Evaluation of Hydromulches as an Erosion Control Measure Using Intermediate-Scale Experiments

by

Wesley Thurman Wilson

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Approved by

Wesley C. Zech, Chair, Associate Professor of Civil Engineering
Prabhakar Clement, Professor of Civil Engineering
Larry G. Crowley, Associate Professor of Civil Engineering

Abstract

Discharge of sediment-laden stormwater from active construction sites, such as highway construction projects, is a growing concern in the construction industry (Zech et al. 2007, 2008). The United States Environmental Protection Agency (USEPA) (2009c) has recently proposed a 280 nephelometric units (NTU) effluent limitation guideline (ELG) pertaining to construction site runoff, and the Alabama Department of Environmental Management (ADEM) requires construction site runoff in the state of Alabama to retain turbidity levels within 50 NTUs above background levels. The Alabama Department of Transportation (ALDOT) is one of many agencies in the construction industry striving to meet the federal and state government construction site ELGs; therefore there has been an increased interest in research efforts to test the performance of many different erosion control practices. One such erosion control practice, hydromulching, is the hydraulic application of mulches. Although mulching fill slopes for erosion control is not a new practice, new technologies and innovations in the hydromulch industry has allowed the development of superior erosion control products. The performance of perhaps the oldest and cheapest form of erosion control, conventional straw mulch, has been tested and reported by many researchers to be an effective erosion control measure. However, with advancing technologies and a rise in concern for nonpoint source (NPS) pollution flowing from construction sites into our

streams, rivers, and lakes, the research of new and improved practices that reduce both erosion and sedimentation is needed.

The purpose of this research effort was to test the intermediate-scale performance of four hydromulches: (1) Excel® Fibermulch II, (2) GeoSkin®, (3) HydraCX^2®, and (4) HydroStraw® BFM and compare them to the performance of two conventional straw practices, crimped or tackified, and a bare soil control. The first phase of this research focused on researching and developing a method to accurately, uniformly, and efficiently apply hydromulch treatments to compacted and scoured 3H:1V fill slopes that mimic conditions similar to a highway embankment. The goal was to consistently achieve manufacturer specified application rates through the use of scientific methods. Ultimately, a method was developed enabling researchers to determine application rates per spray by a hydroseeder through confirmation of collected wet and dry mulch ratios. The second phase of this research focused on testing the performance of the four hydromulch treatments, the two conventional straw treatments, normalized to a bare soil condition, using 2 ft (0.6 m) wide by 4 ft (1.2 m) long test plots. Each treatment was subject to simulated rainfall, which was divided into four 15 minute rainfall events with 15 minute breaks in between, producing a total cumulative rainfall of 4.4 inches, representative of a 2-year, 24 hour storm event.

To determine the overall performance of each treatment, initial turbidities, turbidity over time, and soil loss measurements were consistently collected from plot runoff. Large amounts of collected data enabled researchers to effectively determine the performance of each practice tested. According to experimental results from this research effort, HydroStraw® BFM has the potential to meet ADEM ELGs of 50 NTUs,

with an approximate 100% average erosion reduction and 99% average sediment reduction when normalized to the bare soil (control) condition. Straw, tackified and HydraCX^2(R) were capable of meeting the USEPA's 280 NTU ELG, and on average reduced erosion by approximately 98% and 99% respectively. Overall, the results showed that all six practices tested were successful in controlling erosion. However, it is recommended to use additives such as polyacrylamide (PAM) in conjunction with the six tested practices to promote deposition and further reduce turbidity levels of construction site discharge. The results discussed in this research are qualified by several factors such as scale, slope, soil type, soil compaction, rainfall simulation, and rainfall intensity; therefore the potential for biased conclusions and recommendations must be acknowledged and may not be representative of field-scale performance.

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List of Abbreviations

ADEM	Alabama Department of Environmental Management
ALDOT	Alabama Department of Transportation
ANOVA	Analysis of Variance
ASTM	American Society for Testing and Materials
ASWCC	Alabama Soil and Water Conservation Committee
BFM	Bonded Fiber Matrix
BMP	Best Management Practices
CWA	Clean Water Act
ECP	Erosion Control Product
ECTC	Erosion Control Technology Council
ELG	Effluent Limitation Guideline
ESC	Erosion and Sediment Control
FRM	Fiber Reinforced Matrix
HECP	Hydraulically Applied Erosion Control Product
HM	Hydraulic Mulch
IDF	Intensity Duration Frequency
MBFM	Mechanically Bonded Fiber Matrix
MC	Moisture Content
NCAT	National Center for Asphalt Technology

NPDES	National Pollution Discharge Elimination System
NPS	Non-point Source
NTU	Nephelometric Units
OMC	Optimum Moisture Content
PAM	Polyacrylamide
SHA	State Highway Agency
SLR	Soil Loss Ratio
SMM	Stabilized Mulch Matrix
USEPA	United States Environmental Protection Agency

Chapter 1 Introduction

1.1 Background

Discharge of sediment-laden stormwater from active construction sites, such as highway construction projects, is a growing concern in the construction industry (Zech et al. 2007, 2008). The United States Environmental Protection Agency (USEPA) labels such discharge as nonpoint source (NPS) pollution and is defined as land runoff, precipitation, atmospheric deposition, seepage or hydrologic modification that does not meet the legal definition of 'point source' in section 502(14) of the Clean Water Act. NPS pollution can include bacteria, oil, grease and toxic chemicals, excess fertilizers from agricultural runoff, salt from irrigation practices, and sediment from improperly managed construction sites (USEPA, 2008). According to the USEPA's *Storm Water Phase II Final Rule Fact Sheet Series* (2008), sedimentation from construction site runoff is one of the most widespread pollutants affecting rivers and streams, second only to pathogens (i.e., bacteria). In an effort to reduce erosion and sedimentation, the USEPA has implemented a numeric limitation of 280 nephelometric units (NTUs) to be phased in over the next four years, beginning in August of 2011, for construction sites that disturb 10 or more acres at a time (USEPA, 2009c). In addition to federal guidelines, the Alabama Department of Environmental Management (ADEM), with authority given by the federal government, has implemented effluent limitation guidelines (ELGs) forbidding construction sites in the State of Alabama not to exceed runoff turbidities of 50 NTUs above background levels. These federal and state guidelines have encouraged the construction industry to establish a scientific approach to evaluate the performance of erosion and sediment control (ESC) practices in reducing erosion rates and turbidity levels.

1.2 Erosion, Sedimentation, and Turbidity

Erosion and sedimentation produced by construction site runoff is a main contributor of NPS pollution in the construction industry. "The erosion process is influenced primarily by climate, topography, soils, and vegetative cover" (ASWCC, 2009). Erosion, sedimentation, and turbidity can be described as a chain reaction; erosion of land leads to sediment transport in stormwater runoff, which in turn causes water to become turbid, eventually resulting in sedimentation as water velocities decrease. Erosion is defined by the Alabama Soil and Water Conservation Committee (ASWCC) as the "process by which the land surface is worn away by the action of water, wind, ice or gravity" (ASWCC, 2009). Sedimentation can be defined as "the process that describes soil particles settling out of suspension as the velocity of water decreases" (ASWCC, 2009). Turbidity occurs as sediment particles are being transported in stormwater runoff, causing water to become turbid, cloudy, or muddy prior to deposition. High levels of turbidity in rivers, streams, and lakes can have severe negative impacts (e.g., killing fish from gill abrasion, decreasing light penetration, smothering food sources, etc.) on the environment and wild life (ASWCC, 2009).

Although the ASWCC (2009) states that it is difficult, perhaps impossible, to totally eliminate the transport of clay and silt particles even with the most effective ESC practices, research and evaluation of ESC products is required to minimize NPS pollution discharges from construction sites to acceptable levels.

1.3 Best Management Practices (BMPs)

Federal and state ELGs have encouraged the construction industry to develop best management practices (BMPs) in an effort to effectively control erosion and sedimentation caused by construction site runoff. BMPs are methods that have been determined to be the most effective, practical means of preventing or reducing pollution from NPS pollution. A list of BMPs has been developed by ASWCC (2009) to guide contractors in properly selecting the BMP or combination of BMPs for specific construction site circumstances. The list is summarized below in Table 1.1.

Table 1.1 Summary of Different BMPs for Protecting Against Erosion, Sedimentation, and Stormwater Discharge

BMP Categories	Types Best Management Practices
Surface Stabilization	Chemical Stabilization; Erosion Control Blankets; Mulching; Permanent Seeding; Retaining Walls; Sodding;
Runoff Conveyance	Check Dams; Diversions; Drop Structures; Outlet Protection; Subsurface Trains; Swales
Sediment Control	Brush/Fabric Barriers; Drop Inlet Protection; Filter Strips; Floating Turbidity Barriers; Inlet Protection; Sediment Barriers; Sediment Basins; Sediment Traps
Stormwater Management	Bioretention Area; Porous Pavement; Stormwater Detention Basins
Stream Protection	Buffer Zones; Channel Stabilization; Stream Diversion Channel; Streambank Protection; Temporary Stream Crossings

The BMPs listed in Table 1.1 are a sample of specific BMPs that can be implemented to prevent pollution from construction generated NPS. This study will focus on hydraulically applied mulch, referred herein as hydromulch, which inherently falls under the ‘Surface Stabilization’ BMP category. The Alabama Department of Transportation (ALDOT) specifications for *Mulching and Vegetation Establishment* state that a hydromulch “shall be manufactured in such a manner that after addition and agitation in slurry tanks with soil amendments, the fibers in the material will become uniformly suspended to form a homogenous slurry; and that when hydraulically sprayed on the ground, the material will form a ground cover; and which after application will allow the absorption of moisture and allow rainfall or mechanical watering to percolate to the underlying soil” (ALDOT, 2008). Technological advancements in methods of application and mixing hydromulches has provided the construction industry with tools to manufacture new hydromulches that claim to be superior to traditional erosion control practices such as conventional straw mulch. However, since available scientific knowledge is limited, it is desirable to conduct performance-based intermediate-scale tests to quantify hydromulch erosion control efficiencies.

