCTF, should be tested to compare this system to the small-scale results and the results of other erosion control practices under large-scale rainfall simulation.

Based upon this research performed at the AU-ESCTF, the following recommendations are made to better enhance future testing efforts.

1) Additional rainfall simulators should be constructed to increase the capabilities of the test facility.

2) When constructing additional rainfall simulators, the design of the rainfall simulator should be altered from the original design to reduce the slope preparation, testing, and data collection time. The test plots should be lined with concrete to prevent the erosion of the area surrounding the rainfall simulator and to increase safety. The catch basin should not be wider than the test plot to prevent runoff from areas other than the test plot from entering the catch basin. A removable winch mounting system should be installed at the top of the test slope to allow equipment easy access to the top of the test plot. The ease of access for the equipment would decreased the time it takes to rebuild the test plot. The electrical control box should be moved to the bottom of the test plot for ease of access during an experiment and to allow the equipment access at the top of the slope.

3) During this research project, a pulley system was installed on the wind curtains; however, this system was not a viable long-term option. Future wind curtain systems that have an efficient and effective pulley system would reduce the amount of time required to install the wind curtains. During the construction of future wind curtains, ensure the wind curtains are able to be installed to better mimic the slope of the plots so that better coverage is provided. The existing rainfall simulators wind curtains have resulted in a system that at some points are shorter than the sprinklers, causing some minimal wind disruption.

REFERENCES

Alabama Department of Transportation (2018).“Standard Specifications for Highway Construction.” Montgomery, AL.

Alabama Soil and Water Conservation Committee (2018).“Alabama Handbook for Erosion Control, Sediment Control and Stormwater Management on Construction Sites and Urban Areas.” Montgomery, AL.

ASTM (2008). “Standard Test Method for Determination of Water (Moisture) Content of Soil by Microwave Oven Heating.” West Conshohocken, PA, 1-7.

ASTM (2010). “Standard Test Method for Density of Soil in Place by the Drive-Cylinder Method.” West Conshohocken, PA, 1-7.

ASTM (2012). “Standard Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3)).” West Conshohocken, PA, 1-13.

ASTM (2013). “Standard Test Methods for Filterable Matter (Total Dissolved Solids) and Nonfilterable Matter (Total Suspended Solids) in Water.” West Conshohocken, PA, 1-9.

ASTM (2014). “Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.” West Conshohocken, PA, 1-5.

ASTM (2017). “Standard Test Method for Determination of Turbidity Above 1 Turbidity Unit (TU) in Static Mode.” West Conshohocken, PA, 1-22.

ASTM (2017). “Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.” West Conshohocken, PA, 1-20.

ASTM (2017). “Standard Test Method for Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing.” West Conshohocken, PA, 1-4.

ASTM (2017). “Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis.” West Conshohocken, PA, 1-25.

ASTM (2019). “Standard Test Method of Rolled Erosion Control Product (RECPs) Performance in Protecting Hillslopes from Rainfall Induced Erosion.” West Conshohocken, PA, 1-10.

Barnett, A. P., Diseker, E. G., and Richardson, E. C. (1967). “Evaluation of Mulching Methods for Erosion Control on Newly Prepared and Seeded High Backslopes.” *Agronomy Journal, Vol. 59*, 83-85.

Benik, S. R., Wilson, B.N., Biesboer, D. D., Hansen, B., and Stenlund, D. (2003). “Performance of Erosion Control Product s on a Highway Embankment.” *Transactions of ASABE*, 46(4), 1113-1119.

Bjorneberg, D. J., Aase, J. K., and Westermann, D. T. (2000). "Controlling Sprinkler Irrigation Runoff, Erosion, and Phosporus Loss with Straw and Polyacrylamide." *Soil and Water Division of ASAE* , 1545-1551.

Brady, N. C., and Weil, R. R. (1999). *The Nature and Properties of Soils*, Prentice Hall, Upper Saddle River, New Jersey.

Bubenzer, G. D., and Jones Jr., B. A. (1971). "Drop Size and Impact Velocity Effects on the Detachment of Soils under Simulated Rainfall." *Transactions of the ASABE*, 14(4), 625-628.

Cabalka, D. A., Clopper, P. E., Johnson, A. G., and Vielleux, M. T. (1998)."Research, Development and Implementation of Test Protocols for Rainfall Erosion Facilities (REFS)." American Excelsior Company – Earth Science Division.

Clopper, P. , Vielleux, M., and Johnson, A. (2004)."Quantifying the Performance of Hillslope Erosion Control Best Management Practices." *American Society of Civi Engineers*, 1-10.

Early, J. J., Clopper, P. E., and Johnson, T. "Quantitative Erosion Control Product Testing Under Simulated Rainfall.", 293-300.

ECTC (2014). "Rolled Erosion Control Products (RECPs) General Usage and Installation Guidelines for Slope. " https://www.ectc.org/rolled-erosion-control-products-recps-.

Eigel, J. D., and Moore, I. D. (1983). "A Simplified Technique for Measuring Raindrop Size and Distribution." *American Society of Agricutural Engineers Soil and Water Division*, 1079-1084.

Elbasit, M. A. M., Ojha, C. S. P., Ahmed, Z., Yasuda, H., Salmi, A., and Ahmed, F. (2015). "Rain Microstructure and Erosivity Relationships under Pressurized Rainfall Simulator." *Journal of Hydrologic Engineering*, 1-6.

Faucette, L.B., Governo, J., Jordan, C.F., Lockaby, B.G., Carino, H.F., and Governo, R. (2007). "Erosion Control and Storm Water Quality from Straw with PAM, Mulch, and Compost Blankets of Varying Particle Size." *Soil and Water Conservation*, 404-413.

Foltz, R.B., and Dooley, J.H. (2003). "Comparison of Erosion Reduction between Wood Strands and Agricultural Straw." *American Society of Agricultural Engineers*, 1389-1396.

Gholami, L., Sadeghi, S.H., and Homaee, M. (2012). "Straw Mulching Effect on Splash Erosion, Runoff, and Sediment Yield from Eroded Plots." *Soil Science Society of America*, 268-278.

Hall, M. J. (1970). "Use of the Stain Method in Determination the Drop-Size Distribution of Coarse Liquid Sparys." *American Society of Agricutural Engineers*, 33-41.

Holt , G., Buser, M., Harmel, D., and Potter, K. (2005)."Comparison of Cotton-based Hydro-mulches and Conventional Wood and Paper Hydro-mulches - Study II." *Journal of Cotton Science*, 128-134.

Horne, M.A., Zech, W.C., Fang, X., and Vasconcelos, J.G. (2017). "Design and Construction of a Rainfall Simulator for Large Scale Testing of Erosion Control Practices and Products." Auburn University.

Jayawardena, A.W., and Rezaur, R.B. (2000). "Measuring Drop Size Distribution and Kinetic Energy of Rainfall Using a Force Transducer." *Hydrological Processes*, 37-49.

Karpilo Jr., R. D., and Toy, T. J. (2004). "RUSLE *C*-Factors for Slope Protection Applications." *Journal American Society of Mining and Reclamation*, vol. 2004, no. 1, 995–1013.

Kathiravelu, G., Lucke, T., and Nichols, P. (2016). "Rain Drop Measurement Techniques: A Review." *Water, 8(29), 1-20*.

Khan, M. N., Gong, Y., Hu, T., Lal, R., Zheng, J., Justine, M. F., Azhar, M., Che, M., and Zhang, H. (2016). "Effect of Slope, Rainfall Intensity and Mulch on Erosion and Infiltration under Simulated Rain on Purple Soil of Soiuth Western Sichuan Province, China." *Water*, 8 (528), 1-18.

Kincaid, D C, Solomon, K. H., and Oliphant, J. C. (1996). "Drop Size Distribution for Irrigation Sprinklers." *American Society of Agricultural Engineers*, 839-845.

Laws, J. O., and Parsons, D. A. (1943). "The Relation of Raindrop-Size to Intensity." *Transactions of the American Geophysical Union*, 24, 452-460.

Lipscomb, C. M., Johnson, T., Nelson, R., and Lancaster, T. (2006). "Comparison of Erosion Control Technologies: Blown Straw vs. Erosion Control Blankets." *Erosion Control Technology Council*.

Mid-American Regional Council (2020). "What is Sediment Pollution " https://cfpub.epa.gov/npstbx/files/ksmo_sediment.pdf

Ming-Han, L. (2014). "Evaluating erosion control performance of crimped straw mulch in comparison with RECPs on simulated highway roadsides." *International Journal of Geotechnical Engineering*, 307-314.

Ming-Han, L., McFalls, J., and Yi, Y. (2013). "Comparing Erosion Control Products Performance Results from Field and Large-Scale Laboratory Testing ." *Indian Geotechnical Society,*: 382-387.

Novotny, V. (2003). *Water Quality: Diffuse Pollution and Watershed Management*, J. Wiley, Hoboken, New Jersey.

Pall, R., Dickinson, W. T., Beals, D., and McGirr, R. (1983). "Development and Calibration of a Rainfall Simulator." *Canadian Agricultural Engineering, Vol. 25*, 181-187.

Rickson, R J. (2006)."Controlling Sediment at Source: An Evaluation of Erosion Control Geotextiles." *Wiley Interscience*, 550-560.

Risse, M., and Faucette, B. (2001). "Compost Utilization for Erosion Control. University of Georgia Cooperative Extension Service Bulletin 1200. Athens, GA.

Robeson, M. D., Abt, S. R., Watson, C. C., and Williams, J. D. (2014). "Unification of Large-Scale Laboratory Rainfall Erosion Testing." Colorado State University.

U.S. Department of Agriculture, Agricultural Research Service. (1978). "Predicting Rainfall Erosion Losses." Agriculture Handbook No. 537, Washington, D.C.

U.S. Department of Agriculture, Agricultural Research Service. (1997). "Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation." Agriculture Handbook No. 703, Washington D.C.

U.S. Environmental Protection Agency.(2019). "EPA's 2017 Construction General Permit (CGP) and Related Documents." Retrieved fromhttps://www.epa.gov/npdes/epas-2017-construction-general-permit-cgp-and-related-documents.

Wilson , W. T., Zech, W. C., Clement, P., Crowley, L. G. (2010) "Evaluation of Hydromulches as an Erosion Control Measure Using Intermediate - Scale Experiments." Auburn University.

Ziegler , A D, Sutherland, R. A., and Tran, L. T. (1997). "Influence of Rolled Erosion Control Systems on Temporal Rainsplash Response - A Laboratoray Rainfall Simulation Experiment ." *Land Degredation and Development*, 139-157.

APPENDICES

Appendix A: Manufacturer Specifications for Rainfall Simulator Components

Appendix B: Erosion Control Product Specifications

Appendix C: Experimental Data

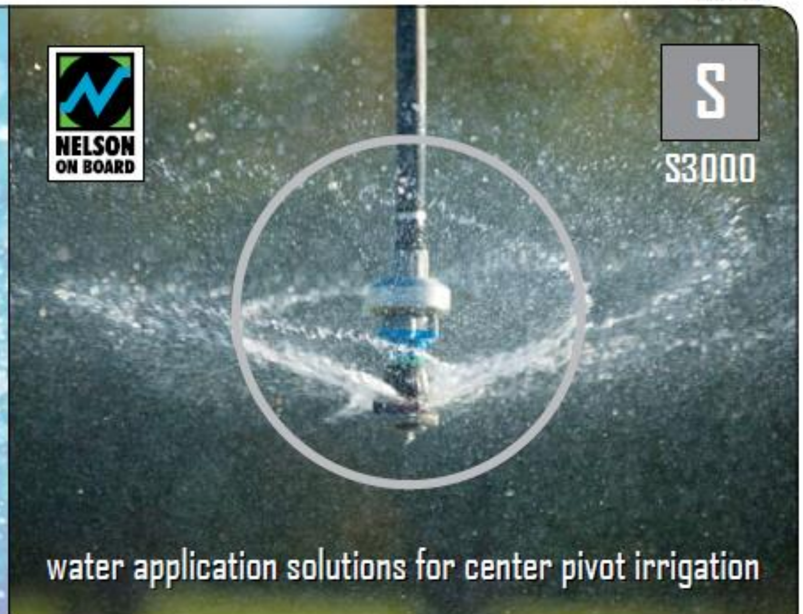
APPENDIX A

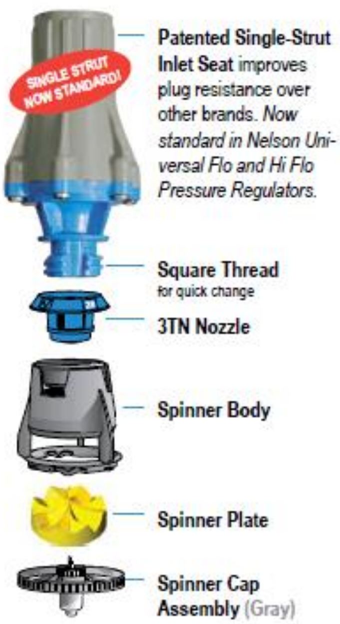
MANUFACTURER SPECIFICATIONS FOR RAINFALL SIMULATOR COMPONENTS

S3000-4 4/08

S3000

SPINNER





IMPORTANT! If your system is designed with Nelson sprinklers, use Nelson Pressure Regulators. Individual manufacturers' pressure regulator performance varies. Interchanging could result in inaccurate nozzle selection.

NELSON

SAVE WATER, SAVE ENERGY AND DO A BETTER JOB OF IRRIGATING

NELSON'S S3000 SPINNER PIVOT SPRINKLER

Developed as a variation of the original Nelson Pivot Rotator®, the Spinner has proven to be a popular sprinkler choice for use on sensitive crops and soils that do well under a more gentle application of water. The S3000 uses the spinning action of the rotor plate to produce a desirable canopy of droplets.

FEATURES & BENEFITS:

SUPERIOR UNIFORMITY AT LOW PRESSURE. A low pressure alternative to fixed sprayheads, the S3000 provides higher uniformity with better overlap and lower application rates.

"LOW ENERGY DOWN IN THE CROP." The crop-guarded body design provides protection for operation down in tall growing crops. The spinning action of the rotor plate creates consistent droplets that penetrate the canopy.

NO SPECIAL MOUNTING ASSEMBLY REQUIRED because the S3000 Spinner operates without vibration. Retrofit on rigid, semi-rigid, or flexible drop hose assemblies.

COLOR-CODED NOZZLES. The 3TN Nozzle system is at the center of the 3000 Series Pivot Product line with easy-to-identify, wear-resistant, precision-accurate nozzles. The quick-change adapter allows you to remove the Spinner for easy cleaning of a plugged nozzle — without tools and without shutting down the system. It's a snap to change nozzles in mid-season.

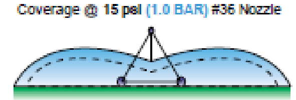
VERSATILE MODULAR DESIGN. Because no one sprinkler is right for all conditions, the 3000 Series features modular design components which are easily changed with a simple push and turn. You may want to start out the season with one configuration and change to a different one later.

> S3000 SPINNER PERFORMANCE*

NEW! Protective Shield provides longer wear life and enhanced reliability.

ADVANCED DESIGN. The plates of the S3000 Spinner are specifically engineered for high performance.