1.4 Research Objectives

This research effort is an extension of the erosion and sediment control study conducted by the Highway Research Center at Auburn University in conjunction with ALDOT to further the collective knowledge of BMPs on highway construction sites. This study incorporated test methods and protocols used by Shoemaker et al. (2009). Tests were conducted at an ESC facility located on the premises of the National Center for Asphalt Technology (NCAT) near Opelika, AL.

The overall objective of this research effort was to test the erosion control performance of the following four hydromulch practices: (1) Excel® Fibermulch II, (2) GeoSkin®, (3) HydraCX^2®, and (4) HydroStraw® BFM. A comparative analysis will be conducted to quantify performance by comparing the hydromulch practices to bare soil and two conventional straw treatments: (1) conventional straw, crimped and (2) conventional straw, tackified. To accurately test these six erosion control practices, this study was divided into two phases: (1) experimental preparations and (2) experimentation and evaluation.

PHASE 1: EXPERIMENTAL PREPARATIONS

1. Design and construct a flume that modifies Shoemaker's (2008) runoff collection device.
2. Research and develop a uniform and consistent method of applying conventional straw that is crimped or tackified.
3. Research and develop uniform and consistent methods of applying each hydromulch tested to ensure manufacturer specified application rates are achieved.

PHASE 2: EXPERIMENTATION & EVALUATION

1. Examine the effectiveness of and the four selected hydromulches for use as an erosion control measure on a compacted, 3:1 slope.

2. Analyze the results to provide scientific-data-based recommendations for hydromulching on highway construction sites.

1.5 Experimental Qualifications

There are five qualifying experimental factors that may have an impact on conclusions that are drawn from the results reported from this research, which include: (1) soil type, (2) slope, (3) soil compaction, (4) rainfall simulator, and (5) rainfall intensity. These qualifying factors were designed into the experimental procedures and have the potential to create a biased outcome on some conclusions and recommendations that can be made for erosion control practices tested. It should also be noted the intermediate-scale results reported herein may not be scale-able to field-scale or practical-scale performance on active construction sites.

1.6 Organization of Thesis

This thesis is divided into five descriptive chapters to present and explain the steps taken to complete the objectives of this research. Following this chapter, Chapter 2: *Literature Review* will explain conventional straw mulching practices, introduce and define different types of hydromulch as well as the hydromulches tested in this research effort, and review previous studies conducted on conventional straw and hydromulch practices. Chapter 3: *Intermediate-Scale Methods and Procedures*, will present the design and development of the intermediate-scale testing procedures and protocols. Chapter 4: *Experimental Results* will compare and analyze the data collected from the experiments, including an ANOVA statistical analysis performed for determination of significance between bare soil, conventional straw, and hydromulch treatments. Chapter 5:

Conclusions and Recommendations combines the data, results, and analyses conducted throughout this research effort to develop scientifically-based recommendations for the performance and use of each hydromulch. These recommendations will aid ALDOT in selecting proper types and applications of hydromulch products on highway construction sites with the goal of complying with federal and state effluent limitations.

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Chapter 2 Literature Review

2.1 Introduction

The process of urbanization (e.g. construction of highways, buildings, farms, parking lots, residential developments, etc.) modifies the natural orientation of the land and environment. Therefore when a rainfall event occurs, the path by which water flows to rivers, lakes and streams is ultimately altered. These unnatural, impervious altercations to the earth's surface cause an increase in total runoff volumes. When large, concentrated volumes of water traverse over areas disturbed by construction, there is an increased risk for erosion.

"Both falling rain and flowing water, typically referred to as stormwater, perform work in detaching and moving soil particles" (ASWCC, 2009), herein referred to as soil erosion. Soil erosion is considered the largest contributor to non-point source pollution in the U.S. (USEPA, 1997). An estimated $27 billion annually is spent in the U.S. in an effort to control soil erosion (Brady and Weil, 1996). It is also reported that soil loss rates are 20 times greater from construction sites than agricultural lands, and 1,000 to 2,000 times greater than forest lands (USEPA, 2005b). When soil is eroded from construction sites, other harmful particulates such as fertilizers, pesticides and fuels attach to the soil and are transported into municipal storm sewer systems (MS4s) (Risse and Faucette 2001;

USEPA, 2005a). Polluted stormwater systems transport construction site runoff directly to surface waters, ultimately causing sedimentation. "Sedimentation impairs 84,503 river and stream miles (12% of the assessed river and stream miles and 31% of the impaired river and stream miles)" (USEPA, 2000). Sedimentation of surface water can lead to deterioration of aquatic habitats, rapid loss of storage capacity of reservoirs, eroded streambanks, and increased turbidities of the waters, reducing photosynthesis and clogging fish gills (Novotny, 2003). An annual estimate of $17 billion is spent in the U.S. alone in an effort to control sedimentation, bringing the national total to over $44 billion in erosion and sediment control (Brady and Weil, 1996). Thus, the combination of environmental and economic downfalls related to erosion and sedimentation in the construction industry has developed a need for scientific research to be performed to understand the overall performance of ESC practices used at the federal, state, and local levels.

The primary goal of this research was to develop intermediate-scale experimental procedures to test the performance of hydromulches as an erosion control practice on a typical 3H:1V highway construction slope. This research effort and its stated objectives discussed in Section 1.4 were established in an effort to gain scientific knowledge on the performance of several hydromulch products relative to bare soil and conventional straw practices. Typical highway construction sites rely heavily upon the success of ESC practices to control erosion and sedimentation while complying with USEPA regulations. Thus the research conducted herein will provide ALDOT with scientific findings regarding performance characteristics of erosion control products for use on future construction projects.

Before these research objectives can be satisfied, it is pertinent to conduct a thorough literature review. The literature review herein will focus on identifying: (1) federal, state, and local environmental regulations specific to construction site ESC, (2) a review of erosion control practices, specifically conventional straw and hydromulches, and (3) previous literature related to conventional straw and hydromulch tests.

2.2 Environmental Regulations

The USEPA has developed ELGs to establish national standards for the regulation of construction stormwater runoff, which are the minimum standards state highway agencies (SHAs) are required to comply with. However, if a state chooses to impose stricter regulations than the required federal regulations and attain permission by the federal government to do so, then they have mandate to enforce higher effluent standards. This section will discuss a brief history of regulating our nation's waters, present USEPA environmental guidelines, and the ELGs required by the state of Alabama, upheld by ADEM.

2.2.1 USEPA Regulations

In 1899, the United States made its first federal action towards protecting our nation's waters with the Refuse Act. This act outlawed the "dumping of refuse that would obstruct navigation of navigable waters, except under a federal permit," which would in the 1960's be redefined to cover industrial waste (USEPA, 2010a). It wasn't until 1972 that the National Pollution Discharge Elimination System (NPDES) was created in section 402 of the Clean Water Act (CWA), prohibiting the discharge "of pollutants from any point source into the nation's waters except as allowed under an NPDES permit" (USEPA, 2010a). Five years later, Congress amended the CWA to focus on controlling toxic discharge, and in 1987 Congress passed an act calling for the increased monitoring of water bodies to ensure water quality standards were upheld by on-site construction contractors (USEPA, 2010a).

In 1990, Phase I of the USEPA stormwater program was promulgated under the CWA, relying on the NPDES "permit coverage to address stormwater runoff from: (1) 'medium' and 'large' municipal separate storm sewer systems (MS4s) generally serving populations of 100,000 or greater, (2) construction activity disturbing 5 acres of land or greater, and (3) ten categories of industrial activity" (USEPA, 2005a). In 1999, the Stormwater Phase II final rule expanded Phase I by implementing six measures, which in summary required "additional operators of MS4s in urbanized areas and operators of small construction sites, through the use of NPDES permits, to implement programs and practices to control polluted stormwater runoff" (USEPA, 2005a). Despite Phase I and Phase II's ESC efforts, the 2000 National Water Quality Inventory (USEPA, 2000) reported that in the U.S., approximately 40% of surveyed water bodies are still impaired, and 13% of impaired rivers, 18% of impaired lake acres and 32% of impaired estuaries were still affected by urban/suburban stormwater runoff.

In 2009, the USEPA released a full national economic and environmental analysis of ELGs for the construction industry in the *Economic Analysis of Final Effluent Limitation Guidelines and Standards for the Construction and Development* (USEPA, 2009a) and the *Environmental Impact and Benefits Assessment for Final Effluent Guidelines and Standards for the Construction and Development Category* (USEPA, 2009b). These two documents were the basis of support for the *Final Rule: Effluent Guidelines for Discharge from the Construction and Development Industry*, which promulgated ELGs and new source performance standards (NSPS) to control the discharge of pollutants from construction sites (USEPA, 2009c). In summary, this final rule contains stringent requirements for soil stabilization, acquiring NPEDS permits, and implementation of ESC practices. Also, the USEPA is implementing a numeric limitation of 280 NTUs to be phased-in over the next four years, beginning in August of 2011 to "allow permitting authorities adequate time to develop monitoring requirements and to allow the regulated community time to prepare for compliance with the numeric limitation." (USEPA, 2009c). This rule states "construction sites that disturb 20 or more acres at one time will be required to conduct monitoring of discharges and comply with the numeric limitation beginning 18 months after the effective date of the final rule" (USEPA, 2009c). Also, it states that after the four years, the 280 NTU limitation will apply to construction sites disturbing 10 or more acres at one time. In the USEPA's costs and benefits analysis (2009c), it was estimated that approximately 4 billion pounds of sediment discharged from construction sites will be reduced, saving about $953 million annually, once this final rule reaches final implementation.

2.2.2 The State of Alabama Regulations

Alabama is an authorized state, meaning the USEPA has given the State of Alabama permission to administer state environmental regulations in lieu of most federal environmental regulations (ADEM, 2010a). One such federal environmental regulation Alabama has permission to administer is the standards regarding water quality of water bodies within the State. ADEM is responsible for ensuring federal regulations are followed. Therefore, in Division 6, Volume 1 of their rules and regulations, ADEM "prescribes regulations for development and implementation of water quality standards and water body use classifications for all waters of the State; prescribes conditions relevant to the issuance of permits to include effluent limitations for each discharge for which a permit is issued; and such other rules as necessary to enforce water quality standards. Within ADEM's water quality program, *Chapter 335-6-10 Water Quality Criteria* (2010b), they require "no turbidity other than natural origin that will cause substantial visible contrast with the natural appearance of waters or interfere with any beneficial uses which they serve. Furthermore, in no case shall turbidity exceed 50 NTU above background levels. Background levels will be interpreted as the natural condition of receiving waters without the influence of man-made or man-induced causes. Turbidity caused by natural runoff will be included in establishing background levels."

Although the USEPA is phasing in a 280 NTU effluent guideline, the 50 NTU regulation from ADEM overrules in the State of Alabama. Therefore, for ALDOT and the research herein, 50 NTU above background levels is the numerical guideline followed.

2.3 Erosion and Sediment Control (ESC) Practices

The USEPA defines BMPs as "a technique, process, activity, or structure used to reduce the pollutant content of a storm water discharge."

It is important to identify the length of time a BMP is expected to perform. Erosion control products (ECPs) can be divided into two categories: short term and permanent ECPs. The Erosion Control Technology Council (ECTC) defines short term ECPs as products "designed to provide erosion protection for longer than three months and up to 12 months," which is basically one growing season for the establishment of vegetation (ECTC, 2008). Permanent ECPs can be defined as a product designed to provide permanent, long term protection from erosion. Typical short term ECPs are erosion control blankets, spray-emulsion products (i.e., hydromulches), and straw mulches, where the best long term control is well established vegetation (Benik et al., 2003). The focus of this research is on short term, temporary performance of ECPs.

The USEPA (2006) has developed a menu of BMPs for erosion and sediment control on construction sites along with their reported cost and effectiveness from previous researchers, shown in Table 2.1. According to Table 2.1, the most common BMPs in the erosion control industry today are chemical stabilizers with a 70% to 90% efficiency rate, compost blankets with a 70% to 100% efficiency rate, geotextiles, gradient terraces, mulching with a 53% to 99.8% efficiency rate, seeding with an average efficiency rate of 90%, and sodding with an average efficiency rate of 99%. As reported by the USEPA

(2006), these are all efficient forms of ESC; however the focus in this research effort is on mulching practices such as conventional straw and hydraulically applied mulches.

Table 2.1 USEPA Menu of BMPs and Reported Cost and Effectiveness

BMPs*	Description	Cost[1, 2]	Effectiveness
Chemical Stabilizers	Soil binders or soil palliatives, provide temporary soil stabilization.	\$4-\$35/lb	70-90% (Aicardo, 1996)
Compost Blankets	A layer of loosely applied compost or composted material that is placed on the soil in disturbed areas to control erosion and retain sediment resulting from sheet-flow runoff.	\$0.83-\$4.32/yd^3 (Faucette, 2004)	70-100% (Faucette and Risse, 2002)
Geotextiles (RECPs)	Manufactured by weaving or bonding fibers that are often made of synthetic materials such as polypropylene, polyester, polyethylene, nylon, polyvinyl chloride, glass, and various mixtures of these materials. As a synthetic construction material, geotextiles are used for a variety of purposes such as separators, reinforcement, filtration and drainage, and erosion control (USEPA, 1992).	\$0.50-\$10/yd^2 (SWRCP, 1991)	n/a
Gradient Terraces	Earthen embankments or ridge and channel systems that reduce erosion by slowing, collecting and redistributing surface runoff to stable outlets that increase the distance of overland runoff flow.	n/a	n/a
Mulching	**An erosion control practice that uses materials such as grass, hay, wood chips, wood fibers, straw, or gravel to stabilize exposed or recently planted soil surfaces.**	**\$800-\$3500/acre (USEPA, 1993)**	**53-99.8% (Harding, 1990)**
Riprap	A layer of large stones used to protect soil from erosion in areas of concentrated runoff.	\$35-\$60/yd^2 (Mayo et al., 1993)	n/a
Seeding	Used to control runoff and erosion on disturbed areas by establishing perennial vegetative cover from seed.	\$200-\$1000/acre (USEPA, 1993)	50-100% (90% avg.) (USEPA, 1993)
Sodding	A permanent erosion control practice and involves laying a continuous cover of grass sod on exposed soils.	\$0.10-\$1.10/ft^2 (USEPA, 1993)	99%

Note: '*' Source: USEPA, 2010b
'1' 1 lb = 0.45 kg
'2' 1 ft = 0.31 m

2.4 Mulching

According to the USEPA (2006), “mulching is an erosion control practice that uses materials such as grass, hay, wood chips, wood fibers, straw or gravel to stabilize exposed to or recently planted soil surfaces.” The *Alabama Handbook for Erosion Control, Sediment Control and Stormwater Management on Construction Sites and Urban Areas* (2009) states that “surface mulch is the most effective, practical means of controlling runoff and erosion on disturbed land prior to vegetation establishment;” however is most effective when used in conjunction with vegetation (USEPA, 2006). As shown in Table 2.1, one of the most expensive types of erosion control is mulching; nonetheless, mulches report a maximum potential of 99.8% efficiency. Lancaster and Theisen (2004) recall that although methods of ESC practices such as mulching are expensive, “expense and performance increase with the level of engineering.” Researchers (Box and Bruce, 1996; Bruce et al., 1995; Sutherland, 2006, 1998) have reported that mulches used to control erosion have a two-fold advantage, having the capability to reduce soil loss while protecting grass seeds and soil amendments from being washed away. Additionally, mulches are also capable of reducing solar radiation, suppress fluctuations of soil temperature, reduce water loss through evaporation, dissipate rainfall impact, and help prevent soil crust formation (Sutherland, 1998; 1986; Rickson, 1995; Turgeon, 2002; Singer et. al 1981; Bruce et. al. 1995).

Table 2.2 shows typical mulching materials and application rates used in Alabama (ASWCC, 2009; USEPA, 2006). In summary, the table represents application rates and guidelines for conventional straw with and without seed, wood chips, bark, pine straw, and peanut hulls.

Table 2.2 Mulching Materials and Application Rates

(Source: ASWCC, 2009)

Mulch	Rate Per Acre and (Per 100 ft^2)[1]	Guidelines
Conventional Straw with Seed	1.5-2 tons (70 lbs-90 lbs)	Spread by hand or machine to attain 75% groundcover; anchor when subject to blowing.
Conventional Straw (no seed)	2.5-3 tons (115 lbs-160 lbs)	Spread by hand or machine; anchor when subject to blowing.
Wood Chips	5-6 tons (225 lbs-270 lbs)	Treat with 12 lbs. nitrogen/ton.
Bark	35 cubic yards	Can apply with mulch blower.
Pine Straw	1-2 tons (45 lbs-90 lbs)	Spread by hand or machine; will not blow like straw.
Peanut Hulls	10-20 tons (450 lbs-900 lbs)	Will wash off slopes. Treat with 12 lbs. nitrogen/ton.

Notes: ‘1’ 1 lb = 0.45 kg; 1 ton = 0.89 metric tons

When selecting the proper mulch to apply to a slope for erosion control, the mulch should be based on soil conditions, slope steepness and length, season, type of vegetation established, and size of the area (ASWCC, 2009; USEPA, 2006). Mulches such as wood chips are often highly considered as an erosion control measure when germination is not an option. Wood chips do not require tacking, but they decompose slowly, requiring a treatment of 12 pounds (5.44 kg) of nitrogen per ton to prevent nutrient deficiency in plants.

Although there are several adequate mulches for erosion control on highway construction slopes, illustrated in Table 2.2, the focus in this research effort is on conventional straw practices and hydraulically applied mulches. The following sections of the literature review will report on: (1) conventional straw erosion control practices and (2) typical hydraulically applied mulches.

2.4.1 Conventional Straw Erosion Control Practices

The purpose of testing conventional straw herein was to have a traditional, low-cost, widely used ESC practice to compare to the performance of hydromulch products. Straw is considered one of the most common ground covers used to reduce erosion on construction sites (ASWCC, 2009), and as shown in Table 2.1, has been reported to reduce erosion rates by more than 90 percent if applied at sufficient rates (Mannering and Meyer, 1963; McLaughlin and Brown, 2006; Meyer et al., 1970; Singer et al.,1981). Turgeon (2002) states that straw is also capable of encouraging grass establishment by reducing runoff, increasing infiltration, and improving soil conditions. Advancements in technology have made the application of conventional straw a simple and unproblematic procedure. The application of conventional straw on large construction sites can be achieved with commercial blowers that break up straw bales and blow the straw onto the soil, illustrated in Figure 2.1.

Figure 2.1 Commercial Straw-Blower.
(Source: http://www.revolutionequipment.com.au/strawblower-gallery.html)

The *Alabama Handbook for Erosion Control, Sediment Control and Stormwater Management on Construction Sites and Urban Areas* (2009) requires approximately 75% ground cover when applying conventional straw. Straw's performance depends heavily upon the contractor for achieving consistent, uniform application and coverage of straw on the soil surface. If application of the straw is inconsistent, the performance of the installation will be compromised (Babcock et al., 2008; Lancaster et al., 2006).

Conventional straw is also effectively applied by hand, which was the application method used for the research herein; however, this method can become very costly when applied at a large scale due to labor costs (Babcock et al., 2008). When applying straw by hand, it is encouraged to "divide the area into sections of approximately 1,000 ft^2 (92.9 m^2) and place 70 to 90 pounds (31.8 to 40.8 kg) of straw (1½ to 2 bales) in each section to facilitate uniform distribution" (ASWCC, 2009). Conventional straw is very lightweight, therefore it is susceptible to wind erosion, and needs to be immediately anchored with a mulch anchoring tool such as a mulch crimping machine, shown in Figure 2.2, or tackifiers (ALDOT, 2008; ASWCC, 2009; Babcock et al., 2008; USEPA, 2006).

Figure 2.2 Straw-Crimper.
(Source: http://www.mulchers.com/images/straw-crimper.jpg)

Straw crimpers are typically used to crimp or punch straw into the soil when the soil is not too sandy (Babcock et al., 2008). ALDOT (2008) classifies straw mulch placed on 3H:1V or flatter slopes using a crimper as a “Class A, Type 1” mulch. If crimpers are not available or necessary, liquid mulch binders are used to ‘tack’ mulch by spraying them over the straw, but applying straw and binder together is the most effective method (ASWCC, 2009). ALDOT (2008) specifies straw mulch that requires an adhesive and shall be used on slopes steeper than 3H:1V are classified as “Class A, Type 2” mulches. “Emulsified asphalt is the most commonly used mulch binder” (ASWCC, 2009); however wood and paper fiber hydromulches, guar, and starch-based tackifiers are also commonly used to bind straw (Babcock et al., 2008).