- Speed Control
- Uniformity built-in
- Droplet control solutions:
  - Gentle — for sensitive crops and soils
  - Windfighting — for maximum irrigation efficiency

SPRINKLER & PLATE TYPE	DESCRIPTION	PRESSURE RANGE**	3TN NOZZLE RANGE		THROW DIAMETER DATA*** (NO-WIND TESTS)
			MINIMUM	MAXIMUM	
 D6-12º RED PLATE	**FOR DROP TUBE APPLICATIONS** Lowest trajectory; gentle rainlike droplets.	10-20 PSI .7-1.4 BAR	#14 @ 15 PSI (1.0 BAR) #18 for lower pressures	#50	Coverage @ 15 psi (1.0 BAR) #36 Nozzle  Mounting Ht. / Throw Diameter: 6 ft. (1.8 M) ——— 44 ft. (13.4 M); 3 ft. (.9 M) - - - - 42 ft. (12.8 M)
 D6-20º PURPLE PLATE	**FOR DROP TUBE APPLICATIONS** All around performer; high uniformity, and gentle, rainlike droplets.	10-20 PSI .7-1.4 BAR	#14 @ 15 PSI (1.0 BAR) #16 for lower pressures	#50	Coverage @ 15 psi (1.0 BAR) #36 Nozzle  Mounting Ht. / Throw Diameter: 6 ft. (1.8 M) ——— 54 ft. (16.5 M); 3 ft. (.9 M) - - - - 48 ft. (14.6 M)
 NEW! D8 YELLOW PLATE	**FOR DROP TUBE APPLICATIONS** Multi-trajectory plate for maximum wind-fighting ability and even water distribution.	10-20 PSI .7-1.4 BAR	#14 @ 15 PSI (1.0 BAR) #16 for lower pressures	#50	Coverage @ 15 psi (1.0 BAR) #36 Nozzle  Mounting Ht. / Throw Diameter: 6 ft. (1.8 M) ——— 50 ft. (15.2 M); 3 ft. (.9 M) - - - - 44 ft. (13.4 M)
 NEW! BEIGE PLATE	**FOR DROP TUBE APPLICATIONS** Specialty plate for use with small nozzles near the pivot point to prevent over-watering. The beige plate should be used on flexible drops, or those with at least 1ft. (.3 m) of hose. The smaller nozzles will be more susceptible to plugging.	10-15 PSI .7-1.0 BAR	#10 @ 10 PSI (.7 BAR)	#15	Coverage @ 15 psi (1.0 BAR) #12 Nozzle  Mounting Ht. / Throw Diameter: 6 ft. (1.8 M) ——— 38 ft. (11.6 M); 3 ft. (.9 M) - - - - 34 ft. (10.4 M)

* Careful selection of pressure and sprinkler configuration must be taken into account to optimize droplet size. ** Pressure limits may exist on minimum and maximum nozzle sizes. *** Throw Distance Varies with Pressure, Nozzle Size, Mounting Height and Hydraulic Conditions.

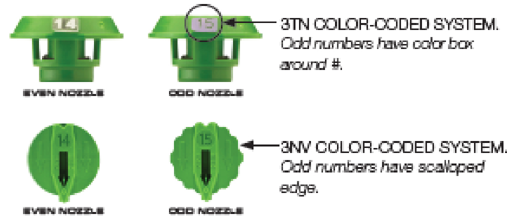
NELSON
Nelson Irrigation Corporation
848 Airport Rd., Walla Walla, WA 99362 USA
Tel: 509.525.7660 Fax: 509.525.7907 info@nelsonirrigation.com
Nelson Irrigation Corporation of Australia Pty. Ltd.
35 Sudbury Street, Darra QLD 4074 info@nelsonirrigation.com.au
Tel: +61 7 3715 8555 Fax: +61 7 3715 8666

WWW.NELSONIRRIGATION.COM

3TN & 3NV NOZZLE CHART

14 15 16 17 18 19

The nozzle sizing system is based on 128th inch increments, e.g. 3TN/3NV Nozzle #26 has an orifice diameter of 26/128th inches while 3TN/3NV Nozzle #27 has an orifice diameter of 27/128th inches. For 3TN Nozzles, the odd-numbered nozzles have a color box around the number marking. This color box denotes the color of the next larger nozzle size. The odd-numbered 3NV Nozzles have a scalloped edge rather than secondary coloring.



NOZZLE #		#9		#10		#11		#12		#13		#14		#15		#16		#17		#18		#19	
Color		Light Blue		Beige		Beige		Gold		Gold		Lime		Lime		Lavender		Lavender		Gray		Gray	
Stripe		Beige				Gold				Lime				Lavender				Gray				Turquoise	
PSI	BAR	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM
6	0.4	0.34	1.28	0.42	1.59	0.50	1.89	0.61	2.30	0.71	2.68	0.82	3.10	0.95	3.59	1.08	4.08	1.22	4.61	1.36	5.14	1.53	5.79
10	0.7	0.44	1.66	0.54	2.04	0.65	2.46	0.79	2.99	0.92	3.48	1.06	4.01	1.23	4.65	1.40	5.29	1.58	5.98	1.75	6.62	1.97	7.45
15	1.0	0.53	2.00	0.66	2.50	0.79	2.99	0.96	3.63	1.13	4.27	1.29	4.88	1.51	5.71	1.71	6.47	1.93	7.30	2.14	8.09	2.41	9.12
20	1.4	0.62	2.34	0.76	2.87	0.92	3.48	1.11	4.20	1.30	4.92	1.49	5.63	1.74	6.58	1.98	7.49	2.23	8.44	2.48	9.38	2.79	10.55
25	1.7	0.69	2.61	0.85	3.22	1.02	3.86	1.24	4.69	1.46	5.52	1.67	6.32	1.95	7.38	2.21	8.36	2.50	9.46	2.77	10.48	3.12	11.81
30	2.1	0.76	2.87	0.93	3.52	1.12	4.23	1.36	5.14	1.59	6.01	1.83	6.92	2.14	8.09	2.42	9.15	2.74	10.37	3.03	11.46	3.41	12.90
40	2.8	0.87	3.29	1.07	4.05	1.29	4.88	1.57	5.94	1.84	6.96	2.11	7.98	2.47	9.34	2.80	10.59	3.16	11.96	3.50	13.24	3.94	14.91
50	3.4	0.97	3.67	1.20	4.54	1.45	5.48	1.76	6.66	2.06	7.79	2.36	8.93	2.76	10.44	3.13	11.84	3.53	13.32	3.91	14.79	4.41	16.69

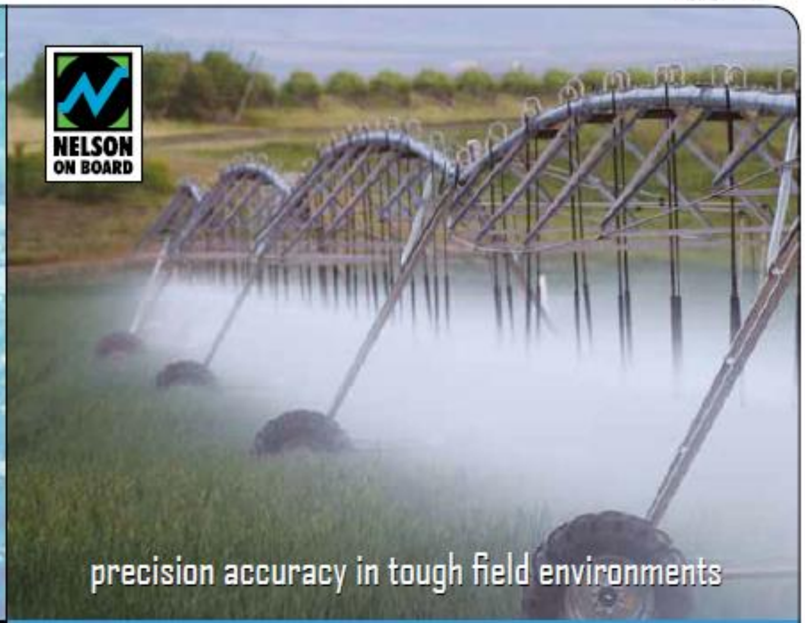
NOZZLE #		#20		#21		#22		#23		#24		#25		#26		#27		#28		#29		#30	
Color		Turquoise		Turquoise		Yellow		Yellow		Red		Red		White		White		Blue		Blue		Dark Brown	
Stripe				Yellow				Red				White				Blue				Dark Brown			
PSI	BAR	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM
6	0.4	1.70	6.43	1.84	6.96	2.04	7.72	2.22	8.40	2.44	9.23	2.64	9.99	2.87	10.86	3.07	11.61	3.35	12.68	3.58	13.55	3.83	14.49
10	0.7	2.19	8.28	2.38	9.00	2.64	9.99	2.86	10.82	3.16	11.96	3.41	12.90	3.70	14.00	3.97	15.00	4.32	16.35	4.62	17.48	4.94	18.69
15	1.0	2.69	10.18	2.91	11.01	3.23	12.22	3.50	13.24	3.86	14.61	4.17	15.78	4.53	17.14	4.86	18.38	5.29	20.02	5.66	21.42	6.06	22.93
20	1.4	3.10	11.73	3.36	12.71	3.73	14.11	4.05	15.32	4.46	16.88	4.82	18.24	5.23	19.79	5.61	21.23	6.11	23.12	6.53	24.71	6.99	26.45
25	1.7	3.47	13.13	3.76	14.23	4.17	15.78	4.52	17.10	4.99	18.88	5.39	20.39	5.85	22.14	6.27	23.73	6.83	25.85	7.30	27.63	7.82	29.59
30	2.1	3.80	14.38	4.12	15.59	4.56	17.25	4.96	18.77	5.47	20.70	5.90	22.33	6.41	24.26	6.87	26.00	7.48	28.31	8.00	30.28	8.56	32.39
40	2.8	4.39	16.61	4.76	18.01	5.27	19.94	5.72	21.65	6.31	23.88	6.81	25.77	7.40	28.00	7.94	30.05	8.64	32.70	9.24	34.97	9.89	37.43
50	3.4	4.90	18.54	5.32	20.13	5.88	22.29	6.40	24.22	7.06	26.72	7.61	28.80	8.28	31.33	8.87	33.57	9.66	36.56	10.33	39.13	11.06	41.86

NOZZLE #		#31		#32		#33		#34		#35		#36		#37		#38		#39		#40		#41	
Color		Dark Brown		Orange		Orange		Dark Green		Dark Green		Purple		Purple		Black		Black		Dark Turquoise		Dk. Turquoise	
Stripe		Orange				Dark Green				Purple				Black				Dk. Turquoise				Mustard	
PSI	BAR	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM
6	0.4	4.06	15.36	4.36	16.50	4.65	17.60	4.94	18.69	5.20	19.68	5.47	20.07	5.84	22.10	6.18	23.38	6.52	24.68	6.85	25.92	7.26	27.48
10	0.7	5.24	19.83	5.63	21.30	6.00	22.71	6.37	24.11	6.72	25.43	7.06	26.72	7.54	28.54	7.97	30.16	8.42	31.87	8.85	33.49	9.37	35.47
15	1.0	6.41	24.26	6.89	26.07	7.35	27.81	7.81	29.56	8.23	31.15	8.65	32.74	9.24	34.97	9.77	36.98	10.31	39.02	10.84	41.02	11.48	43.45
20	1.4	7.40	28.00	7.96	30.12	8.49	32.13	9.01	34.10	9.50	35.95	9.98	37.77	10.67	40.38	11.28	42.69	11.91	45.08	12.51	47.35	13.26	50.19
25	1.7	8.28	31.34	8.90	33.68	9.48	35.91	10.08	38.15	10.62	40.19	11.16	42.24	11.92	45.11	12.61	47.72	13.31	50.38	13.99	52.95	14.82	56.09
30	2.1	9.07	34.32	9.75	36.90	10.39	39.32	11.04	41.78	11.64	44.05	12.23	46.29	13.06	49.43	13.81	52.27	14.58	55.18	15.33	58.02	16.23	61.43
40	2.8	10.47	39.62	11.26	42.62	12.00	45.42	12.75	48.25	13.44	50.87	14.12	53.44	15.08	57.07	15.95	60.37	16.84	63.74	17.70	66.99	18.75	70.97
50	3.4	11.71	44.32	12.59	47.65	13.42	50.79	14.25	53.93	15.02	56.85	15.79	59.76	16.86	63.81	17.83	67.48	18.81	71.20	19.79	74.90	20.96	79.33

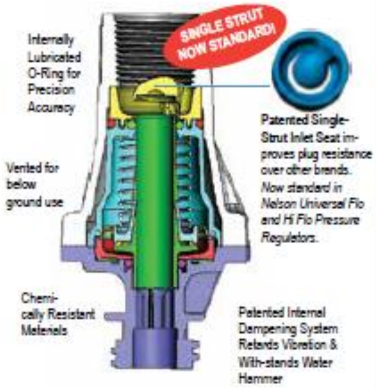
NOZZLE #		#42		#43		#44		#45		#46		#47		#48		#49		#50	
Color		Mustard		Mustard		Maroon		Maroon		Cream		Cream		Dark Blue		Dark Blue		Copper	
Stripe				Maroon				Cream				Dark Blue				Copper			
PSI	BAR	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM	GPM	LPM
6	0.4	7.60	28.76	7.96	30.13	8.33	31.52	8.73	33.04	9.12	34.51	9.58	36.26	9.96	37.69	10.31	39.02	10.77	40.76
10	0.7	9.81	37.13	10.28	38.91	10.75	40.69	11.27	42.66	11.77	44.54	12.36	46.78	12.86	48.67	13.31	50.38	13.91	52.64
15	1.0	12.01	45.45	12.59	47.65	13.17	49.84	13.80	52.23	14.41	54.54	15.14	57.30	15.75	59.61	16.30	61.70	17.03	64.45
20	1.4	13.87	52.49	14.54	55.03	15.20	57.53	15.93	60.30	16.64	62.98	17.49	66.20	18.19	68.84	18.82	71.23	19.67	74.45
25	1.7	15.51	58.70	16.25	61.51	17.00	64.34	17.81	67.41	18.61	70.43	19.55	74.00	20.33	76.94	21.05	79.67	21.99	83.23
30	2.1	16.99	64.30	17.80	67.37	18.62	70.47	19.51	73.85	20.38	77.13	21.42	81.07	22.28	84.32	23.05	87.24	24.09	91.18
40	2.8	19.61	74.22	20.56	77.82	21.50	81.37	22.53	85.28	23.54	89.09	24.73	93.60	25.72	97.35	26.62	100.75	27.82	105.29
50	3.4	21.93	83.00	22.98	86.98	24.04	90.99	25.19	95.34	26.31	99.58	27.65	104.66	28.76	108.85	29.76	112.64	31.10	117.71

This flow data was obtained under ideal test conditions and may be adversely affected by poor hydraulic entrance conditions, turbulence or other factors. Nelson Irrigation makes no representation regarding sprinkler flow rate accuracy under various plumbing and drop pipe conditions.

Tel: +1 509.525.7660 / Fax: +1 509.525.7907 / nelsonirrigation.com / info@nelsonirrigation.com



Cut-away of Pressure Regulator



TECHNICAL TIPS FOR REGULATING SYSTEMS

IMPORTANT: Allow approximately 5 PSI (.35 BAR) extra pressure in order for the regulator to function properly. For example, the minimum design pressure for a 20 PSI (1.4 BAR) pressure regulator is 25 PSI (1.7 BAR).

IMPORTANT: If your system is designed with Nelson sprinklers, use Nelson Pressure Regulators. Individual manufacturers' pressure regulator performance varies. Interchanging could result in inaccurate nozzle selection.

NELSON'S UNIVERSAL FLO AND HI FLO REGULATORS

The function of a pressure regulator is to fix a varying inlet pressure to a set outlet pressure, regardless of changes in the system pressure due to hydraulic conditions, elevation changes, pumping scenarios, etc. The benefits include a uniform depth of water application, controlled sprinkler performance (droplet size and throw distance), and flexibility in system operation.

FEATURES & BENEFITS:

SINGLE STRUT SEAT DESIGN STANDARD WITH UNIVERSAL FLO. The new "single-strut" technology in the Universal Flo regulator minimizes "hair-pinning" of debris around the inlet seat, providing more plug resistance for systems operating in dirty water condtions.

PATENTED DAMPENING SYSTEM. The patented o-ring dampening system of all Nelson pressure regulators handles severe pressure surges to withstand water hammer.

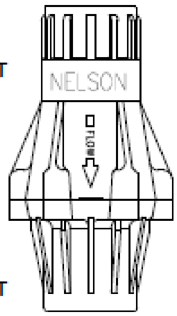
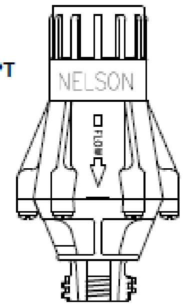
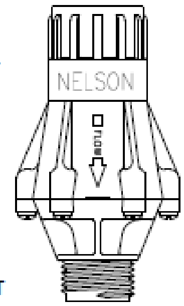
WIDE FLOW RANGE. The Nelson Universal Pressure Regulator has a flow up to 12 GPM (2.7 M^3/H) at 15 PSI (1.0 BAR) and above.

EXTENDED PERFORMANCE AND PRECISION ACCURACY. Precision components coupled with an internally lubricated o-ring minimize frictional drag and hysteresis.

PRECISION MANUFACTURED. Made of the toughest chemically resistant materials. 100% tested for accuracy.

UNIVERSAL 3000 SERIES CONNECTION OPTION. Integral adapter connects directly into all Nelson 3000 Series Pivot Sprinklers and creates an easy to assemble, economical pivot sprinkler package.

> UNIVERSAL FLO and HIGH FLO — CONNECTIONS & PERFORMANCE

PIPE THREAD CONNECTION	3000 SERIES PIVOT CONNECTION *(Integral adapter for 3000 Series Pivot Products)*	HOSE THREAD CONNECTION *(Connections for Micro/Drip)*
INLET **3/4" FNPT**  **OUTLET** **3/4" FNPT**	**INLET** **3/4" FNPT**  **OUTLET** **3000 ST**	**INLET** **3/4" FHT**  **OUTLET** **3/4" MHT**

ORDERING SPECIFICATIONS: When ordering Nelson Pressure Regulators specify Pressure, Flow (Universal Flo or Hi Flo) & Connection (Inlet x Outlet). (Example: 10 PSI Hi Flo 3/4"FNPT x 3/4"FNPT.) **More connection options available — please contact Nelson factory for more information.**

UNIVERSAL FLO REGULATOR

PSI	BAR	GPM	M³/HR	CONNECTIONS AVAILABLE 3/4" FNPT 3/4" FNPT	3/4" FNPT 3/4" ST	3/4" FHT 3/4" MHT
6	0.41	0.5-8	0.11-1.82	■	■	■
10	0.70	0.5-10	0.11-2.27	■	■	■
15	1.0	0.5-12	0.11-2.72	■	■	■
20	1.4	0.5-12	0.11-2.72	■	■	■
25	1.7	0.5-12	0.11-2.72	■	■	■
30	2.0	0.5-12	0.11-2.72	■	■	■
40	2.8	0.5-12	0.11-2.72	■	■	■
50	3.4	0.5-12	0.11-2.72	■	■	■

HI-FLO REGULATOR

PSI	BAR	GPM	M³/HR	CONNECTIONS AVAILABLE 3/4" FNPT 3/4" FNPT	3/4" FNPT 3/4" ST
6	0.41	4-16	.91-3.63	■	■
10	0.70	4-16	.91-3.63	■	■
15	1.0	2-20	.45-4.54	■	■
20	1.4	2-20	.45-4.54	■	■
25	1.7	2-20	.45-4.54	■	■
30	2.0	2-20	.45-4.54	■	■
40	2.8	2-20	.45-4.54	■	■
50	3.4	2-20	.45-4.54	■	■

APPLICATION NOTES

Nelson Pressure Regulators can be used in a variety of applications (e.g. Center Pivot, Solid Set, Tree & Vine). Choose the proper pressure rating for your application.

Performance Tables. Contact the Nelson factory for detailed performance information.

Design Considerations. Maintain a 5 PSI (0.35 BAR) threshold above the nominal spring rated pressure.

CAUTION! Pressure regulators should be installed downstream from all shut-off valves.

WARRANTY AND DISCLAIMER: Nelson Pressure Regulators are warranted for one year from date of original sale to be free of defective materials and workmanship when used within the working specifications for which the products were designed and under normal use and service. The manufacturer assumes no responsibility for installation, removal or unauthorized repair of defective parts. The manufacturer's liability under this warranty is limited solely to replacement or repair of defective parts and the manufacturer will not be liable for any crop or other consequential damages resulting from defects or breach of warranty. THIS WARRANTY IS EXPRESSLY IN LIEU OF ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, INCLUDING THE WARRANTIES OF MERCHANTABILITY AND FITNESS FOR PARTICULAR PURPOSES AND OF ALL OTHER OBLIGATIONS OR LIABILITIES OF MANUFACTURER. No agent, employee or representative of the manufacturer has authority to waive, alter or add to the provisions of this warranty, nor to make any representations or warranty not contained herein.

This product may be covered by one or more of the following U.S. Patent No. 5257646 and other U.S. Patents pending or corresponding issued or pending foreign patents.

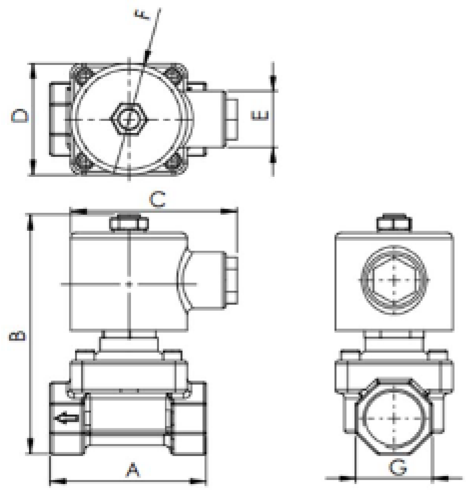
NELSON

Nelson Irrigation Corporation
848 Airport Rd., Walla Walla, WA 99362 USA
Tel: 509.525.7660 Fax: 509.525.7907 info@nelsonirrigation.com
Nelson Irrigation Corporation of Australia Pty. Ltd.
35 Sudbury Street, Darra QLD 4074 info@nelsonirrigation.com.au
Tel: +61 7 3715 8555 Fax: +61 7 3715 8666

WWW.NELSONIRRIGATION.COM

The Brass - Series Semi-Direct acting, 2 Way General Purpose Solenoid Valves provide and on-off control of inherit liquids and gases. Suitable for commercial and residential applications. This valve type is gravity feed capable and is deal for low pressure fluid applistions. Available in sizes from 3/8" - 2" in both Normally Closed and Normally Open operating positions.

*These valves are not intended for use in medical life support, combustion, aviation, aerospace, automotive or similar applications.



Materials	
Valve Body	Brass
Seal	FKM
Shading Ring	Copper
Hardware	S/S

Electrical				
Connection Type	N/C - 5.5" Lead		N/O - DIN	
Protection Class	NEMA 3		IP54	
Available Voltages	DC: 24V	DC: 12V	AC: 24V/60Hz	AC: 110V/60Hz
Power 3/8" - 1"	28 W	18 W	28 W	28 W
Power 1-1/4" - 2"	40 W	30 W	40 W	40 W

Brass - Series						Operating Temp				Dimensions						
Port Size	Thread	Orifice	Cv Value	Min PSI	Max PSI	Min	Max	Duty Cycle	Weight	A	B	C	D	E	F	G
Normally Closed																
3/8"	NPT	5/8	4.8	0	AC145 DC115	15°F	250°F	100%	1lb 7oz	2.36"	4.00"	2.83"	2.00"	1.00"	1.96"	1.05"
1/2"	NPT	5/8	4.8	0	AC145 DC115	15°F	250°F	100%	1lb 7oz	2.36"	4.00"	2.83"	2.00"	1.00"	1.96"	1.06"
3/4"	NPT	3/4	7.6	0	AC145 DC115	15°F	250°F	100%	1lb 10oz	2.65"	4.25"	2.83"	2.00"	1.00"	1.96"	1.30"
1"	NPT	1	12	0	AC145 DC115	15°F	250°F	100%	2lb 5oz	3.25"	4.50"	2.83"	2.60"	1.00"	1.96"	1.57"
1-1/4"	NPT	1 1/4	24	0	AC145 DC90	15°F	250°F	100%	4lbs 11oz	4.00"	5.80"	3.55"	3.22"	1.00"	2.70"	1.95"
1-1/2"	NPT	1 4/7	29	0	AC145 DC90	15°F	250°F	100%	4lbs 14oz	4.33"	6.00"	3.55"	3.35"	1.00"	2.70"	2.20"
2"	NPT	1 7/8	48	0	AC145 DC90	15°F	250°F	100%	7lbs	5.30"	6.50"	3.55"	4.25"	1.00"	2.70"	2.66"
Normally Open																
1/2"	NPT	5/8	4.8	0	90	15°F	250°F	100%	1lb 9oz	2.36"	4.50"	3.50"	1.95"	.80"	1.96"	1.06"
3/4"	NPT	3/4	7.6	0	90	15°F	250°F	100%	1lb 13oz	2.65"	4.70"	3.50"	2.00"	.80"	1.96"	1.30"
1"	NPT	1	12	0	90	15°F	250°F	100%	2lb 7oz	3.20"	5.00"	3.50"	2.60"	.80"	1.96"	1.57"
1-1/2"	NPT	1 4/7	29	0	90	15°F	250°F	100%	5lb 2oz	4.33"	7.00"	4.50"	3.25"	1.15"	2.75"	2.25"
2"	NPT	1 7/8	48	0	90	15°F	250°F	100%	7lb 8oz	5.30"	7.50"	4.50"	4.25"	1.15"	2.75"	2.75"

*Consult a chemical compatibility expert for correct seal and valve body material choice.
*Weight and dimensions may vary slightly from production.

APPENDIX B

EROSION CONTROL PRODUCT SPECIFICATIONS

Profile
Solutions for your Environment™

ProPlus®
Tacking Agent 3®

Tacking Agent 3®- Tackifier

A Tackifier that requires no cure time!

- Tacking Agent 3 has long set the standard as an effective binding agent. It is proven to reduce soil erosion and water runoff immediately after hydroseeding—no cure time is required!
- Tacking Agent 3 contains a flocculant, polyacrylamide and hydro-colloid polymers for enhanced fiber-to-soil bond as well as a marker dye to enhance visual metering when the product is being applied

Hydraulic Fiber Mulch Binding - Slope Gradient/Condition Rate:

>2H:1V Slope 60lbs per acre
3H:1V Slope 40lbs per acre
4H:1V Slope 30lbs per acre
Modest to 5H :1V Slope 20lbs per acre

TANK LOADS	
300 gal	3 lb
500 gal	5 lb
900 gal	10 lb
1,500 gal	15 lb
3,000 gal	30 lb

Amendment Ingredients

Polyacrylamide
Acrylamide copolymer
Hydro-colloid polymers
Marker Dye

Packaging

4 – 8-lb bags per case/60 cases per pallet; 7 – 3-lb water soluble bags per case/56 cases per pallet; 40 – 50-lb bags/50 – 40-lb bags per pallet

GREEN DESIGN ENGINEERING™
EARTH-FRIENDLY SOLUTIONS FOR SUSTAINABLE RESULTS™

Find us on Facebook

For technical information or distribution, please call 800-508-8681.
For customer service, call 800-366-1180.

For warranty information, visit www.profileproducts.com.
750 Lake Cook Road • Suite 440 • Buffalo Grove, IL 60089

IECA

JS-01 03/15

EcoFibre™ Plus Tackifier

PREMIUM WOOD FIBER MULCH PLUS TACKIFIER

EcoFibre™ Plus Tackifier is designed to provide extra protection on difficult sites!

GET MORE BUILD OUT OF EVERY ECO BAG

Profile's Thermally Refined® wood fibers maximize coverage and performance. Our processing technology produces fibers that hold 50% more water than competitive wood fiber products. Atmospherically refined wood fiber simply doesn't provide as much coverage per bag as the Eco line.

- EcoFibre Plus Tackifier is 100% Thermally Refined wood fiber plus an organic polysaccharide tackifier to ensure a smooth hydroseeding application
- EcoFibre Plus Tackifier provides additional protection on difficult sites where slopes, soil conditions or weather call for extra erosion control measures
- Longer wood fibers and tackifier mesh together, interlocking to provide enhanced protection on the soil surface
- With the premium tackifier and fibers, there is no risk of a paper-maché effect
- An environmentally superior product, EcoFibre Plus Tackifier allows for enhanced soil protection and seed germination
- EcoFibre Plus Tackifier decomposes into carbon dioxide, water and organic matter to further aid in plant development
- Its green color assists in even application and also allows the mulch matrix to blend with the environment
- Non-toxic and environmentally safe
- Maximum slope length of 30 feet (9 m)
- Use approved mechanically agitated equipment for optimum pumping and application performance
- EcoFibre Plus Tackifier functional longevity is ≤ 3 months

Product Composition:

Thermally Refined® Wood Fibers – 85% ± 3%
Guar Based Tackifier – 3% ± 1%
Moisture Content – 12% ± 3%

(40) 50-lb (23 kg) bales per pallet

Slope Gradient/Condition	Rate
≤ 4H:1V	2000 lb/ac (2300 kg/ha)
> 4H:1V and ≤ 3H:1V	2500 lb/ac (2800 kg/ha)
> 3H:1V and ≤ 2H:1V	3000 lb/ac (3400 kg/ha)

PROFILE Products LLC • 750 Lake Cook Road • Suite 440 • Buffalo Grove, IL 60089
Technical Assistance: 800-508-8681
www.profile-eco.com

02-eco 03/13

Profile

Solutions for your Environment™

EcoSolutions® EcoFibre® Plus Tackifier

Hydraulic Mulch — Wood with Tack

GREEN DESIGN ENGINEERING™ EARTH-FRIENDLY SOLUTIONS FOR SUSTAINABLE RESULTS™

Description

EcoSolutions® EcoFibre® Plus Tackifier is a fully biodegradable, Hydraulic Mulch (HM) composed of 100% recycled Thermally Refined™ virgin wood fibers and wetting agents (including high-viscosity colloidal polysaccharides). The HM is phytosanitized, free from plastic netting, and upon application forms an intimate bond with the soil surface to create a porous, absorbent and flexible erosion resistant blanket that allows for rapid germination and accelerated plant growth.

Recommended Applications

- Erosion control and revegetation for moderate slopes (≤2H:1V)
- Rough graded slopes
- Enhancement of vegetation establishment

Technical Data

Physical Properties*	Test Method	Units	Tested Value
Mass/Unit Area	ASTM D6566	g/m^2 (oz/yd^2)	≥ 336 (9.9)
Water Holding Capacity	ASTM D7367	%	≥ 1,200
Material Color	Observed	n/a	Green
Performance Properties*	**Test Method**	**Units**	**Tested Value**
Cover Factor[1]	Large Scale[2]	n/a	≤ 0.25
Percent Effectiveness[3]	Large Scale[2]	%	≥ 75
Functional Longevity[4]	ASTM D5338	months	≤ 3
Environmental Properties*	**Test Method**	**Units**	**Tested Value**
Ecotoxicity	EPA 2021.0	%	48-hr LC_{50} > 100%
Biodegradability	ASTM D5338	n/a	Yes
Product Composition			**Typical Value**
Thermally Processed Wood Fibers[5]			97%
Wetting Agent–Including high-viscosity colloidal polysaccharides			3%

* When uniformly applied at a rate of 3000 pounds per acre (3400 kilograms/hectare) under laboratory conditions. 1. Cover Factor is calculated as soil loss ratio of treated surface versus an untreated control surface. 2. Large scale testing conducted at Utah Water Research Laboratory. For specific testing information please contact a Profile technical service representative at 800-508-8681 or +1-847-215-3464. 3. % Effectiveness = One minus Cover Factor multiplied by 100%. 4. Functional Longevity is the estimated time period, based upon ASTM D5338 testing and field observations, that a material can be anticipated to provide erosion control and agronomic benefits as influenced by composition, as well as site-specific conditions, including; but not limited to – temperature, moisture, light conditions, soils, biological activity, vegetative establishment and other environmental factors. 5. Heated within a pressurized vessel to a temperature greater than 380 degrees Fahrenheit (193 degrees Celsius) for 5 minutes at a pressure greater than 50 psi (345 kPa) in order to be Thermally Refined™/Processed and to achieve phyto-sanitization.

Packaging Data

Properties	Test Method	Units	Nominal Value
Bag Weight	Scale	kg (lb)	22.7 (50)
Bags per Pallet	Observed	#	40

UV and weather-resistant plastic bags. Pallets are weather-proof stretch wrapped with UV resistant pallet cover.

Profile Products
750 Lake Cook Road, Ste. 440
Buffalo Grove, IL 60089
800-508-8681 or +1-847-215-3464
www.profileproducts.com

SoilCover® Wood Fiber with Tack

Excellent choice on difficult sites and conditions!

Our experience and expertise result in your success

Each SoilCover® product is created with the knowledge of what makes plants grow and unequaled experience in what makes you successful. Our Thermally Refined® wood fiber is a prime example — holding 13.5 times its weight in water and improving yield. The process that produces Thermally Refined wood fiber uses heat and pressure to break wood down into more fibrous material with greater surface area.