There are advantages and disadvantages to using straw mulch for erosion control. The advantages are that it is inexpensive, quick and easy to apply using a straw-blower, capable of achieving efficient grass growth, and no water is needed for application. Conversely, disadvantages of conventional straw include that it does not effectively prevent soil loss as well as more expensive erosion products, is susceptible to wind erosion if not properly anchored, may introduce weed seeds, and fines from straw-blowers can drift long distances (Babcock et al., 2008).

2.4.2 Hydraulically Applied Mulch (a.k.a. Hydromulch)

It has been reported that field practices, such as blown straw, slope interruptions, or gradient terraces, represent the least expensive and least reliable form of erosion control, whereas "an application of a loose or hydraulically applied mulch cover represents an upgraded level of performance," and provide the highest level of erosion control and confidence (Lancaster et al., 2006). Hydraulically applied mulches, referred to herein as 'hydromulches', have shown continuous evolution and improvement over the past 50 years. Advancements in technology have resulted in the production of equipment and materials that offer enhanced performance and greater productivity over many traditional methods of erosion control. There is a knowledge gap between the cost-effectiveness and performance benefits of new products (Morgan and Rickson, 1988; NCHRP, 1980; Sutherland, 1998; Weggel and Ruston, 1992) such as hydromulches, largely due to newly evolving technologies as well as a lack of research involving hydromulch products.

The introduction of water, refined fiber matrices, tackifiers, super-absorbents, flocculating agents, man-made fibers, plant biostimulants and other performance enhancing additives as a hydromulch practices on slopes has forced federal, state, and local governments to begin developing hydromulch guidelines. The American Society for Testing and Materials (ASTM) has proposed new standards for testing hydraulically applied erosion control products (HECPs). Also, ECTC has divided HECPs into four distinct categories, relevant to their corresponding functional longevity, erosion control effectiveness, and vegetative establishment, illustrated in Table 2.3 (ECTC, 2008; Babcock et al., 2008).

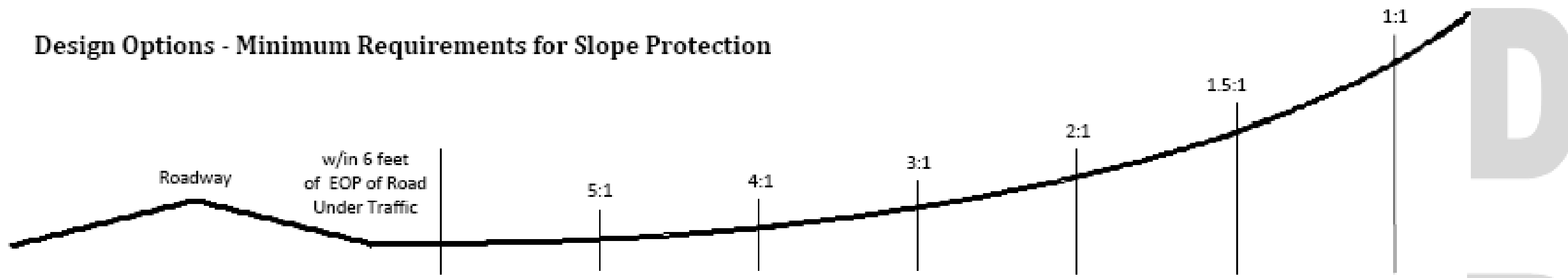
Table 2.3 Types of Hydraulically Applied Erosion Control Products (HECPs)

Slope Ratio	Material	Rate[1] (lbs/acre)	Description
≤2H:1V	Stabilized Mulch Matrix (SMM)	1,500-2,500	Organic fibers with soil flocculants or cross-linked hydro-colloidal polymers or tackifiers. Used to provide erosion control and facilitate vegetative establishment on moderate slopes. Designed to be functional for a minimum of 3 months.
≤2H:1V	Bonded Fiber Matrix (BFM)	3,000-4,000	Organic fibers and cross-linked insoluble hydro-colloidal tackifiers. Used to provide erosion control and facilitate vegetative establishment on steep slopes. Designed to be functional for a minimum of 6 months. May need 24 hr cure time.
≤2.5H:1V	Fiber Reinforced Matrix (FRM)	3,000-4,500	Organic defibrated fibers, cross-linked insoluble hydro-colloidal tackifiers, and reinforcing natural or synthetic fibers. Used to provide erosion control and facilitate vegetative establishment on very steep slopes. Designed to be functional for a minimum of 12 months.
≤6H:1V	Hydraulic Mulch (HM)	1,500	Paper, wood or natural fibers that may or may not contain tackifiers. Used to facilitate vegetative establishment on mild slopes. Designed to be functional for up to 3 months.

Note: '1' Metric unit conversion: 1 lb/acre = 1.12 kg/ha

As shown in Table 2.3, stabilized mulch matrix (SMM) products are used for slopes less than or equal to 2H:1V, applied at a rate of 1,500 to 2,500 lbs/acre (1,680 to 2,800 kg/ha), have a functional longevity of approximately 3 months, and are composed of organic fibers with soil flocculants or cross-linked hydro-colloidal polymers or tackifiers. Bonded fiber matrix products (BFM) are designed for a slope less than or equal to 2H:1V, applied at 2,000 to 4,000 lbs/acre (2,240 to 4,480 kg/ha), have a functional longevity of approximately 6 months, and are composed of organic fibers and cross-linked insoluble hydro-colloidal tackifiers. Fiber reinforced matrix (FRM) products should be applied to a slope less than or equal to 2.5H:1V at a rate of 3,000 to 4,500 lbs/acre (3,360 to 5,040 kg/ha), have a functional longevity of approximately one year, and are composed of organic defibrated fibers, cross linked insoluble hydro-colloidal tackifiers, and reinforcing natural or synthetic fibers. Lastly, hydraulic mulches (HM) are designed to apply to a slope less than or equal to 6H:1V at a rate of 1,500 lbs/acre (1,680 kg/ha), have a functional longevity of about 3 months, and are composed of paper, wood or natural fibers that may or may not contain tackifiers.

The ALDOT has released a draft of classifying hydromulches, illustrated in Figure 2.3. Figure 2.3 classifies SSMs, BFMs, and FRMs as “Class C” mulches, ranging in longevity and slope from 3to 12 months and within 6 feet (1.83 m) of edge of pavement on slopes ranging from 0.5H:1V. Table 2.4 contains the products tested in the research herein, along with their corresponding category, designed slope, application rate, and material composition.



<table>
<tr><th>Mulches</th><th colspan="9">Maximum Slope (H:V)</th></tr>
<tr><td rowspan="5">Minimum Functional Longevity</td><td></td><td>w/in 6 feet</td><td>5:1</td><td>4:1</td><td>3:1</td><td>2:1</td><td>1.5:1</td><td>1:1</td><td>0.5:1</td></tr>
<tr><td rowspan="2">3 Months</td><td>Class A Type 2</td><td colspan="3">Class A Type 1</td><td colspan="4">Class A Type 2</td></tr>
<tr><td colspan="5">Class C – SMM</td><td colspan="2" rowspan="2">Class C - BFM</td><td rowspan="2">Class C – FRM</td></tr>
<tr><td>6 Months</td><td colspan="5">Class C - BFM</td></tr>
<tr><td>12 Months</td><td colspan="8">Class C – FRM</td></tr>
</table>

Figure 2.3 Proposed ALDOT (2009) Minimum Requirements and Classifications

Table 2.4 Product Specifications used in this Research

Product	Category	Material Composition[1]	Slope (H:V)	Application Rate[2] (lbs/acre)
GeoSkin®	Hydraulic Mulch (HM)	Mechanically Processed Straw: 84±3% Mechanically Processed Reclaimed Cotton Plant Material: 15±3% Proprietary Blend of Tackifiers, Activators and Additives: <1%	≤4:1	1,500
			>4:1≤3:1	2,000
HydraCX^2®	Bonded Fiber Matrix (BFM)	Mechanically Processed Straw: 65±3% Mechanically Processed Reclaimed Cotton Plant Material: 25±3% Proprietary Hydro-Colloid Tackifiers and Activators: 10±1%	≥1:1	4,500
			≥2:1<1:1	4,000
			≥3:1<2:1	3,500
			<3:1	3,000
Excel® Fibermulch II	Hydraulic Mulch (HM)	Organic Matter: 99.3±0.2% Ash Content: 0.7±0.2% Water Holding Capacity: 1401±10%	≤4:1	2,000-2,500
HydroStraw® BFM	Bonded Fiber Matrix (BFM)	Heat and Mechanically Treated Straw Fibers (HMT): 67±1% Cellulose Paper Mulch: 2.5±1% Natural Fibers for Matrix Entanglement: 10±1% Moisture Content: 10.5±1.5%	≤3:1	3,000
			≤2:1	3,500
			≤1:1	4,500

Note: '1' Material Compositions are based upon and may be limited to availability of information released from manufacturer.
'2' Metric unit conversion: 1 lb/acre = 1.12 kg/ha.

As shown in Table 2.4, GeoSkin® and Excel® Fibermulch II are hydraulic mulches (HM), and HydraCX^2® and HydroStraw® BFM are bonded fiber matrix (BFM) products. The hydromulches in this research effort were selected for testing by the ALDOT; however, in general, when selecting a proper hydromulch for ESC, the slope, soil type, cost of hydromulch, application rate, and predicted effectiveness are factors to consider. A wide variety of hydromulches on the market today allow contractors to select the most applicable hydromulch for specific construction sites conditions. However, unlike conventional straw, hydromulching requires special equipment, including a water tank with a mixer and a high-powered pump (Babcock et al., 2008). Another issue to consider when considering hydromulch as an erosion control practice on a construction site is having access to a nearby water source to fill and refill the hydroseeder. If there is no water source nearby, hydromulching is not feasible, or becomes very expensive (Babcock, 2008). Similar to straw, hydromulching depends heavily upon consistent, uniform, manufacturer specified application rates. If manufacturer application specifications are not followed, the performance of the hydromulch may be compromised.