- Thermally Refined wood fiber holds 13.5 times its weight in water — creating an excellent environment for seed germination
- SoilCover® Wood Fiber with Tack is pre-blended and evenly dispersed within the mulch — eliminating the extra step and mess of field mixing
- Thermally Refined wood fibers interlock to safely secure bare soil
- Improved turf establishment and erosion control with increased bonding to the soil surface
- Enhanced coverage — reduces the number of bales you buy and load
- An environmentally superior product that controls erosion and then decomposes over time
- Greater productivity — eliminates clogs from the coarse fiber found in competitive mulches
- Non-toxic, environmentally safe and biodegradable
- Maximum slope length of 30 feet
- Use approved mechanically agitated equipment for optimum pumping and application performance
- SoilCover Wood Fiber with Tack functional longevity is ≤ 3 months

Product Composition:

Thermally Refined® Wood Fibers – 85% ± 3%
Polymer Based Tackifier – 3% ± 1%
Moisture Content – 12% ± 3%

(40) 50-lb bales per pallet

Slope Gradient/Condition	Rate
≤ 4H:1V	2000 lb/acre
> 4H:1V and ≤ 3H:1V	2500 lb/acre
> 3H:1V and ≤ 2H:1V	3000 lb/acre

PROFILE Products LLC · 750 Lake Cook Road · Suite 440 · Buffalo Grove, IL 60089
Technical Assistance: 800-508-8681
www.profileproducts.com

Profile
Solutions for your Environment

Soil Cover®
Wood with Tack
Hydraulic Mulch — Wood with Tack

GREEN DESIGN ENGINEERING™
EARTH-FRIENDLY SOLUTIONS FOR SUSTAINABLE RESULTS™

Description

SoilCover® Wood with Tack is a fully biodegradable, Hydraulic Mulch (HM) composed of 100% recycled Thermally Refined™ virgin wood fibers and wetting agents (including high-viscosity colloidal polysaccharides). The HM is phytosanitized, free from plastic netting, and upon application forms an intimate bond with the soil surface to create a porous, absorbent and flexible erosion resistant blanket that allows for rapid germination and accelerated plant growth.

Recommended Applications

- Erosion control and revegetation for moderate slopes (≤2H:1V)
- Rough graded slopes
- Enhancement of vegetation establishment

Technical Data

Physical Properties*	Test Method	Units	Tested Value
Mass/Unit Area	ASTM D6566	g/m^2 (oz/yd^2)	≥ 336 (9.9)
Water Holding Capacity	ASTM D7367	%	≥ 1,200
Material Color	Observed	n/a	Green
Performance Properties*	**Test Method**	**Units**	**Tested Value**
Cover Factor[1]	Large Scale[2]	n/a	≤ 0.25
Percent Effectiveness[3]	Large Scale[2]	%	≥ 75
Functional Longevity[4]	ASTM D5338	months	≤ 3
Environmental Properties*	**Test Method**	**Units**	**Tested Value**
Ecotoxicity	EPA 2021.0	%	48-hr LC_{50} > 100%
Biodegradability	ASTM D5338	n/a	Yes
Product Composition			**Typical Value**
Thermally Processed Wood Fibers[5]			97%
Wetting Agent–Including high-viscosity colloidal polysaccharides			3%

* When uniformly applied at a rate of 3000 pounds per acre (3400 kilograms/hectare) under laboratory conditions. 1. Cover Factor is calculated as soil loss ratio of treated surface versus an untreated control surface. 2. Large scale testing conducted at Utah Water Research Laboratory. For specific testing information please contact a Profile technical service representative at 800-508-8681 or +1-847-215-3464. 3. % Effectiveness = One minus Cover Factor multiplied by 100%. 4. Functional Longevity is the estimated time period, based upon ASTM D5338 testing and field observations, that a material can be anticipated to provide erosion control and agronomic benefits as influenced by composition, as well as site-specific conditions, including; but not limited to – temperature, moisture, light conditions, soils, biological activity, vegetative establishment and other environmental factors. 5. Heated within a pressurized vessel to a temperature greater than 380 degrees Fahrenheit (193 degrees Celsius) for 5 minutes at a pressure greater than 50 psi (345 kPa) in order to be Thermally Refined™/Processed and to achieve phyto-sanitization.

Packaging Data

Properties	Test Method	Units	Nominal Value
Bag Weight	Scale	kg (lb)	22.7 (50)
Bags per Pallet	Observed	#	40

UV and weather-resistant plastic bags. Pallets are weather-proof stretch wrapped with UV resistant pallet cover.

Profile Products
750 Lake Cook Road, Ste. 440
Buffalo Grove, IL 60089
800-508-8681 or +1-847-215-3464
www.profileproducts.com

TERRA-MULCH

BETTER SCIENCE. BETTER VEGETATION.

Terra-Mulch® Terra-Wood™ with Tacking Agent 3®

Wood Fiber with Tackifier

Enhanced water-holding capacity excels growth

- 100% wood fiber is just like Terra-Wood™ but with the industry's leading tackifier, Tacking Agent 3®
- Tacking Agent 3 is a three-dimensional blend of polymers and polysaccharide, proven to reduce soil erosion and water runoff immediately after hydroseeding—no cure time required
- Controls erosion without having to cure—ideal on critical sites with up to 2H:1V slopes
- Wood fibers interlock for a more secure fiber-to-soil bond
- Contractors report that our wood fiber delivers up to 30% more yield than competitive products, which means more money in their pockets
- Non-toxic and environmentally safe
- Meets or exceeds all requirements for wood fiber mulch
- Maximum slope length of 30 feet (9 m)
- Use approved hydroseeding equipment for optimum pumping and application performance
- Terra-Wood with Tacking Agent 3 functional longevity is ≤ 3 months

Product Composition:

Thermally Processed (within a pressurized vessel) Wood Fibers	97%
Wetting Agents	3%

(40) 50-lb (22.7 kg) bales per pallet

Slope Gradient/Condition	Rate
≤ 4H:1V	2000 lb/ac (2240 kg/ha)
> 4H:1V and ≤ 3H:1V	2500 lb/ac (2800 kg/ha)
> 3H:1V and ≤ 2H:1V	3000 lb/ac (3360 kg/ha)

Profile

Solutions for your Environment™

PROFILE Products LLC • 750 Lake Cook Road, Suite 440 • Buffalo Grove, IL 60089
Technical Assistance: 800-508-8681
www.terra-mulch.com

01-terra 03/14

Terra-Wood™ with Tacking Agent 3®

Hydraulic Mulch — Wood with Tack

Profile — Solutions for your Environment™

GREEN DESIGN ENGINEERING™ — EARTH-FRIENDLY SOLUTIONS FOR SUSTAINABLE RESULTS™

Description

Terra-Wood™ with Tacking Agent 3® is a fully biodegradable, Hydraulic Mulch (HM) composed of 100% recycled Thermally Refined™ virgin wood fibers and wetting agents (including high-viscosity colloidal polysaccharides). The HM is phytosanitized, free from plastic netting, and upon application forms an intimate bond with the soil surface to create a porous, absorbent and flexible erosion resistant blanket that allows for rapid germination and accelerated plant growth.

Recommended Applications

- Erosion control and revegetation for moderate slopes (≤2H:1V)
- Rough graded slopes
- Enhancement of vegetation establishment

Technical Data

Physical Properties*	Test Method	Units	Tested Value
Mass/Unit Area	ASTM D6566	g/m^2 (oz/yd^2)	≥ 336 (9.9)
Water Holding Capacity	ASTM D7367	%	≥ 1,200
Material Color	Observed	n/a	Green
Performance Properties*	**Test Method**	**Units**	**Tested Value**
Cover Factor[1]	Large Scale[2]	n/a	≤ 0.25
Percent Effectiveness[3]	Large Scale[2]	%	≥ 75
Functional Longevity[4]	ASTM D5338	months	≤ 3
Environmental Properties*	**Test Method**	**Units**	**Tested Value**
Ecotoxicity	EPA 2021.0	%	48-hr LC_{50} > 100%
Biodegradability	ASTM D5338	n/a	Yes
Product Composition			**Typical Value**
Thermally Processed Wood Fibers[5]			97%
Wetting Agent–Including high-viscosity colloidal polysaccharides			3%

* When uniformly applied at a rate of 3000 pounds per acre (3400 kilograms/hectare) under laboratory conditions. 1. Cover Factor is calculated as soil loss ratio of treated surface versus an untreated control surface. 2. Large scale testing conducted at Utah Water Research Laboratory. For specific testing information please contact a Profile technical service representative at 800-508-8681 or +1-847-215-3464. 3. % Effectiveness = One minus Cover Factor multiplied by 100%. 4. Functional Longevity is the estimated time period, based upon ASTM D5338 testing and field observations, that a material can be anticipated to provide erosion control and agronomic benefits as influenced by composition, as well as site-specific conditions, including; but not limited to – temperature, moisture, light conditions, soils, biological activity, vegetative establishment and other environmental factors. 5. Heated within a pressurized vessel to a temperature greater than 380 degrees Fahrenheit (193 degrees Celsius) for 5 minutes at a pressure greater than 50 psi (345 kPa) in order to be Thermally Refined™/Processed and to achieve phyto-sanitization.

Packaging Data

Properties	Test Method	Units	Nominal Value
Bag Weight	Scale	kg (lb)	22.7 (50)
Bags per Pallet	Observed	#	40

UV and weather-resistant plastic bags. Pallets are weather-proof stretch wrapped with UV resistant pallet cover.

Profile Products
750 Lake Cook Road, Ste. 440
Buffalo Grove, IL 60089
800-508-8681 or +1-847-215-3464
www.profileproducts.com

Curlex® Blankets

Excelsior Erosion Control Blankets

American Excelsior Company is the inventor of biodegradable erosion control blankets. Developed in the early 60's, Curlex excelsior blankets are specifically designed to actually promote ideal growing conditions for grass seed, while simultaneously protecting topsoil from wind and water erosion. Curlex excelsior blankets have long passed the test of time. By design, Curlex blankets have a built-in swell factor - wet curled excelsior fibers sightly expand in thickness and interlock to form a strong, fiber matrix. This allows the fibers to provide intimate contact with local terrain. Water flow is trained to follow the curled fiber matrix. The roughness of the curled excelsior matrix slows the velocity to a point where gravity takes over, which allows moisture to slowly seep into the topsoil to promote ideal growing conditions.

Material Characteristics

Curlex blankets consist of unique softly barbed, interlocking, curled, Aspen excelsior fibers. They are weed seed free. Curlex blankets are available with a variety of environmentally sensitive and/or stronger netting types to match job site requirements. We offer a green color-coded plastic netting for applications requiring UV resistance strength and longevity. Our photodegradable QuickMow™ netting is recommended for urban, golf course, and certain roadside projects. It is color-coded white to identify it as a rapid break-down, polypropylene netting designed for use in areas to be mowed. Also available is our FibreNet™ - 100% biodegradable netting - for use in critical environmentally sensitive areas.

Most straight-line fiber blankets draw the line at 270 g/m^2 (.50 lb/yd^2), but not Curlex. At just under 400 g/m^2 (.75 lb/yd^2) Curlex blankets bring 50% more erosion control fibers to your job site. Curlex blankets are available in natural Aspen or QuickGRASS® (green). Combine that with a roll that's wider than conventional blankets and you have today's most effective and efficient, multi-purpose degradable erosion control blanket. Curlex excelsior blankets are available individually wrapped or in master packs to allow for mechanical unloading and stacking.

Performance Capabilities

Product	Slopes	Shear Stress Rating
Curlex I	2H:1V & flatter	84 Pa (1.75 lb/ft^2)
Curlex II	1.5H:1V & flatter	108 Pa (2.25 lb/ft^2)

Typical Applications

- Highway embankments, ditch bottoms and slopes, bridges, approaches and medians
- Residential, commercial, & industrial developments
- Urban drainage, stream banks, and waterways
- Golf course fairways, roughs, waterways, & drop structures
- Landfill caps, side slopes, and let down structures
- Pipeline right-of-ways

American Excelsior Company®
Earth Science Division
Arlington, Texas (800) 777-SOIL • www.curlex.com

MADE IN THE U.S.A.

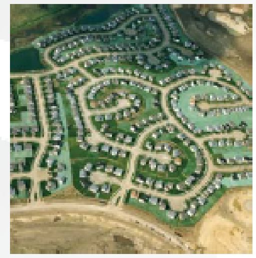
American Excelsior Company®
Earth Science Division

Curlex® Blankets

Excelsior Erosion Control Blankets

SUGGESTED SPECIFICATIONS

Curlex Single Net (Curlex I)



A specific cut of Great Lakes Aspen curled wood excelsior with 80% six-inch fibers or greater fiber length. It shall be of consistent thickness, with fibers evenly distributed throughout the entire area of the blanket. The top of each blanket shall be covered with photodegradable or biodegradable netting. Material shall not contain any weed seed or chemical additives.

Specifications

Recommended Use:	Slopes to 2:1, Channel to 7 ft/s, shear stress to 1.75 lb/ft^2
Roll Sizes:	4' x 112.5' (50 yd^2), 8' x 112.5' (100 yd^2), 16' x 112.5' (200 yd^2)
Standard Weight*:	.73 lb/yd^2
Netting Options:	Green, QuickMow White (90 day), FibreNet
Color:	Natural Aspen or QuickGRASS Green

Curlex Double Net (Curlex II)

A specific cut of Great Lakes Aspen curled wood excelsior with 80% six-inch fibers or greater fiber length. It shall be of consistent thickness, with fibers evenly distributed throughout the entire area of the blanket. The top and bottom of each blanket shall be covered with photodegradable or biodegradable netting. Material shall not contain any weed seed or chemical additives.

Specifications

Recommended Use:	Slopes to 1.5:1, Channels to 9 ft/s, shear stress to 2.25 lb/ft
Roll Sizes:	4' x 112.5' (50 yd^2), 8' x 112.5' (100 yd^2), 16' x 112.5' (200 yd^2)
Standard Weight*:	.73 lb/yd^2
Netting Options:	Green, QuickMow White (90 day), FibreNet
Color:	Natural Aspen or QuickGRASS Green

*Weight is based on a dry fiber weight basis at time of manufacture. Baseline moisture content of Great Lakes Aspen Excelsior is 22%.

Installation

Before installing Curlex blankets, the seedbed shall be inspected by the Owner's Representative to ensure it has been properly compacted and fine graded to remove any existing rills. It shall be free of obstructions, such as tree roots, projections such as stones, and other foreign objects. Grass seed shall match soil conditions to allow for maximum germination, dense vegetation, and a structural root system. Contractor shall proceed when satisfactory conditions are present. After the area has been properly shaped, seeded, fertilized, and compacted, locate the start of the roll, making sure the roll is facing toward the area to be covered, and then roll out the blanket. Blankets shall be rolled out flat, even, and smooth without stretching the material then anchored to the subgrade.

Slopes: It is recommended that the blankets be installed in the same direction as the water flow; however, on short slopes it may be more practical to install horizontally across the width of the application. If more than one width is required, simply abut the edges together and secure the blankets with a common row of biodegradable staples, steel staples, or stakes. Overlapping of Curlex excelsior blankets is not required or recommended. An exception is waterway slopes.

Channels: Curlex blankets shall be centered to offset a seam in the middle of the waterway. They shall be installed in the same direction as the water flow. The adjoining blankets shall be installed away from the center of channel and concentrated water flow. They shall be secured by a common row of staples. It is usually not necessary to overlap Curlex blankets; however, a 2" shingle type installation shall be used in waterway slopes applications. Curlex blanket installation should continue up the side slopes 3' above the anticipated high water elevation. Flanks exposed to runoff, or sheet flow, must be protected by a check slot or trenched. Curlex blankets shall be trenched at the start of the channel and anchored using a staggered staple pattern at end of roll overlaps and end of roll terminations.

MADE IN THE U.S.A.

If you would like to receive more information or consult with one of our Customer Care Center Specialists, please call us toll free at (888-352-9582)
PDF download specifications available in the Technical Support Library at www.curlex.com

Form#235/092013E

ROLLMAX™
ROLLED EROSION CONTROL

Specification Sheet

BioNet® SC150BN™ Erosion Control Blanket

DESCRIPTION

The extended-term double net erosion control blanket shall be a machine-produced mat of 70% agricultural straw and 30% coconut fiber with a functional longevity of up to 18 months. (NOTE: functional longevity may vary depending upon climatic conditions, soil, geographical location, and elevation). The blanket shall be of consistent thickness with the straw and coconut evenly distributed over the entire area of the mat. The blanket shall be covered on the top and bottom sides with a 100% biodegradable woven natural organic fiber netting. The netting shall consist of machine directional strands formed from two intertwined yarns with cross directional strands interwoven through the twisted machine strands (commonly referred to as Leno weave) to form an approximate 0.50 x 1.0 in. (1.27 x 2.54 cm) mesh. The blanket shall be sewn together on 1.50 inch (3.81 cm) centers with degradable thread. The blanket shall be manufactured with a colored thread stitched along both outer edges (approximately 2-5 inches [5-12.5 cm] from the edge) as an overlap guide for adjacent mats.

The SC150BN shall meet Type 3.B specification requirements established by the Erosion Control Technology Council (ECTC) and Federal Highway Administration's (FHWA) FP-03 Section 713.17

Material Content		
Matrix	70% Straw Fiber	0.35 lbs/sq yd (0.19 kg/sm)
	30% Coconut Fiber	0.15 lbs/sq yd (0.08 kg/sm)
Netting	Top: Leno woven 100% biodegradable jute	9.35 lb/1000 sq ft (4.5 kg/100 sm)
	Bottom: 100% biodegradable organic jute	7.7 lb/1000 sq ft (3.76 kg/100 sm)
Thread	Biodegradable	

Standard Roll Sizes			
Width	**6.67 ft (2.03 m)**	8.0 ft (2.4 m)	16 ft (4.87 m)
Length	108 ft (32.92 m)	112 ft (34.14 m)	112 ft (34.14 m)
Weight ± 10%	**52.22 lbs (23.69 kg)**	65.28 lbs (29.6 kg)	130.5 **lbs (59.2 kg)**
Area	80 sq yd (66.9 sm)	100 sq yd (83.61 sm)	200 sq yd (167.22 sm)
	Leno weave top only	Leno top and bottom	Leno top and bottom

Index Property	Test Method	Typical
Thickness	ASTM D6525	0.25 in. (6.35 mm)
Resiliency	ECTC Guidelines	86%
Water Absorbency	**ASTM D1117**	311%
Mass/Unit Area	ASTM D6475	8.32 oz/sy (282.9 g/sm)
Swell	ECTC Guidelines	46%
Smolder Resistance	**ECTC Guidelines**	**Yes**
Stiffness	**ASTM D1388**	0.42 oz-in
Light Penetration	ASTM D6567	7.6%
Tensile Strength - MD	**ASTM D6818**	**201.6 lbs/ft (2.99 kN/m)**
Elongation - MD	**ASTM D6818**	**13.4%**
Tensile Strength - TD	**ASTM D6818**	**164.4 lbs/ft (2.44 kN/m)**
Elongation - TD	**ASTM D6818**	**14.2%**
Biomass Improvement	**ASTM D7322**	**641 %**

Design Permissible Shear Stress	
Unvegetated Shear Stress	**2.10 psf (100 Pa)**
Unvegetated Velocity	**8.00 fps (2.44 m/s)**

Slope Design Data: C Factors			
	Slope Gradients (S)		
Slope Length (L)	≤ 3:1	3:1 – 2:1	≥ 2:1
≤ 20 ft (6 m)	0.001	0.029	0.063
20-50 ft	0.051	0.055	0.092
≥ 50 ft (15.2 m)	0.10	0.080	0.120

Roughness Coefficients – Unveg.	
Flow Depth	Manning's n
≤ 0.50 ft (0.15 m)	0.050
0.50 – 2.0 ft	0.050-0.018
≥ 2.0 ft (0.60 m)	0.018

NORTH AMERICAN GREEN®

Western Green
4609 E. Boonville-New Harmony Rd.
Evansville, IN 47725

nagreen.com
800-772-2040

EC_RMX_MPDS_SC150BN_1.19

Proud Member and Participant of:
www.eastcoasterosion.com
443 Bricker Road Bernville, PA 19506
1.800.582.4005 +1.610.488.8496 Fax +1.610.488.8494

Material and Performance Specification

ECX-2™ Double Net Excelsior Rolled Erosion Control Product

Description:

The ECX-2™ is made with uniformly distributed 100% Aspen wood excelsior and two polypropylene nets securely sewn together with degradable thread. The tightly compressed blankets are wrapped and include a product label, code and installation guide. The blankets are palletized for easy transportation.

The ECX-2™ has functional longevity of approximately 24 months, but will vary depending on soil and climatic conditions, and is suitable for slopes 2:1 to 1.5:1 and medium to high flow channels The ECX-2™ meets Type 3.B specification requirements established by the Erosion Control Technology Council (ECTC) and Federal Highway Administration's (FHWA) FP-03 Section 713.17.

Matrix:	1	2
	Aspen Wood Excelsior	

Netting:	Type	Net Color
Top:	Lightweight Photodegradable Polypropylene	Green
Middle:	None	
Bottom:	Lightweight Photodegradable Polypropylene	

Net Opening:	Top	Middle	Bottom
	0.5" x 0.5"		0.5" x 0.5"

Thread:	Type	Color
	Degradable Thread	White

Roll Sizes:	Standard	"A" Size	Mega
Width:	8 ft 2.4 m	4 ft 1.2 m	16 ft 4.9 m
Length:	112.5 ft 34.3 m	225 ft 68.6 m	112.5 ft 34.3 m
Weight*:	64 lbs 29.0 kg	64 lbs 29.0 kg	128 lbs 58.1 kg
Area:	100 yd² 83.6 m²	100 yd² 83.6 m²	200 yd² 167.2 m²
#/Pallet:	20	9	20

*Weight at time of manufacturing.

Index Value Properties*:

Property	Test Method	Typical	
Mass/Unit Area	ASTM D6475	9.00 oz/yd²	305.1 g/m2
Thickness	ASTM D6525	0.38 in	9.65 mm
Tensile Strength-MD	ASTM D6818	169 lb/ft	2.47 kN/m
Elongation-MD	ASTM D6818	23 %	
Tensile Strength-TD	ASTM D6818	86 lb/ft	1.26 kN/m
Elongation-TD	ASTM D6818	26.0 %	
Light Penetration	ASTM D6567	36 %	
Density / Specific Gravity	ASTM D792	N/A g/cm³	
Water Absorption	ASTM D1117	171 %	

*May differ depending upon raw material variations

Bench-Scale Testing* (NTPEP*):**

Test Method	Parameters	Results
ECTC Method 2 Rainfall	50mm (2in) / hr-30 min	SLR**=6.69
	100mm (4in) / hr-30 min	SLR**=5.18
	150mm (6in) / hr-30 min	SLR**=3.99
ECTC Method 3 Shear Resistance	Shear at .50 in soil loss	2.24 lb/ft²
ECTC Method 4 Germination	Top soil; Fescue; 21 day incubation	530 %

*Bench scale tests should not be used for design purposes.

**Soil Loss Ratio=Soil Loss Bare Soil/Soil Loss with RECP=1/C-Factor

***The preceding test data excerpts were reproduced with the permission of AASHTO, however, this does not constitute endorsement or approval of the product, material or device by AASHTO

Slope Performance Design Values*:

Property	Test Method		Value
C-Factors	ASTM D6459		0.04
Slope Length (L)	≤ 3:1	3:1-2:1	≥ 2:1
< 50 ft (15 m)	0.035	0.144	0.272
50 ft – 100 ft	0.100	0.172	0.377
>100 ft (30 m)	0.210	0.317	0.541

*Large-Scale Results obtained by 3rd Party GAI Accredited Independent Laboratory

Channel Performance Design Values*:

Property	Test Method	Value			
Unvegetated Shear Stress	ASTM D 6460	2.13	lbs/ft²	101.98	Pa
Unvegetated Velocity	ASTM D 6460	10.7	ft/s	3.26	m/s
Vegetated Shear Stress	NA	N/A	lbs/ft²	N/A	Pa
Vegetated Velocity	NA	N/A	ft/s	N/A	m/s
Manning's N (Value Represents a Range)			0.026		

*Large-Scale Results obtained by 3rd Party GAI Accredited Independent Laboratory

The values presented are for guidance purposes and do not constitute the practice of engineering. East Coast Erosion Blankets LLC (ECEB) ascertains that at the time of manufacture, all information presented herein is accurate and reliable and falls within the ECEB manufacturing product specification variances. If the product does not meet the stated values and ECEB is notified in writing prior to installation, the product will be replaced at no cost to the purchaser. ECEB will not be held liable for any type of damage or losses, directly, or indirectly for failure of this product. Current revision supersedes all previous versions for this product.

Revised 1/11/2016

APPENDIX C

EXPERIMENTAL DATA

TABLE C.1: 2 in./hr Rainfall Calibration Data

Rain Gauge Number	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10
1	1.6	1.4	1.4	1.6	1.6	1.0	1.0	1.1	1.3	1.6
2	1.6	1.2	1.5	1.6	1.5	1.0	0.9	1.1	1.2	1.2
3	1.4	1.2	1.4	1.4	1.4	1.3	1.2	1.2	1.0	1.0
4	1.4	1.6	1.3	1.4	1.4	1.8	1.8	1.6	1.6	1.7
5	1.6	1.6	1.7	1.6	1.5	1.0	1.1	1.6	1.6	1.9
6	1.0	1.2	0.9	1.0	1.0	1.4	1.4	1.4	1.5	1.2
7	0.9	1.1	1.0	0.9	1.0	1.8	1.7	1.6	1.4	1.4
8	1.8	2.2	2.1	1.8	1.8	1.8	1.8	1.5	1.6	1.4
9	1.3	1.4	1.4	1.3	1.3	1.3	1.6	1.5	1.8	1.5
10	1.2	1.3	1.4	1.2	1.2	1.2	1.0	1.1	1.0	1.2
11	1.5	1.7	1.6	1.5	1.4	1.4	1.4	1.4	1.4	1.5
12	1.1	1.1	1.0	1.1	1.0	1.2	1.1	1.0	1.1	1.0
13	1.4	1.3	1.4	1.4	1.6	1.6	1.7	1.4	1.4	1.4
14	1.5	1.7	1.4	1.5	1.6	1.7	1.6	1.6	1.6	1.6
15	1.0	1.2	1.2	1.0	1.2	1.6	1.8	1.4	1.4	1.2
16	0.9	1.0	0.8	0.9	0.8	1.6	1.5	1.0	1.2	1.1
17	1.8	1.8	2.0	1.8	2.0	1.0	1.3	1.2	1.1	1.4
18	1.3	0.9	1.0	1.3	1.3	1.6	1.4	1.0	1.0	1.2
19	0.7	0.6	0.7	0.7	0.7	1.6	1.2	0.7	0.8	0.6
20	1.0	1.2	1.0	1.0	0.9	1.2	1.0	0.8	0.8	0.8

Results		
Number of Observations	20	
Total Rainfall Depth	26.4	cm
Avg. Rainfall Depth	1.32	cm
∑|V*i*-VA*vg*| (cm)	3.78	cm
Coefficient of Uniformity (Cu)	85.67	%
Avg. Rainfall Intensity	5.272	cm/hr
Avg. Rainfall Intensity	2.08	in/hr
Standard Deviation	0.043	

TABLE C.2: 4 in./hr Rainfall Calibration Data

Rain Gauge Number	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10
1	3.2	2.6	3.2	3.1	3.1	2.4	2.4	2.2	1.9	2.1
2	3.4	2.9	3.7	3.5	3.2	2.2	2.2	2.4	2.4	2.4
3	2.8	2.9	2.6	2.6	2.7	2.8	2.8	2.6	2.8	2.6
4	3.1	3.2	2.8	2.5	2.8	3.6	3.6	3.6	3.6	3.6
5	2.9	2.6	2.6	2.6	2.6	2.6	2.6	2.8	2.4	2.5
6	2.2	2.4	2.6	2.9	2.6	2.4	2.4	2.4	2.8	2.6
7	2.5	2.8	2.4	2.8	2.9	3.0	3.0	2.8	3.1	3.2
8	3.4	3.6	3.3	2.9	3.1	3.3	3.3	3.3	4.0	3.6
9	2.6	2.4	2.3	2.2	2.4	2.9	2.9	3.0	3.4	3.0
10	2.0	2.1	1.9	1.7	2.1	2.2	2.2	2.0	2.4	2.4
11	2.8	2.6	2.8	2.6	2.8	2.5	2.5	2.4	2.2	2.3
12	2.8	2.5	3.0	3.2	2.8	2.5	2.5	2.3	2.3	2.4
13	3.4	3.4	3.2	2.7	3.2	2.9	2.9	3.0	3.4	3.2
14	3.3	3.2	2.9	2.6	2.9	3.0	3.0	3.2	3.6	3.4
15	2.8	2.4	2.4	2.1	2.2	2.8	2.8	2.7	2.8	2.9
16	1.8	2.0	1.9	1.8	1.9	2.4	2.4	2.3	2.5	2.3
17	3.2	3.8	2.8	2.9	3.1	2.6	2.6	2.5	2.5	2.4
18	2.7	2.5	2.8	2.5	2.6	2.3	2.3	2.2	2.0	2.0
19	1.6	1.4	1.7	1.5	1.6	1.7	1.7	1.6	1.8	1.7
20	2.0	2.1	1.4	1.5	1.7	1.8	1.8	1.8	1.8	1.8

Results		
Number of Observations	20	
Total Rainfall Depth	52.4	cm
Avg. Rainfall Depth	2.62	cm
$\sum\|Vi-VAvg\|$ (cm)	6.55	cm
Coefficient of Uniformity (Cu)	87.49	%
Avg. Rainfall Intensity	10.47	cm/hr
Avg. Rainfall Intensity	4.12	in/hr
Standard Deviation	0.063	

TABLE C.3: 6 in./hr Rainfall Calibration Data

Rain Gauge Number	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10
1	3.4	3.4	2.9	2.9	3.5	3.8	4.0	4.2	4.0	4.0
2	3.7	3.6	4.3	3.5	3.9	4.0	3.7	4.5	4.6	4.4
3	4.0	3.9	4.2	4.2	4.2	4.3	3.6	4.4	4.2	4.3
4	5.1	5.2	4.7	4.5	4.5	4.0	4.3	4.2	4.2	4.0
5	4.0	4.0	3.4	3.6	3.6	4.0	4.6	4.2	4.0	3.7
6	3.4	3.6	4.2	3.6	3.5	3.2	3.0	3.2	3.4	3.3
7	3.8	4.0	4.9	4.2	4.2	3.9	4.0	3.8	4.2	3.9
8	5.9	5.7	6.0	5.3	5.3	4.9	5.2	5.3	5.2	5.4
9	4.0	3.8	3.8	3.8	3.7	3.5	4.2	4.3	3.8	3.6
10	3.1	3.2	3.5	3.9	3.6	3.2	3.1	3.0	3.8	3.4
11	4.3	4.1	3.8	3.8	4.0	4.2	4.2	4.1	3.5	4.0
12	3.5	3.5	3.3	3.3	3.5	3.8	3.3	3.8	4.0	3.6
13	4.7	4.8	4.9	4.8	4.6	4.7	4.3	4.6	4.7	4.4
14	4.4	4.4	4.6	4.3	4.4	4.3	4.1	4.7	4.4	4.3
15	3.9	3.7	3.8	3.8	4.0	4.0	4.2	4.2	4.1	4.1
16	3.5	3.7	3.5	3.4	3.0	2.9	2.9	3.1	3.0	3.1
17	4.6	5.0	4.2	4.7	4.2	4.0	3.6	3.5	4.3	3.5
18	3.5	3.6	3.3	3.1	3.0	3.5	3.5	3.3	3.6	3.1
19	2.2	2.4	2.4	2.9	2.5	2.8	2.7	2.4	2.4	2.4
20	3.3	3.3	2.9	3.0	3.0	2.7	2.6	2.9	2.9	3.0

Results		
Number of Observations	20	
Total Rainfall Depth	77.1	cm
Avg. Rainfall Depth	3.85	cm
∑|V*i*-VA*vg*| (cm)	9.63	cm
Coefficient of Uniformity (Cu)	87.50	%
Avg. Rainfall Intensity	15.418	cm/hr
Avg. Rainfall Intensity	6.07	in/hr
Standard Deviation	0.071	

TABLE C.4: 2 in./hr Flour Pan Method Data

Sieve Size	Sieve Weight (g)	Sieve with Pellet Weight (g)	Pellet Weight (g)	Number of Pellets
No. 4 (4.76 mm)	86.8645	87.0604	0.1959	2
No. 8 (2.38 mm)	83.0172	83.7909	0.7737	24
No. 10 (2.0 mm)	87.2044	87.2901	0.0857	12
No. 14 (1.41 mm)	70.2216	70.4799	0.2583	104
No. 20 (0.841 mm)	69.3934	69.6035	0.2101	280
No. 30 (0.595 mm)	65.9041	65.947	0.0429	85
Pan	46.8335	46.8971	0.0636	0
Total			1.5666	507

Sieve Size	Sieve Weight (g)	Sieve with Pellet Weight (g)	Pellet Weight (g)	Number of Pellets
No. 4 (4.76 mm)	86.8971	86.8971	0	0
No. 8 (2.38 mm)	83.0308	83.9677	0.9369	40
No. 10 (2.0 mm)	87.2059	87.4841	0.2782	36
No. 14 (1.41 mm)	70.2208	70.7525	0.5317	155
No. 20 (0.841 mm)	69.3978	69.5737	0.1759	140
No. 30 (0.595 mm)	65.8989	65.9543	0.0554	120
Pan	46.8318	46.8826	0.0508	0
			1.9781	491