Most hydromulches are sprayed in conjunction with a tackifier or bonding agent; therefore the hydraulic mulch bond strength may not fully develop if the site receives significant rainfall or freezing conditions within 24 to 48 hours after application. Lancaster and Austin (2004) report that hydromulches containing special fibers to mechanically bond the matrix, illustrated in Table 2.3, achieve maximum performance in erosion control; however the bond strength of all hydromulches is limited and can quickly erode from slopes during increased runoff conditions and areas of concentrated flow. The fibers used in hydromulch generally must be less than ½ inch (1.27 cm) in length to pass through the pumps and hoses of most hydroseeders; therefore if the mechanical matrix bond between the mulch is broken, the strength of the mulch is lost, relying on the strength of the short, dimensionally unstable fibers (Lancaster and Austin, 2004). Therefore, "because hydraulic mulches lack appreciable tensile strength, shear strength and life span, their use generally is limited to flatter and shorter slopes with very low overland flows," (Lancaster and Austin, 2004). When a hydromulch fails, repairs on these treated slopes can become very costly.

Costs of hydromulches vary depending on the type of mulch shown in Table 2.3, the application equipment, water availability, and area size. According to Babcock et al. (2008), "application costs can range from $0.41 to $1.15 per square yard ($0.49 to $1.38 per square meter), not including seed, fertilizer, or lime. As a general rule, the more expensive hydromulches, such as bonded fiber matrices, tend to offer better protection against erosion, but actual results are site specific." As the use and research of new and improved hydromulches continues to grow, the knowledge gap of cost-effective data will shorten, allowing for a greater cost analysis of hydromulches to be performed.

2.5 Evaluation of straw Mulch Practices

Literature involving the scientific evaluation of the performance of conventional straw is more prevalent than that of hydromulches. This section will provide an overview of the reported performance previous researchers have provided of conventional straw and hydromulches on both a large- and intermediate-scale.

2.5.1 Conventional Straw Literature

Over the past 50 years, research and experiments examining conventional straw as an erosion control practice vary considerably. Overall, researchers have found it to be an effective measure of erosion control on slopes (McLaughlin and Brown, 2006; Lipscomb et al., 2006; Hayes et al., 2005; Benik et al., 2003; Clopper, 2001; Bjorneberg et al., 2000; Parsons et al., 1994; Harding, 1990; Horner et al., 1990; Burroughs and King, 1989; Buxton and Caruccio., 1979; Dudeck et al., 1970; Barnett et al., 1967; Adams, 1966). This section will give an overview of literature involving testing of conventional straw over the past decade.

Experiments conducted by McLaughlin and Brown (2006) evaluated four types of ground covers, one of which included straw mulch on both a large- and intermediate-scale. On both scales, straw was spread by hand at 1,962 lbs/acre (2,200 kg/ha). The intermediate-scale procedure consisted of 3.28 ft wide by 6.6 ft long by 0.8 inches deep (1 m wide by 2 m long by 9 cm deep) wood boxes placed at both a 10 and 20 percent slope and filled with three different types of soils: sandy clay loam, sandy loam, and a loam. Test plots were subject to a rainfall intensity of 1.34 in/hr (3.4 cm/hr). According to large-scale results produced by McLaughlin and Brown (2006), “the straw always generated the greatest coverage” and “provided significantly better coverage compared to either bare soil” or the mechanically bonded fiber matrix (MBFM) tested. Intermediate-scale results reported that when compared to bare soil, straw mulch reduced soil erosion by approximately 82% and average turbidity by about 67%.

Lipscomb et al. (2006) used ASTM D-6459 (2000) International standard to test a straw RECP against blown straw applied at a rate of 2,500 lbs/acre (2,837 kg/ha). ASTM D-6459 requires plots to be 8 ft (2.4 m) wide by 40 ft (12.2 m) long on a 33% slope (2000). The products were tested on sand, loam, and clay soils. Results reported using a calculated cover factor, based upon sediment runoff comparisons from bares soil plots and treated plots. According to this study, straw-mulch reduced erosion by up to 93.2%. Turbidity measures were not mentioned for this research effort, but it was reported that although straw was an effective erosion control practice on sand soil and shallow loam soil slopes, it provided little benefit on steep, clay soil slopes.

Hayes et al. (2005) tested 10 treatments on 30 large scale runoff plots that were 20 ft (6 m) long and 5 ft (1.5m) wide on 50% and 20% slopes. One of the treatments in this experiment was wheat straw in conjunction with grass seed applied by hand at a rate of 2,000 lbs/acre (2,240 kg/ha). Over a period of 30 days, runoff generated by natural rainfall was collected, yielding an approximate 75% reduction in average turbidity and total sediment loss. This study ultimately concluded that the application of grass seed and straw mulch was highly effective and seldom showed signs of significant improvement with the addition of polyacrylamide (PAM).

In 2003, Benik et al. conducted 4 treatments on 3.9 ft (1.2 m) wide by 32 ft (9.75 m) long plots positioned at a 35% slope. Straw mulch was applied at Minnesota DOT's standard rate of 4,000 lbs/acre (4,480 kg/ha) by hand and was anchored into the soil with a garden spade to approximate disk-anchoring methods. A rotating-boom rainfall simulator (Swanson, 1979) produced rainfall on the large scale test slopes with an intensity of approximately 2.36 in/hr (60 mm/hr), and were tested seasonally. Although average turbidity readings were not stated, spring season results reported a reduction in average sediment yield by approximately 90%.

Clopper et. al. (2001) tested blown straw and compared against a biodegradable erosion control blanket (ECB), Curlex I using procedures described in ASTM D-6459 (ASTM, 2000). Twelve large-scale plots, 8 ft (2.4 m) wide by 40 ft (12.2 m) long on a 33% slope, tested straw applied to sand, loam and clay soil at a rate of 2,500 lbs/acre (2,800 kg/ha). Clopper (2001) reported similar results to Lipscomb et al. (2006), reporting up to a 93% reduction in soil loss; however stated that straw applied to loam soils only slightly reduced soil loss, while testing on clay soils had an apparent increase in soil loss when compared to bare soil tests. The unexpected results were reported to be caused by irregularities in straw application, which is a common when using blown straw.

Bjorneberg et al. (2000) conducted intermediate-scale testing on using six different treatments. In this research effort, six steel boxes, 3.94 ft (1.2 m) wide by 4.92 ft (1.5 m) long by 8 inches (0.2 m) deep, were placed on a 2.4% slope, and filled with a loam soil. Straw was then applied to the test plots at 30 % and 70% cover, at a rate of 600 lbs/acre

(670 kg/ha) and 2,230 lbs/acre (2,500 kg/ha) respectively. Bjorneberg reported that the 70% straw cover decreased sediment loss by more than 80%, and 30% straw cover decreased sediment loss by nearly 50% when compared to bare soil treatments. Table 2.5 provides a summary of conventional straw mulch studies reviewed in the literature.

Table 2.5 Summary of Reviewed Straw Mulch Practices

Study	Test-Scale	No. of Treatments	Application Method	Application Rate (lbs/acre)	Reduction Performance (%)		C-Factor
					Soil Loss	Turbidity	
McLaughlin & Brown (2006)	large & small	4[1]	hand	1962	82	67	UNK
Lipscomb et al. (2006)	large	2[2]	blown	2,500	93.2	UNK	0.86-0.107
Hayes et al. (2005)	large	10[3]	blown	2,000	75	75	UNK
Benik et al. (2003)	large	4[4]	hand, anchored*	4,000	90	UNK	UNK
Clopper et al. (2001)	large	2[5]	blown	2,500	93	UNK	0.81
Bjorneberg et al. (2000)	small	6[6]	hand	600	50	UNK	UNK
				2,230	80	UNK	UNK

Notes: '1' Treatments: (1) conventional straw, (2) straw erosion control blanket (ECB), (3) wood fiber, (4) MBFM.
'2' Treatments: (1) conventional straw, (2) straw erosion control blanket (ECB).
'3' Two types of PAM used: Soilfix and Siltstop. PAM treatments: seed/mulch with and without PAM.
'4' Treatments: (1) conventional straw, (2) wood-fiber blanket, (3) straw/coconut blanket, (4) BFM hydromulch.
'5' Treatments: (1) conventional straw, (2) Curlex I (straw ECB).
'6' Bare soil and conventional straw w/PAM rates of 0, 2, and 4 kg/ha.
'*' Anchored with a garden spade to mimic disk-anchoring methods.

2.5.2 Summary of Conventional Straw Literature

In summary, a review of literature reporting experiments conducted using conventional straw as an erosion control practice was reported as an effective practice in reducing erosion. McLaughlin and Brown (2006) reported straw mulch to reduce soil erosion by approximately 82% and turbidity by about 67%. Lipscomb et al. (2006) and Clopper (2001) both reported reduction in sediment loss by approximately 93% with the use of blown straw as an erosion control practice. Hayes et al. (2005) also found similar results to McLaughlin and Brown (2006), reporting a near 75% reduction in both soil loss and turbidity. Lastly, Bjorneberg et al. (2000) found a reduction in sediment loss by approximately 80% when a 2.4% slope is 70% covered by straw mulch. All of the literature herein reported significant reductions in sediment loss when conventional straw is properly applied to slopes.

2.5.3 Hydromulch Literature

Hydraulic applications of mulch to slopes, referred to herein as hydromulching, for the purpose of erosion control, is a developing industry. However, a review of literature indicate that only a limited number of hydromulch studies conducted (McLaughlin and Brown, 2006; Holt et al., 2005; Benik et al., 2003; Landloch, 2002; Buxton et al., 1979), which indicated a need for further testing of hydromulch practices to effectively evaluate performance of hydromulch products used for erosion control.

McLaughlin and Brown (2006), conducted large- and intermediate-scale tests on four ground cover practices, two of which were straw mulch and a mechanically bonded fiber matrix (MBFM) hydromulch. The MBFM was applied using a commercial hydroseeder at Profile Product's manufacturer specified rate of 3,000 lbs/acre (3,360 kg/ha). In this comparative study of ground covers, it was reported that the ground covers reduced runoff turbidity by a factor of 4 or greater when compared to bare soil. More specifically, on the controlled, intermediate-scale tests, the MBFM reduced average turbidity by approximately 85% and sediment loss by about 86%.

Holt et al. (2005) performed intermediate-scale tests on six hydromulch treatments using 2 ft (0.61 m) wide by 10 ft (3.05 m) long by 3 in (7.6 cm) deep trays with a sandy clay loam. The soil was packed, leveled, and set at a 15.7 % slope, and the following six hydromulches were applied by hand at 1,000 lbs/acre (1,120 kg/ha) and 2,000 lbs/acre (2,240 kg/ha): wood hydromulch, paper hydromulch, cottonseed hulls hydromulch, COBY hydromulch produced from stripper waste (COBY Red), COBY produced from picker waste (COBY Yellow), and COBY produced from ground stripper waste (COBY Green). COBY is a term used in Holt's report to represent a patented cotton by product of cottonseed hulls (Hold and Laird, 2002). Holt's rainfall simulator produced a rainfall intensity of 2.5 in/hr (6.35 cm/hr). The results for Holt's testing were reported using a cover factor at 1,000 lbs/acre (1,120 kg/ha) and 2,000 lbs/acre (2,240 kg/ha), where COBY Green, COBY Red, COBY Yellow, cottonseed hulls, paper, and wood hydromulches yielded factors of approximately 0.20 and 0.32, 0.10 and 0.22, 0.20 and 0.22, 0.16 and 0.21, 0.42 and 0.68, and 0.65 and 0.81 respectively.

Landloch (2002) studied the performance of four hydromulch treatments using fifteen plots that were 16.4 ft long by 4.9 ft wide (5 m long by 1.5 m wide) at a 25% slope on alluvial black, cracking clay soil. Rainfall was simulated mimicking a 1:10 year storm for 20 minutes at an intensity of 5.7 in/hr (145 mm/hr). The four hydromulches tested were paper hydromulch, flax hydromulch, flax plus paper hydromulch, and sugar cane hydromulch, applied at a rate of 893 lbs/acre (1,000 kg/ha), 2,232 lbs/acre (2,500 kg/ha), 2,900 lbs/acre (3,250 kg/ha), and 4,464 lbs/acre (5,000 kg/ha) respectively. Results reported in a cover factor showed paper, flax, flax plus paper, and sugar cane hydromulches to have cover factors of 0.204, 0.149, 0.044, and 0.037 respectively.

Benik et al. (2003) developed a study comparing the effectiveness of five treatments, including Soil Guard® which is a bonded fiber matrix (BFM) that has been on the hydromulch market since 1993. The experimental setup of this experiment is referenced in Section 2.5.1. In this experiment, the BFM was applied at a minimum rate of 3,000 lbs/acre (3,360 kg/ha). Manufacture specifications require a 24 hour drying period; however this procedure was not reported in Benik's research. According to results, the Soil Guard® BFM reduced average sediment yield by approximately 94%. Turbidity was not reported in this research effort.

The last hydromulch study examined was an extensive evaluation of selective erosion control techniques, completed by Buxton and Caruccio in 1979 of the University of South Carolina, in collaboration with the USEPA. For this research effort, 19 soil stabilizing and erosion control treatments were tested at specially prepared field, four of which were hydromulches without tackifiers. The plot sizes used were approximately 5 ft (1.5 m) wide by 10 ft (3 m) long at a 12 to 15% slope, and the soil tested was a Herndon silt loam. The testing relied on natural rainfall, and in central South Carolina, which is where testing was conducted. A 3.5 inch (8.9 cm) 24-hour rainfall event with a recurrence interval of 2 years was recorded. The four hydromulches tested were Conwed wood fiber mulch, Superior wood fiber mulch, Silva wood fiber mulch, and Pulch; each hydromulch was applied at a rate of 1,200 lbs/acre (1,344 kg/ha). In this study, effectiveness of the hydromulches were measured using a vegetative maintenance and erosion control (VM) value, which in 1979 was a new parameter in the Universal Soil Loss Equation (USLE), and represented total loss ration expressed as a decimal. These values ranged from 0.0 to 1.0, where a value of 1.0 means the ESC practice had no effect in reducing erosion. The VM values for Buxton and Cauccio's (1979) report were 0.235, 0.266, 0.655, and 0.280 for Conwed wood fiber mulch, Silva wood fiber mulch, Superior wood fiber mulch, and Pulch, respectively. If these values were translated to measure erosion control performance in percent efficiency, Conwed, Silva, Superior, and Pulch hydromulches would have respective values of 76.5%, 73.4%, 34.5%, and 72%, respectively.

Table 2.6 provides a summary of hydromulch studies reviewed in the literature.

Table 2.6 Summary of Reviewed Hydromulch Practices

Study	Type of Hydromulch	Test-Scale	Slope	Application Rate (lbs/acre)	Reduction Performance (%)		C-Factor
					Soil Loss	Turbidity	
McLaughlin & Brown (2006)	MBFM[1]	large & intermediate	10% and 20%	3,000	86	85	UNK
Holt et al. (2005)[2]	Wood	intermediate	15.7%	1,000 and 2,000	35 and 19	UNK	0.65 and 0.81
	Paper				58 and 32	UNK	0.42 and 0.68
	Cottonseed hulls				84 and 79	UNK	0.16 and 0.21
	COLBY red				90 and 88	UNK	0.10 and 0.22
	COLBY yellow				80 and 88	UNK	0.20 and 0.22
	COLBY green				80 and 68	UNK	0.20 and 0.32
Benik et al. (2003)	BFM[3]	large	35%	3,000	94	UNK	UNK
Landloch (2002)	Paper	large	25%	892	80	UNK	0.204
	Flax			2232	85	UNK	0.149
	Flax plus paper			2900	96	UNK	0.044
	Sugar Cane			4464	96	UNK	0.037
Buxton and Caruccio (1979)[4]	Conwed*	large	12% to 15%	1,200	77	UNK	0.235
	Superior*				73	UNK	0.266
	Silva*				35	UNK	0.265
	Pulch*				72	UNK	0.280

Notes: '1' Mechanically Bonded Fiber Matrix.
'2' Hydromulches were applied by hand.
'3' Bonded Fiber Matrix.
'4' A Modified Universal Soil Loss Equation (USLE) was used to calculate C-factors.
'*' All are wood-fiber hydromulches.

2.5.4 Summary of Hydromulch Literature

In summary, although the literature data on hydromulch is limited, the research results show significant reductions in soil loss and turbidity. McLaughlin and Brown (2006) conducted intermediate-scale tests to determine the performance of a MBFM, and concluded an 85% reduction in turbidity and 86% reduction in soil loss when compared to bare soil conditions. Similarly, Benik et al. (2003) reported a near 94% reduction in sediment loss while testing the performance of a BFM on a large-scale. Holt et al. (2005) and Landloch (2002) tested the performance of several wood and paper hydromulches, and Landloch added cottonseed hull hydromulches to his effort; amongst these tests, sediment reduction results were reported as low as 19% to as high as 96%. Lastly, during a time when hydromulching was less common, extensive intermediate-scale testing of four hydromulches containing no tackifiers by Buxton and Carrucio (1979) yielded results on several fiber-mulch products to have erosion control capabilities of nearly 76%. Although the experimental designs and procedures varied, it was concluded by each researcher that when hydromulch is applied at manufacturer specifications, it is a very effective erosion control practice.

2.6 Literature Review Summary

Runoff from construction sites has been recorded to be the largest contributor of non-point source pollution in the United States. Therefore, over the past century, the USEPA has been actively developing guidelines to control construction site runoff.

In this chapter, a history of USEPA ELG and regulations were discussed as well as guidelines that have been established within the past year. These federal guidelines are vital knowledge for the research effort herein because they set specific parameters for construction site runoff. The federal government, however, has given the state of Alabama the authority to create stricter ELGs and regulations for construction site runoff, as discussed previously.

With the implementation of stricter ELGs and regulations for construction sites over the past decade, there has been an increased desire in the state of Alabama from contractors and the ALDOT to obtain knowledge of products that provide the most effective ESC. One of the oldest, cheapest, and most prevalent measures of erosion control is conventional straw mulch. Researchers' results within reports on the use and effectiveness of conventional straw were widely different. However, overall, it is accepted that when conventional straw is applied properly and uniformly to slopes that are less than a 33% grades, it is very effective erosion control practice. When slopes are equal to or steeper than 33%, to avoid wind erosion or runoff washing away the lightweight straw, the straw must be anchored to the ground. As discussed, the two most common forms are 'crimping' the straw to the ground with a machine, or applying a tackifier to create a bond between the straw and the ground.

The hydraulic application of mulch (a.k.a. hydromulching) is a relatively new ESC practice, and due to advancements in technologies has become a widely use practice in the industry. Hydromulching has enabled contractors to apply mulches containing tackifiers and bonding agents to steep slopes efficiently and effectively. Although limited, previous studies reviewed commonly report hydromulching to be an effective erosion control measure, due the inconsistencies of reported results, it is difficult to properly determine the effectiveness of hydromulches. Thus, further experiments need to be conducted on hydromulches to gain a more comprehensive understanding of hydromulch performance.

Chapter 3 Intermediate-Scale Test Methods and Procedures

3.1 Introduction

Research previously conducted by Shoemaker et al. (2009) shows several different experimental methods, procedures, and designs to test the performance of ESC practices. To create comparable data, Shoemaker's (2009) intermediate-scale test methods and procedures where used as a guideline for this research effort. However, several modifications to his designs were made, which include: (1) a replicate design and construction of new intermediate-scale test plots, with a new flume design that was used as the collection device, (2) attaining and testing new soil from a local stockpile and conducting soil and compaction analyses, and (3) newly developed hydromulch experimental procedures.

3.2 Intermediate-Scale Testing

The validity of this research effort relies heavily on the amount of reproducible data that is collected during experiments which can be used for comparative analyses to evaluate ESC practice performance and effectiveness. Thus, when designing the experimental procedures, it was pertinent that the size of the test plots were constructed with the purpose of testing ESC practices with ease, speed, accuracy, and mobility throughout the experiment. Thus, if all procedural expectations were satisfied, replications of experiments could be performed to develop adequate data sets for comparative analyses.

The focus of this chapter is to discuss the facility, equipment, modifications made to previous experimental design (Shoemaker, 2009), setup, and testing procedure.