Sieve Size	Sieve Weight (g)	Sieve with Pellet Weight (g)	Pellet Weight (g)	Number of Pellets
No. 4 (4.76 mm)	86.8971	86.8971	0	0
No. 8 (2.38 mm)	83.0315	84.1939	1.1624	49
No. 10 (2.0 mm)	87.215	87.3974	0.1824	24
No. 14 (1.41 mm)	70.232	70.5271	0.2951	105
No. 20 (0.841 mm)	69.4018	69.536	0.1342	134
No. 30 (0.595 mm)	65.9139	65.9479	0.034	126
Pan	46.8325	46.8763	0.0438	0
			1.8081	438

TABLE C.5: 4 in./hr Flour Pan Data

Sieve Size	Sieve Weight (g)	Sieve with Pellet Weight (g)	Pellet Weight (g)	Number of Pellets
No. 4 (4.76 mm)	86.931	87.1616	0.2306	4
No. 8 (2.38 mm)	83.0428	84.6899	1.6471	66
No. 10 (2.0 mm)	87.215	87.3719	0.1569	16
No. 14 (1.41 mm)	70.2317	70.4306	0.1989	52
No. 20 (0.841 mm)	69.4006	69.5615	0.1609	216
No. 30 (0.595 mm)	65.9002	66.0182	0.118	398
Pan	46.8312	46.9238	0.0926	0
Total			2.5124	752

Sieve Size	Sieve Weight (g)	Sieve with Pellet Weight (g)	Pellet Weight (g)	Number of Pellets
No. 4 (4.76 mm)	86.9156	87.0325	0.1169	2
No. 8 (2.38 mm)	83.0431	84.515	1.4719	81
No. 10 (2.0 mm)	87.2306	87.4439	0.2133	28
No. 14 (1.41 mm)	70.2278	70.7133	0.4855	126
No. 20 (0.841 mm)	69.4041	69.7133	0.3092	237
No. 30 (0.595 mm)	65.9159	65.9911	0.0752	158
Pan	46.8306	46.8789	0.0483	0
			2.672	632

Sieve Size	Sieve Weight (g)	Sieve with Pellet Weight (g)	Pellet Weight (g)	Number of Pellets
No. 4 (4.76 mm)	86.9389	87.259	0.3201	4
No. 8 (2.38 mm)	83.0398	84.3213	1.2815	67
No. 10 (2.0 mm)	87.2311	87.4773	0.2462	29
No. 14 (1.41 mm)	70.2289	70.3929	0.164	35
No. 20 (0.841 mm)	69.4018	69.5295	0.1277	195
No. 30 (0.595 mm)	65.9142	65.9808	0.0666	152
Pan	46.832	46.8846	0.0526	0
			2.2061	482

TABLE C.6: 6 in./hr Flour Pan Method Data

Sieve Size	Sieve Weight (g)	Sieve with Pellet Weight (g)	Pellet Weight (g)	Number of Pellets
No. 4 (4.76 mm)	86.9518	87.185	0.2332	3
No. 8 (2.38 mm)	83.0578	84.4492	1.3914	69
No. 10 (2.0 mm)	87.2372	87.5993	0.3621	65
No. 14 (1.41 mm)	70.2253	70.7432	0.5179	231
No. 20 (0.841 mm)	69.4028	69.7644	0.3616	377
No. 30 (0.595 mm)	65.8946	66.026	0.1314	283
Pan	46.8318	46.8934	0.0616	0
Total			2.9976	1028

Sieve Size	Sieve Weight (g)	Sieve with Pellet Weight (g)	Pellet Weight (g)	Number of Pellets
No. 4 (4.76 mm)	86.9303	87.6492	0.7189	8
No. 8 (2.38 mm)	83.0389	85.444	2.4051	97
No. 10 (2.0 mm)	87.2422	87.8105	0.5683	99
No. 14 (1.41 mm)	70.2426	71.1175	0.8749	294
No. 20 (0.841 mm)	68.4026	69.8623	1.4597	342
No. 30 (0.595 mm)	65.8844	66.0875	0.2031	445
Pan	46.8305	46.9563	0.1258	0
			6.23	1285

Sieve Size	Sieve Weight (g)	Sieve with Pellet Weight (g)	Pellet Weight (g)	Number of Pellets
No. 4 (4.76 mm)	86.9353	87.1075	0.1722	2
No. 8 (2.38 mm)	83.05	85.0595	2.0095	90
No. 10 (2.0 mm)	87.2635	87.4822	0.2187	34
No. 14 (1.41 mm)	70.222	70.9371	0.7151	240
No. 20 (0.841 mm)	69.4265	69.9717	0.5452	515
No. 30 (0.595 mm)	65.8853	65.9968	0.1115	256
Pan	46.8238	46.9141	0.0903	0
			3.7722	1137

TABLE C.7: Sandy Loam Soil Analysis

Sieve No.	Sieve Size (mm)	Mass of Sieve (g)	Mass Soil + Sieve (g)	Mass of Soil (g)	% Retained	Cum. Percent Retained
4	4.750	0.0	0.0	0.00%	0.00%	100.00%
10	2.000	15.8	15.8	7.66%	7.66%	92.34%
20	0.841	30.9	15.1	7.32%	14.98%	85.02%
40	0.420	57.4	26.5	12.85%	27.82%	72.18%
80	0.177	102.5	45.1	21.86%	49.68%	50.32%
100	0.150	112.9	10.4	5.04%	54.73%	45.27%
200	0.075	142.5	29.6	14.35%	69.07%	30.93%
Pan	0.000	206.3	63.8	30.93%	100.00%	0.00%
		Total:	206.3			

Time, min	Hydrometer Reading, R	Rcp	% Finer	Rcl	L (cm)	A	D (mm)	% Finer Total
0							0.075	30.93%
0.25	51	48.15	96.30	51	7.9	0.0133	0.075	29.78%
0.5	48	45.15	90.30	48	8.4	0.0133	0.055	27.93%
1	47	44.15	88.30	47	8.6	0.0133	0.039	27.31%
2	46	43.15	86.30	46	8.8	0.0133	0.028	26.69%
4	44	41.15	82.30	44	9.1	0.0133	0.020	25.45%
8	41	38.15	76.30	41	9.6	0.0133	0.015	23.60%
15	38	35.15	70.30	38	10.1	0.0133	0.011	21.74%
30	35	32.15	64.30	35	10.5	0.0133	0.008	19.89%
60	32	29.15	58.30	32	11.0	0.0133	0.006	18.03%
120	28	25.15	50.30	28	11.7	0.0133	0.004	15.56%
240	26	23.15	46.30	26	12.0	0.0133	0.003	14.32%
480	23	20.15	40.30	23	12.5	0.0133	0.002	12.46%
1440	21	18.15	36.30	21	12.8	0.0133	0.001	11.23%

Compacted Soil -Sample No.	1	2	3	4	5
Tin No.	A-3	C-6	H-6	E-3	55
Tin Weight (g)	13.8	14.3	14.2	14.1	13.9
Moist Sample Weight + Tin (g)	87.3	86	97.5	96.6	96.5
Dry Sample Weight + Tin (g)	79.5	76.8	84.9	86.6	84.9
Moist Sample Weight (g)	73.5	71.7	83.3	82.5	82.6
Dry Sample Weight (g)	65.7	62.5	70.7	72.5	71
Mw = Mass of Pore Water (g)	7.8	9.2	12.6	10	11.6
W = Moisture Content	11.87%	14.72%	17.82%	13.79%	16.34%
Weight of Mold (g)	4279.4	4279.9	4281.4	4280.4	4281.4
Weight of Compacted Soil + Mold (g)	6160.9	6235	6183.7	6233.2	6207.4
Weight of Wet Soil in Mold (g)	1881.5	1955.1	1902.3	1952.8	1926
Wet Unit Weight (lb/ft3)	124.44	129.31	125.82	129.16	127.38
Dry Unit Weight of Compaction (lb/ft3)	111.23	112.72	106.78	113.50	109.49
Optimal Moisture Content	**13.5%**				
Optimal Compaction	**113.6**				

Plastic Limit		
Sample Number	**1**	**2**
Container No.	F-9	BC
Mass Moist Soil + Container (g)	25.9	21.7
Mass Dry Soil + Container (g)	23.7	20.3
Mass Container (g)	14.1	14
Water Content (%)	22.92%	22.22%

Liquid Limit			
Test Number	**1**	**2**	**3**
Container No.	56	F-A	F-3
Mass Moist Soil + Container (g)	40.5	46.2	41.8
Mass Dry Soil + Container (g)	35	39.5	37
Mass Container (g)	14.2	14.1	14.1
Water Content (%)	32.83%	26.38%	20.96%
Number of Blows	18	26	34
Target Blows	15 - 25	20 - 30	25 - 35
Liquid Limit	31.55%	26.50%	21.76%

TABLE C.8: Loam Soil Analysis

Sieve No.	Sieve Size (mm)	Mass of Sieve (g)	Mass Soil + Sieve (g)	Mass of Soil (g)	% Retained	Cum. Percent Retained	% Finer
4	4.76	510.4	510.4	0	0.00%	0.00%	100.00%
10	2	488.7	489.4	0.7	0.77%	0.77%	99.23%
20	0.841	414	417.8	3.8	4.19%	4.96%	95.04%
40	0.42	466	474.2	8.2	9.04%	14.00%	86.00%
60	0.25	429.4	437.4	8	8.82%	22.82%	77.18%
100	0.149	334.7	342.8	8.1	8.93%	31.75%	68.25%
200	0.074	500.1	510.8	10.7	11.80%	43.55%	56.45%
Pan	0	362.4	362.8	51.2	56.45%	100.00%	0.00%
Total				90.7			

Time (min)	Hydrometer Reading, R	Rcp	% Finer	Rcl	L (cm)	A	D (mm)	% Finer Total
0							0.074	56.45%
0.25	51	49.9	98.23	51	7.9	0.0132	0.074	55.45%
0.5	49	47.9	94.29	49	8.3	0.0132	0.054	53.23%
1	46	44.9	88.39	46	8.8	0.0132	0.039	49.89%
2	43	41.9	82.48	43	9.2	0.0132	0.028	46.56%
4	40	38.9	76.57	40	9.7	0.0132	0.021	43.23%
8	35	33.9	66.73	35	10.6	0.0132	0.015	37.67%
15	31	29.9	58.86	31	11.2	0.0132	0.011	33.23%
30	26	24.9	49.02	26	12	0.0132	0.008	27.67%
60	23	21.9	43.11	23	12.5	0.0132	0.006	24.34%
120	19	17.9	35.24	19	13.2	0.0132	0.004	19.89%
240	16	14.9	29.33	16	13.7	0.0132	0.003	16.56%
360	13	11.9	23.43	13	14.2	0.0132	0.003	13.22%
480	12	10.9	21.46	12	14.3	0.0132	0.002	12.11%
1440	10	8.9	17.52	10	14.7	0.0132	0.0013	9.89%

Compacted Soil Sample Number	1	2	3	4	5
Tin Number	81	700	5	91	10
Tin Weight (g)	14.8	14.7	14.7	14.7	14.7
Moist Sample Weight + Tin (g)	53.7	52.4	61	56.9	58.6
Dry Sample Weight + Tin (g)	50.2	48.2	53.8	48.9	49.8
Moist Sample Weight (g)	38.9	37.7	46.3	42.2	43.9
Dry Sample Weight (g)	35.4	33.5	39.1	34.2	35.1
Mw = Mass of Pore Water (g)	3.5	4.2	7.2	8	8.8
W = Moisture Content	9.89%	12.54%	18.41%	23.39%	25.07%
Weight of Mold (g)	4283.8	4282.8	4280.1	4285	4291.4
Weight of Compacted Soil + Mold (g)	5737.5	5817.8	5987.5	6039.6	6014.9
Weight of Wet Soil in Mold (g)	1453.7	1535	1707.4	1754.6	1723.5
Wet Unit Weight (lb/ft3)	96.15	101.52	112.93	116.05	113.99
Dry Unit Weight of Compaction (lb/ft3)	87.50	90.21	95.36	94.05	91.14
Optimal Moisture Content	**20.0%**				
Maximum Compaction	**96.0**				

Sample Number	1	2
Container No.	81	93
Mass Moist Soil + Container (g)	20.8	21
Mass Dry Soil + Container (g)	19.5	19.6
Mass Container (g)	14.7	14.9
Water Content (%)	27.08%	29.79%

Liquid Limit			
Test Number	**1**	**2**	**3**
Container No.	5	42	12
Mass Moist Soil + Container (g)	26.6	29.3	53.1
Mass Dry Soil + Container (g)	24.0	24.9	47.3
Mass Container (g)	14.6	11.9	31.7
Water Content (%)	27.66%	33.85%	37.18%
Number of Blows	30	23	18
Target Blows	15 - 25	20 - 30	25 - 35
Liquid Limit	28.28%	33.51%	35.73%

TABLE C.9: Sandy Loam Bare Soil Test

Date:	9/12/18		Weather During Calibration		
Operator:	BF		Temperature:	75	F
Operating Pressure:	31	psi	Average wind speed:	0.20	mph
Test Intensity:	4.08	in/hr	Max wind speed:	0.40	mph
Test Start Time:	9:35		Wind Direction:	W	
Test Finish Time:	10:35		Humidity	81	%

Drive Cylinder Compaction Data

Cylinder Number	1	2	3
Test Location Number	26	16	43
Thickness of Soil Sample (in)	1.05	0.90	0.95
Volume of Drive Cylinder (in^3)	216.11	185.24	195.53

Wet Weight of Pan and Soil (g)	435	410	435
Dry Weight of Pan and Soil (g)	390	360	385
Weight of Pan (g)	55	60	55
Moisture Lost (g)	45	50	50
Dry Weight of Soil (g)	335	300	330
Water Content (%)	13.43	16.67	15.15

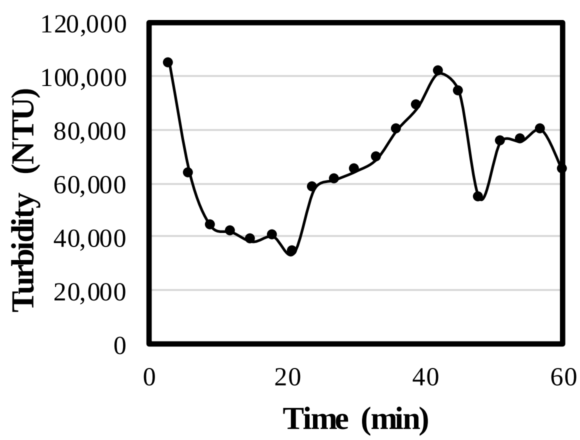
Wet Density (g/cm^3)	1.7583	1.8894	1.9434
Dry Density (g/ $cm^3$3)	1.5501	1.6195	1.6877
Maximum Dry Density (g/ cm^3)	113.6	113.6	113.6
Optimum Water Content (%)	13.30	13.30	13.03
Percent Compacted (%)	85.1	89.0	82.7

Collected Sediment Loss

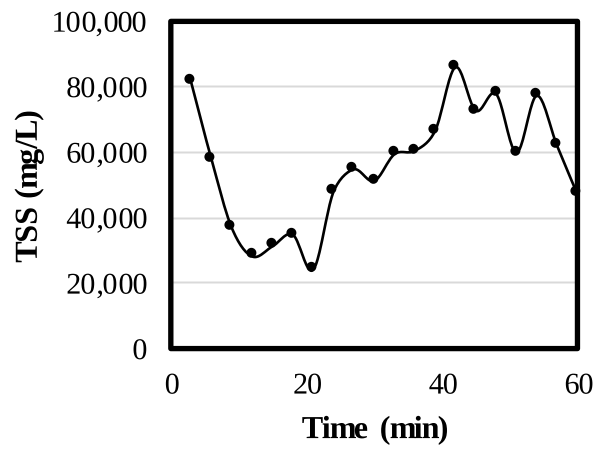
Sample Number	1	2	3	4
Settling Time (min)	60	60	60	60
Total Wet Weight of Sediment, lb	711.6	114.8	346.4	110.9
Container Weight, lb	46	4.6	16.1	6.9
Wet Weight + Container , lb	757.6	119.4	362.5	117.8
Dry Weight, lb	287.6681	92.78356	269.6805	75.54058
Moisture Content, %	59.57%	19.18%	22.15%	31.88%
Average Moisture Content, %	33.20%			
Total Dry Weight of Sediment, lb	725.67			

TSS and Turbidity Data

Sample ID	Time (min)	Dilution Factor	Turbidity Reading (NTU)	Filter + Crinkle Dish (g)	Dry Filter + Soil + Crinkle Dish (g)	Original Sample	
						Turbidity (NTU)	TSS (mg/L)
2801	3	128	816	1.3971	1.413	104448	81408
2802	6	128	491	1.365	1.3763	62848	57856
2803	9	128	343	1.3904	1.3976	43904	36864
2804	12	128	326	1.3739	1.3794	41728	28160
2805	15	64	596	1.3703	1.3825	38144	31232
2806	18	64	626	1.385	1.3986	40064	34816
2807	21	64	528	1.3882	1.3976	33792	24064
2808	24	64	903	1.3901	1.4088	57792	47872
2809	27	64	956	1.3677	1.3891	61184	54784
2810	30	128	503	1.3746	1.3846	64384	51200
2811	33	128	538	1.3888	1.4004	68864	59392
2812	36	128	624	1.3825	1.3943	79872	60416
2901	39	128	690	1.3704	1.3834	88320	66560
2902	42	128	789	1.3797	1.3965	100992	86016
2903	45	128	735	1.3668	1.381	94080	72704
2904	48	128	423	1.371	1.3862	54144	77824
2905	51	128	589	1.385	1.3967	75392	59904
2906	54	128	591	1.3775	1.3926	75648	77312
2907	57	128	623	1.3791	1.3912	79744	61952
2908	60	128	504	1.3743	1.3835	64512	47104



(a) Test 1 Turbidity Results



(b) Test 1 TSS Results

Water Quality Results.

TABLE C.10: Loose Straw Test Data

Date:	11/30/18		Weather During Calibration		
Operator:	BF		Temperature:	60	F
Operating Pressure:	32	psi	Average wind speed:	0.2	mph
Test Intensity:	4.07	in/hr	Max wind speed:	0.1	mph
Test Start Time:	8:46		Wind Direction:	SSE	
Test Finish Time:	9:50		Humidity	60	%

Drive Cylinder Compaction Data

Cylinder Number	1	2	3
Test Location Number	5	26	52
Thickness of Soil Sample (in)	1.0	0.70	0.55
Volume of Drive Cylinder (in^3)	205.82	144.08	113.20

Wet Weight of Pan and Soil (g)	515	410	355
Dry Weight of Pan and Soil (g)	467.4	371.4	328.2
Weight of Pan (g)	150	150	145
Moisture Lost (g)	47.6	38.6	26.8
Dry Weight of Soil (g)	317.4	221.4	183.2
Water Content (%)	15.0	17.43	14.63

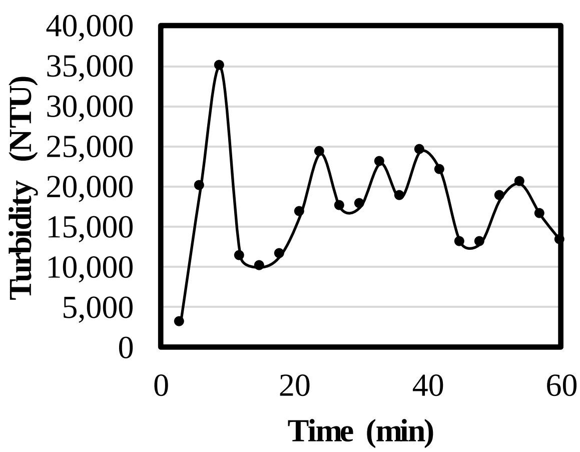
Wet Density (g/cm^3)	1.7734	1.8046	1.8551
Dry Density (g/ $cm^3$3)	1.5421	1.5367	1.6183
Maximum Dry Density (g/ cm^3)	113.6	113.6	113.6
Optimum Water Content (%)	13.30	13.30	13.30
Percent Compacted (%)	84.7	84.4	88.9

Collected Sediment Loss

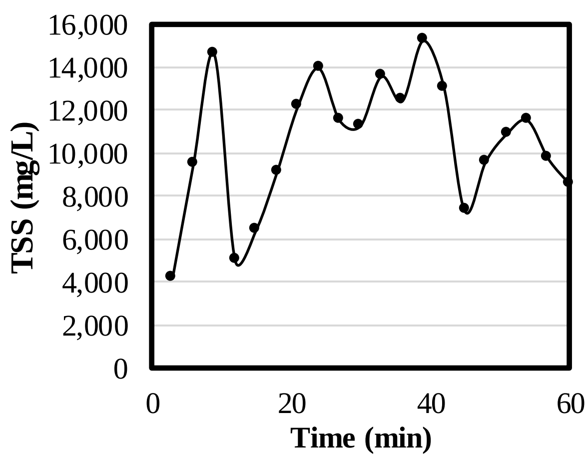
Sample Number	1	2
Settling Time (hr)	24	24
Total Wet Weight of Sediment, lb	55.2	231.3
Container Weight, lb	2	16.1
Wet Weight + Container , lb	57.2	247.4
Dry Weight, lb	40.35	72.71
Moisture Content, %	26.91%	68.56%
Average Moisture Content, %	47.74%	
Total Dry Weight of Sediment, lb	113.06	

TSS and Turbidity Data

Sample ID	Time (min)	Dilution Factor	Turbidity Reading (NTU)	Filter + Crinkle Dish (g)	Dry Filter + Soil + Crinkle Dish (g)	Original Sample	
						Turbidity (NTU)	TSS (mg/L)
101	3	4	748	1.4014	1.4274	2992	4160
102	6	32	620	1.3682	1.3756	19840	9472
103	9	64	543	1.3953	1.401	34752	14592
104	12	32	349	1.3808	1.3847	11168	4992
105	15	32	310	1.3747	1.3797	9920	6400
106	18	32	356	1.3908	1.3979	11392	9088
107	21	32	515	1.3929	1.4024	16480	12160
108	24	32	752	1.3962	1.4071	24064	13952
109	27	32	539	1.3733	1.3823	17248	11520
110	30	32	546	1.3798	1.3886	17472	11264
111	33	32	714	1.3944	1.405	22848	13568
112	36	32	579	1.3891	1.3988	18528	12416
113	39	32	761	1.3765	1.3884	24352	15232
114	42	32	682	1.3766	1.3868	21824	13056
115	45	32	405	1.3683	1.374	12960	7296
116	48	32	403	1.3949	1.4024	12896	9600
117	51	32	577	1.3692	1.3777	18464	10880
118	54	32	633	1.3938	1.4028	20256	11520
119	57	32	512	1.3908	1.3984	16384	9728
120	60	32	413	1.3834	1.3901	13216	8576



(a) Test 1 Turbidity Results



(b) Test 1 TSS Results

TABLE C.11: Loam Bare Soil Raw Data

Date:	3/9/20		Weather During Calibration		
Operator:	BF		Temperature:	52	F
Operating Pressure:	26	psi	Average wind speed:	0.43	mph
Test Intensity:	4.08	in/hr	Max wind speed:	0.75	mph
Test Start Time:	9:21		Wind Direction:	ESE	
Test Finish Time:	10:37		Humidity	78	%

Drive Cylinder Compaction Data

Cylinder Number	1	2	3
Test Location Number	13	27	41
Thickness of Soil Sample (in)	1.05	1.35	1.55
Volume of Drive Cylinder (in^3)	216.11	277.86	319.02

Wet Weight of Pan and Soil (g)	900	990	1055
Dry Weight of Pan and Soil (g)	830	905	975
Weight of Pan (g)	530	530	530
Moisture Lost (g)	70	85	80
Dry Weight of Soil (g)	300	375	445
Water Content (%)	23.33	22.67	17.98

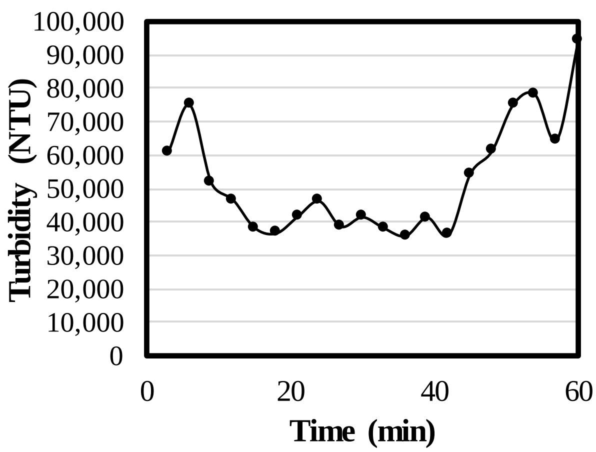
Wet Density (g/cm^3)	1.7121	1.6555	1.6456
Dry Density (g/cm^3)	1.3882	1.3496	1.3949
Maximum Dry Density (g/cm^3)	96.0	96.0	96.0
Optimum Water Content (%)	20.0	20.0	20.0
Percent Compacted (%)	90.2	87.7	90.7

Collected Sediment Loss

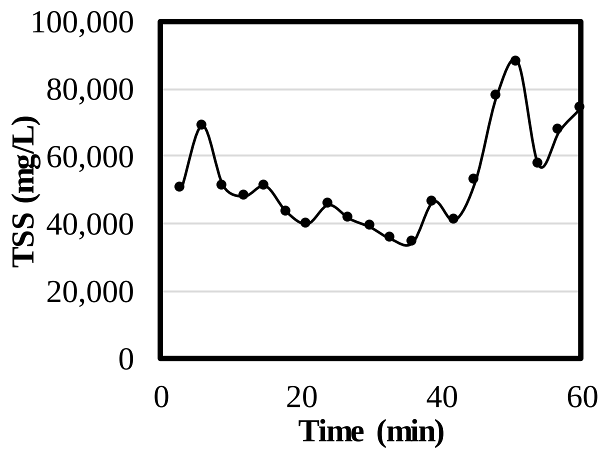
Sample Number	2 in/hr	4 in/hr			6 in/hr		
Settling Time (hr)	24	24	24	24	24	24	24
Total Wet Weight of Sediment (lb)	66	212.6	518.6	213.6	674.9	467.1	771
Container Weight (lb)	6.6	13.2	37.4	12	41.8	28.6	44
Dry Weight (lb)	28.65	106.30	330.74	213.60	359.28	333.32	500.87
Moisture Content (%)	56.59	50.00	36.22	34.39	46.77	28.64	35.04
Average Moisture Content (%)	56.59	40.20			36.81		
Total Dry Weight of Sediment (lb)	28.65	650.64			1193.46		

TSS and Turbidity Data

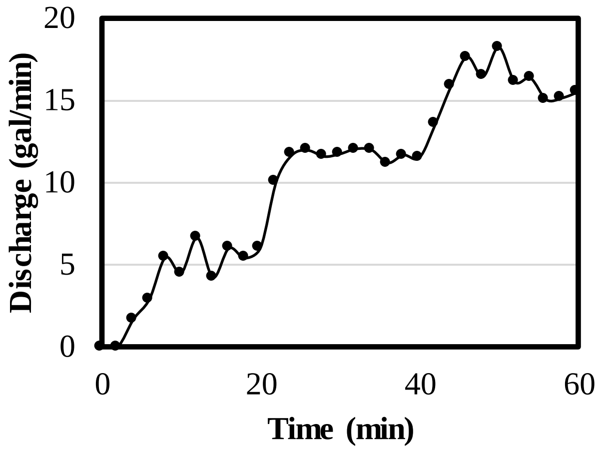
Sample ID	Time (min)	Dilution Factor	Turbidity Reading (NTU)	Filter + Crinkle Dish (g)	Dry Filter + Soil + Crinkle Dish (g)	Original Sample	
						Turbidity (NTU)	TSS (mg/L)
1	3	64	950	1.3763	1.3959	60800	50176
2	6	128	586	1.3849	1.3984	75008	69120
3	9	128	404	1.3797	1.3897	51712	51200
4	12	128	365	1.3786	1.3880	46720	48128
5	15	128	299	1.3856	1.3956	38272	51200
6	18	128	286	1.3774	1.3859	36608	43520
7	21	128	325	1.3776	1.3854	41600	39936
8	24	128	361	1.3807	1.3896	46208	45568
9	27	128	302	1.3825	1.3906	38656	41472
10	30	128	324	1.3962	1.4038	41472	38912
11	33	128	298	1.4004	1.4073	38144	35328
12	36	128	280	1.3897	1.3964	35840	34304
13	39	128	323	1.3760	1.3851	41344	46592
14	42	128	282	1.3907	1.3987	36096	40960
15	45	128	425	1.3733	1.3836	54400	52736
16	48	128	478	1.3769	1.3921	61184	77824
17	51	128	588	1.3651	1.3823	75264	88064
18	54	256	305	1.3857	1.3913	78080	57344
19	57	128	504	1.3917	1.4049	64512	67584
20	60	128	736	1.3817	1.3962	94208	74240



(a)bare soil turbidity results



(b) bare soil TSS results



Discharge over Time

TABLE C.12: Curlex I Test Results

Date:	1/31/20		Weather During Calibration		
Operator:	BF		Temperature:	58	F
Operating Pressure:	28	psi	Average wind speed:	0.48	mph
Test Intensity:	4.05	in/hr	Max wind speed:	0.8	mph
Test Start Time:	1:26		Wind Direction:	NE	
Test Finish Time:	2:38		Humidity	31	%

Drive Cylinder Compaction Data

Cylinder Number	1	2	3
Test Location Number	29	4	54
Thickness of Soil Sample (in)	0.95	1.25	1.45
Volume of Drive Cylinder (in^3)	195.53	257.28	298.44

Wet Weight of Pan and Soil (g)	475	565	645
Dry Weight of Pan and Soil (g)	425	505	565
Weight of Pan (g)	155	150	160
Moisture Lost (g)	50	60	80
Dry Weight of Soil (g)	270	355	405
Water Content (%)	18.52	16.90	19.75

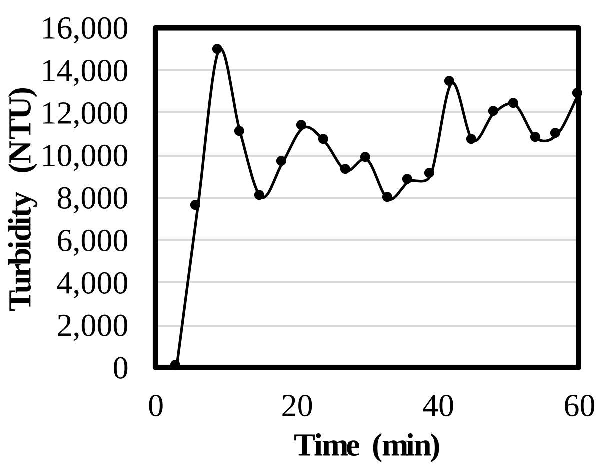
Wet Density (g/cm^3)	1.6366	1.6130	1.6251
Dry Density (g/ cm^{3}3)	1.3809	1.3798	1.3571
Maximum Dry Density (g/ cm^3)	96.0	96.0	96.0
Optimum Water Content (%)	20.0	20.0	20.0
Percent Compacted (%)	89.8	89.7	88.2

Collected Sediment Loss

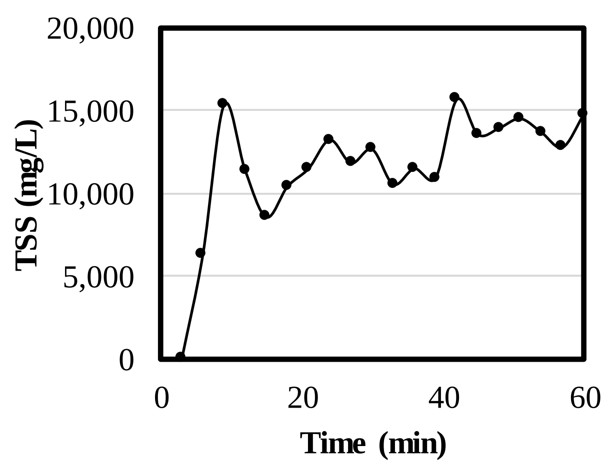
Sample Number	2 in/hr	4 in/hr	6 in/hr	
Settling Time (hr)	24	24	24	24
Total Wet Weight of Sediment (lb)	19.6	67.8	189.6	124
Container Weight (lb)	2.2	4.6	13.2	6.6
Dry Weight (lb)	1.70	15.84	7.39	61.23
Moisture Content (%)	91.30	76.64	96.10	50.62
Average Moisture Content (%)	91.30	76.64	73.36	
Total Dry Weight of Sediment (lb)	1.70	15.84	68.62	