3.2.1 Intermediate-Scale Test Facility

A 20 ft by 30 ft by 15 ft (6.1 m by 9.1 m by 4.6 m) building, consisting of two drum roll up doors at opposite ends of the structure located at the National Center for Asphalt Technology (NCAT), as depicted in Figure 3.1(a) was used to perform all intermediate-scale experiments. As shown in Figure 3.2, the interior of the building is equipped with two water faucets located at the northeast and southeast corners of the building that are supplied by a nearby underground well, indoor lighting, electrical outlets, and WI-FI internet access. Southwest of the building, jersey barriers were aligned to established areas to stockpile soil used during experiments and dispose of post-experiment soil, shown in Figure 3.1(b). A tarp covers the soil to be tested to ensure consistent moisture content and to prevent contamination of the stockpile. Gravel surrounds the building as an erosion control measure and for heavy equipment mobility.

(a) Testing Facility Building

(b) Storage bins

Figure 3.1 Test Facility Exterior.

(a) East Side of Building

(b) West Side of Building

Figure 3.2 Test Facility Interior.

3.2.2 Hydroseeder

The hydroseeder used to apply the hydromulch to all test plots was a Turf Maker® 380 as shown in Figure 3.3(a), 3.3(b), and 3.3(c). This hydroseeder has a 380 gallon capacity to hold hydromulch and water mixtures. The hydroseeder has a mechanical agitator and a positive displacement pump that are powered by a Briggs and Stratton Intex 1450 engine.

(a) TurfMaker® 380

(b) Mechanical Agitator

(c) Engine and Discharge Pump

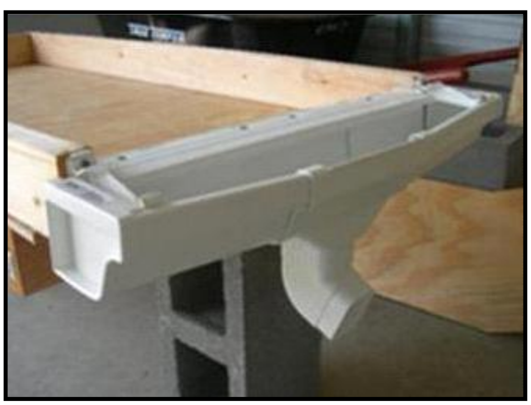
Figure 3.3 Illustrations of TurfMaker® 380 and Various Features.

3.3 Experimental Design

The experimental design, adopted from Shoemaker's (2009) intermediate-scale research efforts is specific to compacted highway embankments on a 3H:1V slope, which are subject to a simulated 2-yr, 24-hr rainfall event.

3.3.1 Intermediate-Scale Test Plots

Test plots constructed for this research effort were replicas of Shoemaker's (2009) test plots with the exception of the runoff collection device. Each test plot is 2 ft in width by 4 ft in length (0.6 m by1.2 m) by 3.5 inches (7.62 cm) in depth. In previous efforts (Shoemaker 2009), a gutter device was designed and constructed to collect runoff from test plots. The gutter device shown in Figure 3.4(a), collected soil and runoff from the test plots, however the device had to be constantly monitored to ensure soil did not reside within the gutter itself, ultimately affecting quantification of soil loss over time. Therefore, when the new test plots were constructed, an aluminum flume was designed and constructed to ensure consistent collection of runoff, as depicted in Figure 3.4(b).



(a) Shoemaker (2009) Gutter Collection Device

(b) Flume Collection Device

Figure 3.4 Comparison of Collection Devices.

The abovementioned intermediate-scale test plots were constructed for the purpose of simultaneous experimentation. Each plot was constructed with pressurized, treated timber. The base of the plot was cut out of a ½ inch (1.27 cm) piece of plywood and the perimeters of the box plot were built with two-by-fours. After construction, the box plots were primed, painted, and the crevices were caulked to increase the durability of the box plots and to minimize water seepage. Also, galvanized handles were screwed to the side of the plots to aid in mobilization. With the intention of observing and collecting any possible infiltration through the soil, a metal strip with 3/8 inch (9.525 mm) holes and a polyvinyl chloride (PVC) pipe cut in half was installed at the base of the test plot, shown in Figure 3.4(b). The infiltration holes were deemed unnecessary after several tests in which no infiltration was observed or collected. The flumes were designed and constructed with the help of Auburn University's Machine Shop, and fastened securely to the end of the box plots with four, 1½ inch (38.1 mm) galvanized exterior screws.

In Shoemaker's (2009) previous research efforts, a total of 2 inches (5.08 cm) of compacted soil was placed in each plot, one inch layer at a time, which allowed for approximately 1½ inches (3.81 cm) difference in height between the top of the soil and the top of the plot perimeter. After discussions with ALDOT, it was determined that by compacting 1 inch (2.54 cm) layers at a time inherently over compacted each soil layer. Therefore a decision was made to compact 3 inches (7.62 cm) of soil, in one layer, leveling the top of the soil with the box plot perimeter. After the first test run, it was evident two sideboards needed to be constructed out of flashing and two by fours to direct runoff from the compacted box plots to the flume outflow, illustrated in Figure 3.5.

Figure 3.5 Sideboards Installed on Test Plots.

Mobility of the box plots was a crucial factor in the experimental design because it allowed the researcher to have a rapid setup, as well as a quick cleanup post-experiment. The setup shown in Figure 3.6 illustrates that each box plot was positioned on a 3H:1V slope supported by sawhorses and cinder blocks.

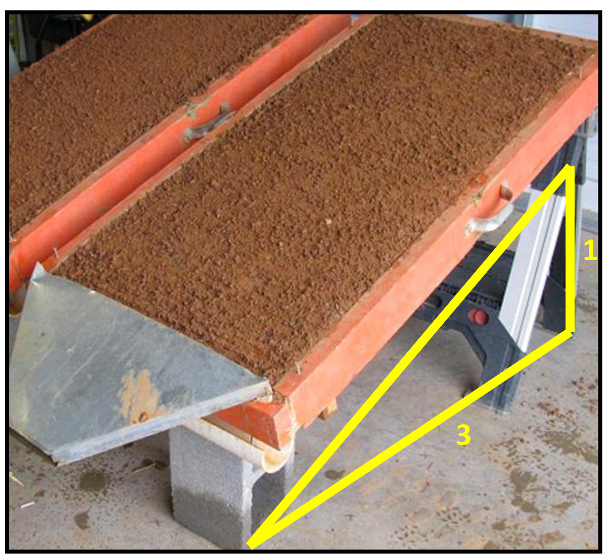


Figure 3.6 3H:1V Slope using Cinderblocks and Saw Horses.

The distance between the flume and the floor provided ample space for collection buckets to be placed under the discharge point.

3.3.2 Rainfall-Simulator and Rain Regime

Shoemaker (2009) constructed a rainfall simulator using a single FullJet™ ½ HH – 30WSQ nozzle, with a wide angle uniform square spray area, and medium to large drop size distribution, simulating natural rainfall. To regulate flow-rate, Shoemaker (2009) attached the inlet hose to a Norgren™ R43-406-NNLA pressure regulator with ½ inch (1.27 cm) port sizes. To maintain a consistent pressure specific to the desired rainfall event, a pressure gauge was attached to the pressure regulator to observe and regulate operating water pressure. As shown in Figure 3.7, the rainfall simulator is constructed of two by fours, a ½ inch (1.27 cm) diameter steel pipe, support braces, a garden hose, and electrical wiring for the solenoid valve. The simulator is supported and attached to the frame of the building by steel brackets, which keeps the nozzle suspended approximately 5 ft (1.5 m) from the building wall, and 10 ft (3 m) from the floor as shown in Figure 3.8.

Figure 3.7 Illustration of Rainfall Simulator.

Figure 3.8 Illustration of Simulator Relative to Plots.

Shoemaker's research efforts also included an extensive calibration and validation of the rainfall simulator to determine and analyze rainfall amount and uniformity (2009). The Christiansen Uniformity Coefficient (ASAE Standards, 2000) was used to quantify the uniformity of the rainfall distribution over the 8 ft by 8 ft (2.4 m by 2.4 m) spray area the nozzle covers. Shoemaker was able to quantify that the rainfall distribution uniformity ranged from 83% to 88%; generally, in the center 4 ft by 4 ft (1.2 m by 1.2 m) area. Christiansen Uniformity Coefficients of 80% or higher are deemed to be uniform.

After calibrating the rainfall simulator, a proper rainfall regime needed to be designed to be representative of a 2-yr, 24-hr rainfall event. Previous literature reviewed showed varying rainfall regimes due to various intensity-duration-frequency (IDF) curves and locations. ALDOT stormwater inspection guidelines state that an inspection of any ESC practice is required within 72 hours of a 'qualifying event'. A qualifying event is any rainfall that accumulates 0.75 inches (1.9 cm) of rain within a 24 hour period (ALDOT 2004). Therefore, 0.75 inches (1.9 cm) was used as a baseline to select the design storm rainfall regime. From Shoemaker's calibration process, he was able to determine that an operating pressure of 10 psi (69 kPa) is capable of generating an intensity of 4.39 in/hr (11.15 cm/hr) (2009). From this intensity, a rainfall duration of 15 minutes produces approximately 1.1 inches (2.8 cm) of rain, which is above the 0.75 inch (1.9 cm) baseline. In addition to ALDOT's inspection guidelines, Shoemaker used an IDF curve for Auburn, Alabama. Using ALDOT's guidelines, the IDF curve, and Shoemaker's rainfall calibration, it was determined that a 2-year, 24-hour rain event for Auburn, Alabama would produce a cumulative rainfall amount of 4.39 in/hr (11.2 cm/hr) intensity. To simulate a 2-yr, 24-hr design storm, the rainfall simulator which produces 1.1 inches (2.8 cm) over a 15 minute period would need to consist of 4, 15 minute rainfall events, lasting 1 hour. The rain regime used by Shoemaker (2009) was adopted for this research effort consisting of 4, 15 minute events, representative of a 2-yr, 24-hr event with a total rainfall amount of 4.4 inches (10.9 cm).

3.4 Experimental Procedures Pre-Condition Application

A large majority of the experimental procedures and methods were adopted from Shoemaker (2009), however there were several modifications made to the experimental procedures due to a change in the ESC practices tested. Modifications included test protocol and procedures pertaining to application of the hydromulch product. Also, a soil and compaction analysis were conducted on a new stockpile of soil.