TSS and Turbidity Data

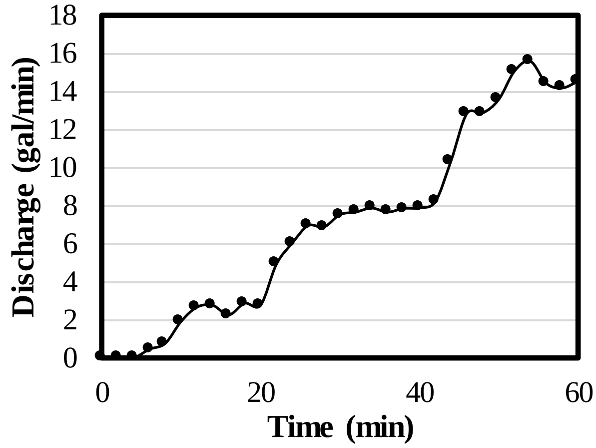
Sample ID	Time (min)	Dilution Factor	Turbidity Reading (NTU)	Filter + Crinkle Dish (g)	Dry Filter + Soil + Crinkle Dish (g)	Original Sample	
						Turbidity (NTU)	TSS (mg/L)
	3	0	0	0.0000	0.0000	0	0
1	6	16	471	1.3791	1.3890	7536	6336
2	9	32	467	1.3900	1.4020	14944	15360
3	12	32	347	1.3825	1.3914	11104	11392
4	15	32	251	1.3822	1.3889	8032	8576
5	18	16	602	1.3897	1.4060	9632	10432
6	21	16	706	1.3811	1.3991	11296	11520
7	24	16	665	1.3815	1.4022	10640	13248
8	27	16	580	1.3857	1.4042	9280	11840
9	30	16	612	1.3867	1.4065	9792	12672
10	33	16	496	1.4001	1.4166	7936	10560
11	36	16	549	1.4048	1.4228	8784	11520
12	39	16	565	1.3955	1.4126	9040	10944
13	42	16	837	1.3797	1.4042	13392	15680
14	45	16	669	1.3942	1.4154	10704	13568
15	48	16	749	1.3791	1.4009	11984	13952
16	51	16	773	1.3818	1.4045	12368	14528
17	54	16	675	1.3722	1.3936	10800	13696
18	57	16	687	1.3921	1.4121	10992	12800
19	60	16	805	1.3972	1.4203	12880	14784



(a) Test 1 Turbidity Results



(b) Test 1 TSS Results



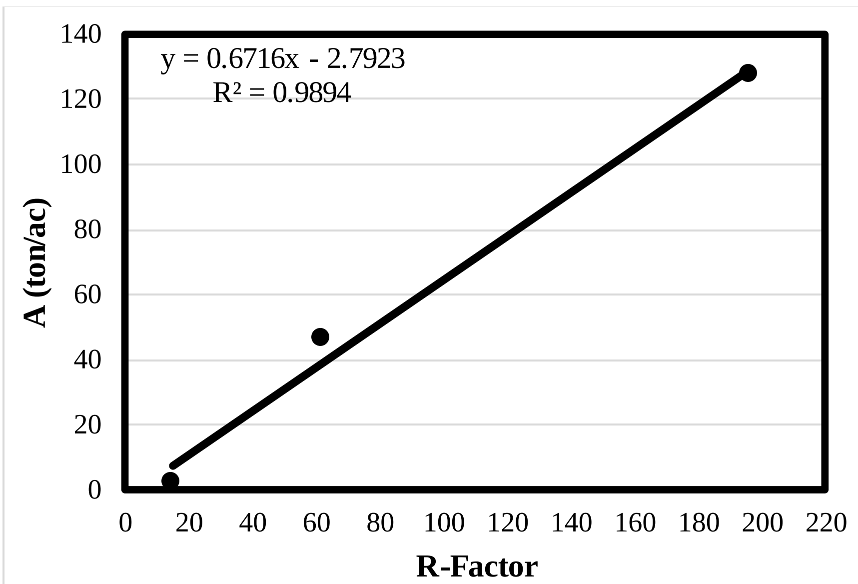
Discharge over Time

TABLE C.13: *R*-factor and K-factor Calculations

Target Storm Event	Gauge Reading (in.)	Rainfall (in.)	Test Intensity (in./hr)	Particle Diameter Range (mm)	Average raindrop size (mm)	% of rainfall	Fall Vel (m/s)	Fall Vel (ft/s)
2 in/hr	0.7	0.77	2.30	4.76+	6.03	3.95%	7.79	25.57
	0.8			4.76-2.38	3.79	55.36%	7.38	24.21
	0.9			2.38-2.0	2.50	10.10%	6.38	20.92
	0.8			2.0-1.41	1.81	19.39%	5.61	18.42
	0.7			1.41-0.841	1.21	8.93%	4.83	15.85
	0.7			0.841-0.59	0.91	2.27%	4.39	14.39
Average	**0.77**					100.00%		
4 in/hr	2	1.32	3.95	4.76+	5.29	9.56%	7.84	25.73
	2.2			4.76-2.38	3.52	60.59%	7.22	23.68
	2.3			2.38-2.0	2.59	8.23%	6.47	21.22
	2.1			2.0-1.41	2.00	11.03%	5.84	19.16
	2			1.41-0.841	1.21	7.38%	4.82	15.81
	1.9			0.841-0.59	0.89	3.21%	4.35	14.27
Average	**2.08**					100.00%		
6 in/hr	4	2.10	6.30	4.76+	5.78	9.33%	7.83	25.69
	4.1			4.76-2.38	3.65	46.08%	7.29	23.93
	4.3			2.38-2.0	2.28	8.70%	6.15	20.17
	4.4			2.0-1.41	1.76	15.53%	5.55	18.22
	4.4			1.41-0.841	1.55	17.20%	5.29	17.36
	3.9			0.841-0.59	0.95	3.16%	4.45	14.59
Average	**4.18**					100.00%		

Target Storm Event	Rainfall Vol (ft^3)	Rainfall Weight (lbf)	Rainfall Mass (slugs)	Incr. Rainfall Mass (slugs)	$KE_{rainfall}$ (ft-lbf)	$KE_{totalrainfall}$ (ft-tonf)	Incremental E (ft-tonf/acre)	E (hundred ft-tons/ac)
2 in/hr	20.44	1275.73	39.62	1.56	511.28	0.26	34.80	0.35
				21.93	6426.04	3.21	437.37	4.37
				4.00	875.27	0.44	59.57	0.60
				7.68	1303.61	0.65	88.73	0.89
				3.54	443.98	0.22	30.22	0.30
				0.90	93.19	0.05	6.34	0.06
Average				*39.619*	*9653.38*	*4.83*	*657.03*	*6.57*
4 in/hr	35.11	2190.93	68.04	6.51	2152.83	1.08	146.53	1.47
				41.23	11554.66	5.78	786.44	7.86
				5.60	1260.64	0.63	85.80	0.86
				7.50	1377.81	0.69	93.78	0.94
				5.02	627.95	0.31	42.74	0.43
				2.18	222.17	0.11	15.12	0.15
Average				*68.041*	*17196.07*	*8.60*	*1170.41*	*11.70*
6 in/hr	56.00	3494.40	108.52	10.12	3340.87	1.67	227.39	2.27
				50.00	14311.37	7.16	974.07	9.74
				9.44	1920.78	0.96	130.73	1.31
				16.85	2798.99	1.40	190.51	1.91
				18.67	2813.48	1.41	191.49	1.91
				3.43	365.41	0.18	24.87	0.25
Average				*108.522*	*25550.89*	*12.78*	*1739.06*	*17.39*

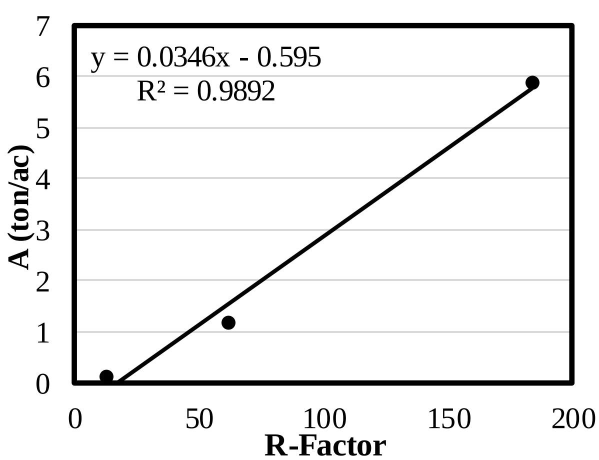
Target Storm Event	Incremental E (hundred ft-tons/ac)	I_{30} (in./hr)	Incremental EI_{30}	Soil Loss per Intensity (lb)	Soil Loss per Intentisty (ton)	A (ton/ac)
2 in/hr	6.57	2.30	15.11	28.65	0.01	1.95
Average						
4 in/hr	18.27	3.40	62.13	650.64	0.33	46.23
Average						
6 in/hr	35.66	5.52	196.75	1193.46	0.60	127.46
Average						



	Slope	Intercept
y =	0.6716	-2.7923
x =	182.02	
y =	119.46	
K =	A/RLSCP	**K-factor uses slope of regression line and theoretical R to normalize it for normalized *C*-factor calculations**
A =	119.46	
Theoretical R =	182.02	
LS Factor =	2.86	
C =	1	
P =	1	
A/R =	0.672	
K =	0.23	

TABLE C.14: *C*-factor Calculations

Target Storm Event	Gauge Reading (in.)	Incremental E (hundred ft-tons/ac)	I_{30} (in./hr)	Incremental EI_{30}	Soil Loss (lb) per Intensity	Soil Loss (ton) per Intensity	A (ton/ac)	Control Soil Loss for Test's Cum. *R*-Factor	C Factor (using control)	C Factor (using RUSLE Equ.)
2 in/hr	0.7	6.14	2.15	13.20	1.70	0.00	0.12	8.87	0.01	0.0130
	0.7									
	0.8									
	0.8									
	0.6									
	0.7									
Average	**0.72**									
4 in/hr	1.9	18.14	3.42	61.99	15.84	0.01	1.19	41.63	0.03	0.0287
	2.2									
	2.2									
	2.2									
	1.9									
	2									
Average	**2.07**									
6 in/hr	3.8	34.57	5.32	183.78	68.62	0.03	5.86	123.43	0.05	0.0475
	4.1									
	4.3									
	4.2									
	3.9									
	4									
Average	**4.05**									



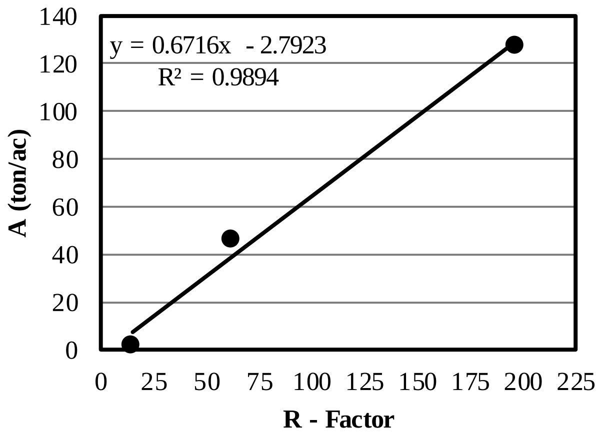
Test	Rainfall Data			Soil Loss Data				RUSLE Calculations					
	Target Intensity (in./hr)	Depth (in.)	Actual Intensity (in./hr)	Soil Loss (lbs)	Soil Loss (ton)	Soil Loss (ton/acre)	Cumm. Soil Loss Ratio	Cumm. A (ton/ac)	Incremental R - Factor	Control Soil Loss for Test's Cum. *R*-Factor (ton/acre)	K-Factor	LS-Factor	C - Factor per Intensity from actual soil loss A
Control	2	0.77	2.30	28.65	0.01	1.95	N/A	1.95	15.11	N/A			
	4	1.32	3.95	650.64	0.33	46.23	N/A	48.18	62.13	N/A			N/A
	6	2.10	6.30	1193.46	0.60	127.46	N/A	175.65	196.75	N/A			
Test 1	2	0.72	2.15	1.70	0.00	0.12	0.01	0.12	13.20	8.87			0.0130
	4	1.35	4.05	15.84	0.01	1.19	0.03	1.19	61.99	41.63			0.0287
	6	1.98	5.95	68.62	0.03	5.86	0.05	5.86	183.78	123.43	0.23	2.86	0.0475
Test 2	2	0.70	2.10	4.49	0.00	0.31	0.04	0.31	12.60	8.46			0.0361
	4	1.37	4.10	25.16	0.01	2.02	0.05	2.02	62.31	41.85			0.0482
	6	2.00	6.00	67.25	0.03	6.60	0.05	6.60	186.28	125.11			0.0527
Test 3	2	0.72	2.15	3.21	0.00	0.22	0.02	0.22	13.20	8.87			0.0246
	4	1.37	4.10	18.25	0.01	1.46	0.03	1.46	63.10	42.38			0.0345
	6	2.03	6.10	65.53	0.03	5.92	0.05	5.92	190.87	128.19			0.0462
												Average *C*-Factor =	0.0488

CONTROL		
	Slope	Intercept
y =	0.6716	-2.7923
x =	182.02	
	K =	A/RLSCP
	A =	119.46
	Theoretical R =	182.02
	LS Factor =	2.86
	C =	1
	P =	1
	A/R =	0.671
	K =	0.23

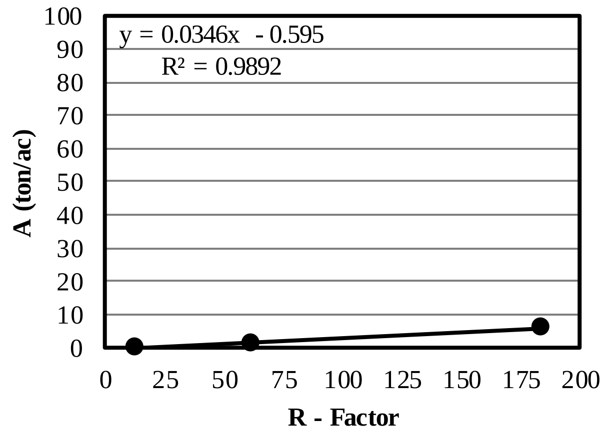
TEST 1		
Test 1	Slope	Intercept
y =	0.0346	-0.5950
x =	182.02	
	C =	A/RKLSP
	A =	5.70
	Theoretical R =	182.02
	LS Factor =	2.86
	K =	0.23
	P =	1.00
	A/R =	0.0345
	C =	0.05

TEST 2		
Test 2	Slope	Intercept
y =	0.0363	-0.1917
x =	182.02	
	C =	A/RKLSP
	A =	6.42
	Theoretical R =	182.02
	LS Factor =	2.86
	K =	0.23
	P =	1.00
	A/R =	0.0363
	C =	0.05

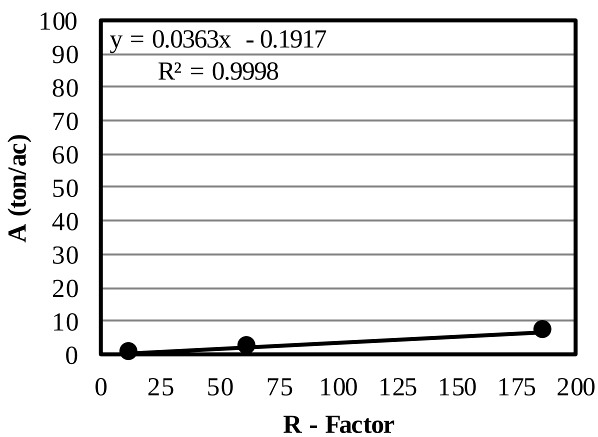
TEST 3		
Test 3	Slope	Intercept
y =	0.0327	-0.3746
x =	182.02	
	C =	A/RKLSP
	A =	5.57
	Theoretical R =	182.02
	LS Factor =	2.86
	K =	0.23
	P =	1.00
	A/R =	0.032652
	C =	0.05



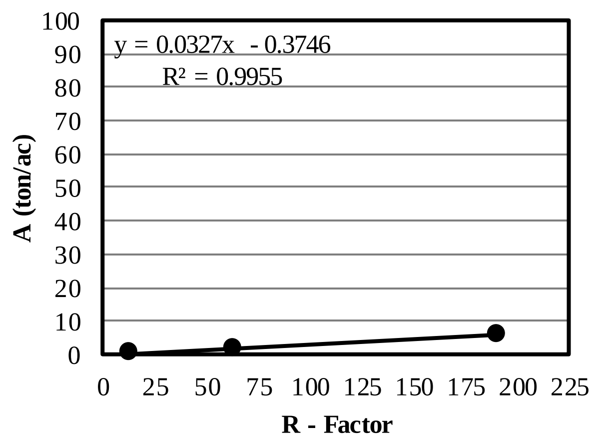
(a) Bare Soil



(b) Curlex I Test 1



(c) Curlex I Test 2



(d) Curlex I Test 3