3.4.1 Soil Analysis

Soil for the research effort herein was provided by a local grading contractor from a construction site near the NCAT test track in Opelika, Alabama (32°33'5" N, 85°20'28" W). A soil analysis was conducted by the Auburn University Soil Testing Laboratory to determine the soil composition, shown in Table 3.1 below.

Table 3.1 Percent Composition and Classification of Experimental Soil

% Sand	% Silt	% Clay	Classification
67.5	2.5	30	Sandy Clay Loam

The soil analysis yielded nearly 2/3 sand and 1/3 clay composition, and less than 3% silt content which classified the soil as a sandy, clay loam.

3.4.2 Compaction Analysis

After classifying the soil, a compaction test was conducted. ALDOT specifies in its *Standard Specifications for Highway Construction* (2008) that on a typical highway embankment, slopes should be compacted to 95% compaction. This requirement was adopted by Shoemaker (2009) who used hand tamps dropped on the box plots to achieve optimum compaction.

To determine the number of drops required to compact the soil, two compaction tests were completed. The first soil compaction test was to determine the optimum moisture content (OMC) of the soil. This was completed using a modified Proctor test, as specified in American Society for Testing and Materials (ASTM) D1557. The modified Proctor test enabled researchers to develop a Proctor curve representing the moisture content of the soil versus the dry unit weight of the soil, as shown in Figure 3.9.

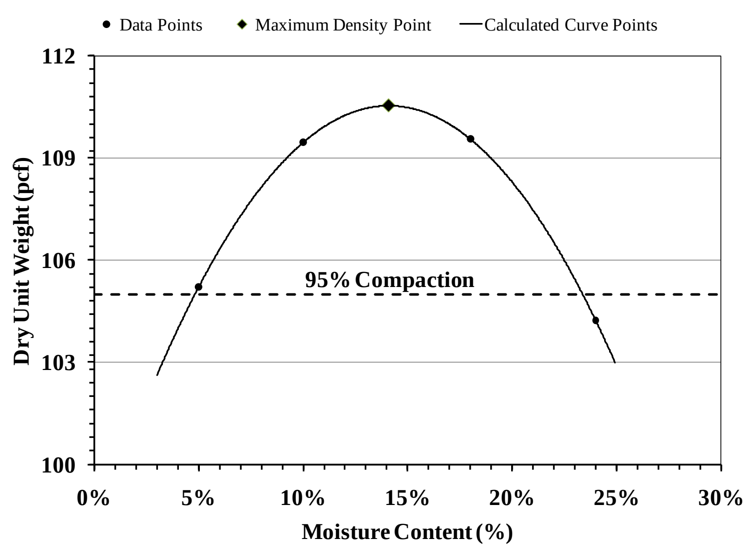


Figure 3.9 Proctor Curve for Experimental Soil.

The Proctor curve shown in Figure 3.9 illustrates four determined moisture contents to achieve a specific dry unit weight for the tested soil. An optimum moisture content (OMC) was determined to be 111 pcf (1762 kg/m^3) at 14% moisture content (MC) by locating the maximum dry unit weight on the Proctor curve. The dotted line shown in Figure 3.9 represents the minimum dry unit weight of 105 pcf (1682 kg/m^3) required to reach ALDOT's specified 95% compaction rate over a range of moisture content (5% to 23%).

The second compaction test, also adopted from Shoemaker was created to test the number of hand tamps required to achieve 95% compaction. Shoemaker designed and constructed a 1ft by 1ft (30.5 cm by 30.5 cm) wood box specifically sized to fit the hand tamps, shown in Figure 3.10.

Figure 3.10 Mold used to Determine Required Compaction Rate with Hand-Tamp.

The molded boxes were designed to allow the hand tamps to fit inside the perimeter. The hand-tamps measured 10 in. by 10 in. (25.4 cm by 25.4 cm), and the mold measured 1 ft by 1 ft (30.5 cm by 30.5 cm). The purpose of this compaction test was to drop the hand tamp a specified number of times upon a known volume of compacted soil to determine a corresponding unit weight. Soil with a MC of approximately 14% was loaded into the 1 ft by 1 ft by 2 inch (30.5 cm by 30.5 cm by 5.1 cm) box and a hand tamp was dropped approximately 12 inches (30.5 cm) from the soil surface in a series of 5 sets: 10 drops, 20 drops, 30 drops, 50 drops, and 60 drops. After each set of drops, the mold was screeded to a height of 1 inch, the known volume of soil was weighed, and a measured compacted dry unit weight was calculated, and plotted on a graph, shown in Figure 3.11.

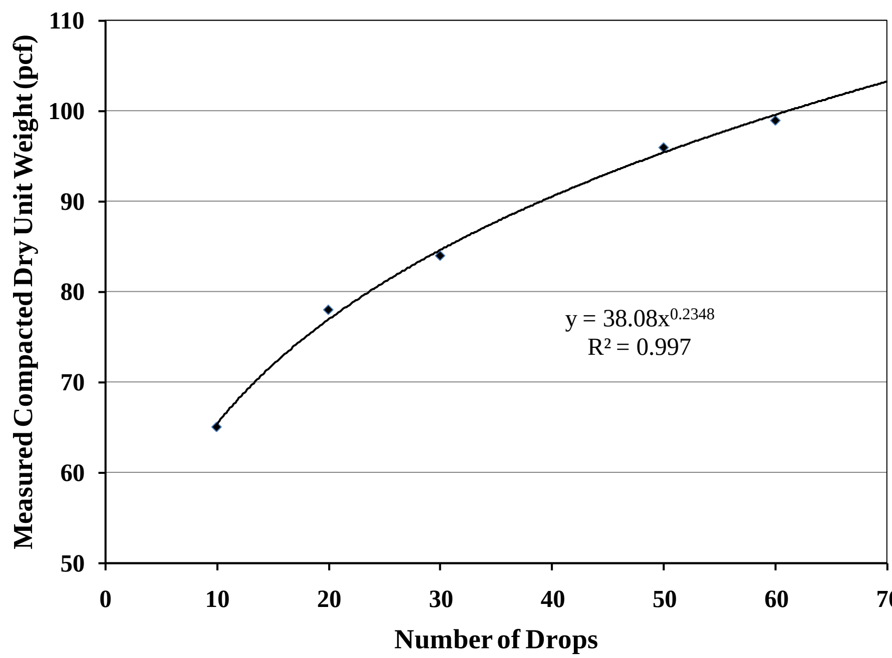


Figure 3.11 Compaction of Soil Using Hand Tamps.

Figure 3.11 is a representation of number of drops with a hand tamp in correlation with its corresponding measured compacted dry unit weight. When compacted, soil will approach a point where it has reached maximum compaction, preventing any further compaction. A regression line and power function was applied to the points on the plot to illustrate the point at which soil can no longer be further compacted. When the regression line levels off, the soil has reached maximum compaction, regardless of energy applied by the hand tamps. Using the power function, the specified number of drops required to reach optimum compaction was calculated, shown in Table 3.2.

Table 3.2 Calculated Dry Unit Weight (pcf) and Required Number of Drops

Number of Drops	Dry Unit Weight (pcf)
10	65.4
20	76.9
30	84.6
40	90.5
50	95.4
60	99.6
70	103.3
80	**106.5**
90	109.5
100	112.3

To obtain a minimum of 95% compaction, a minimum dry unit weight of 105 pcf (1,682 kg/m^3) was required, which corresponded to approximately 80 hand-tamps.

3.4.3 Hydromulch Product Selection

Stricter regulations by the USEPA regarding ESC on construction sites has established a need to determine practices that can be installed easily, cost efficiently, and comply with EPA stormwater runoff regulations. In the summer of 2009, ALDOT and the Department of Civil Engineering at Auburn University showed a joint interest in testing the performance of mulches that are hydraulically applied, referred to herein as hydromulches, to 3H:1V fill slopes as an innovative erosion control practice. Although mulching is not a new erosion control practice, advanced technologies in pumps and hydroseeders have made hydraulic application of mulch a highly prevalent procedure of application. Hydromulches have been tested on a large-scale (McLaughlin and Brown, 2006; Holt et al., 2005; Benik et al., 2003; Landloch, 2002; Buxton and Caruccio, 2000), however, further investigation of the performance of hydromulch products on an intermediate-scale is needed. Therefore, ALDOT assigned a number of hydromulches that are ubiquitous in the erosion control industry to be tested and evaluated. Table 3.3 below shows a list of four hydromulches and their corresponding mulch classification that were tested in this research effort.

Table 3.3 Assigned Hydromulch and Classification

Type of Hydromulch	Classification
GeoSkin	Hydraulic Mulch Product, w/Tackifier
HydraCX^2	Bonded Fiber Matrix (BFM)
Excel Fibermulch II	Hydraulic Mulch Product, w/o Tackifier
HydroStraw BFM	Bonded Fiber Matrix (BFM)

To create a baseline comparison, bare soil control was tested, as well as two conventional straw mulch practices: (1) that has been crimped and (2) that has been applied with a tackifier. Although bare soil was the only condition used as a basis of analyzing erosion control performance, conventional straw, crimped or tackified, was tested and evaluated as a second baseline comparison due to its cost efficiency and that is it a predominantly used mulch in the industry.

3.4.4 Experimental Organization

Figure 3.12 is a flowchart showing the seven conditions tested: (1) one bare soil control; (2) conventional straw, crimped; (3) conventional straw, tackified; (4) GeoSkin®; (5) HydraCX^2®; (6) Excel® Fibermulch II; and (7) HydroStraw® BFM. The bare soil condition serves as the control, and conventional straw conditions were developed as a baseline condition for comparison of traditional mulching practices to newer hydromulch technologies currently being used in the industry. The experimental setup was organized to allow two full experiments, consisting of 4 total plots, to be run on each condition. An experiment, as illustrated in Figure 3.12, consists of two test plots centered beneath the rainfall simulator to experience the design rainfall event and total rainfall amount discussed in Section 3.3.2. As previously discussed, and shown in the flowchart, four 'tests' were simulated within a single experiment, with a 15 minute break between storm events to allow for data collection.

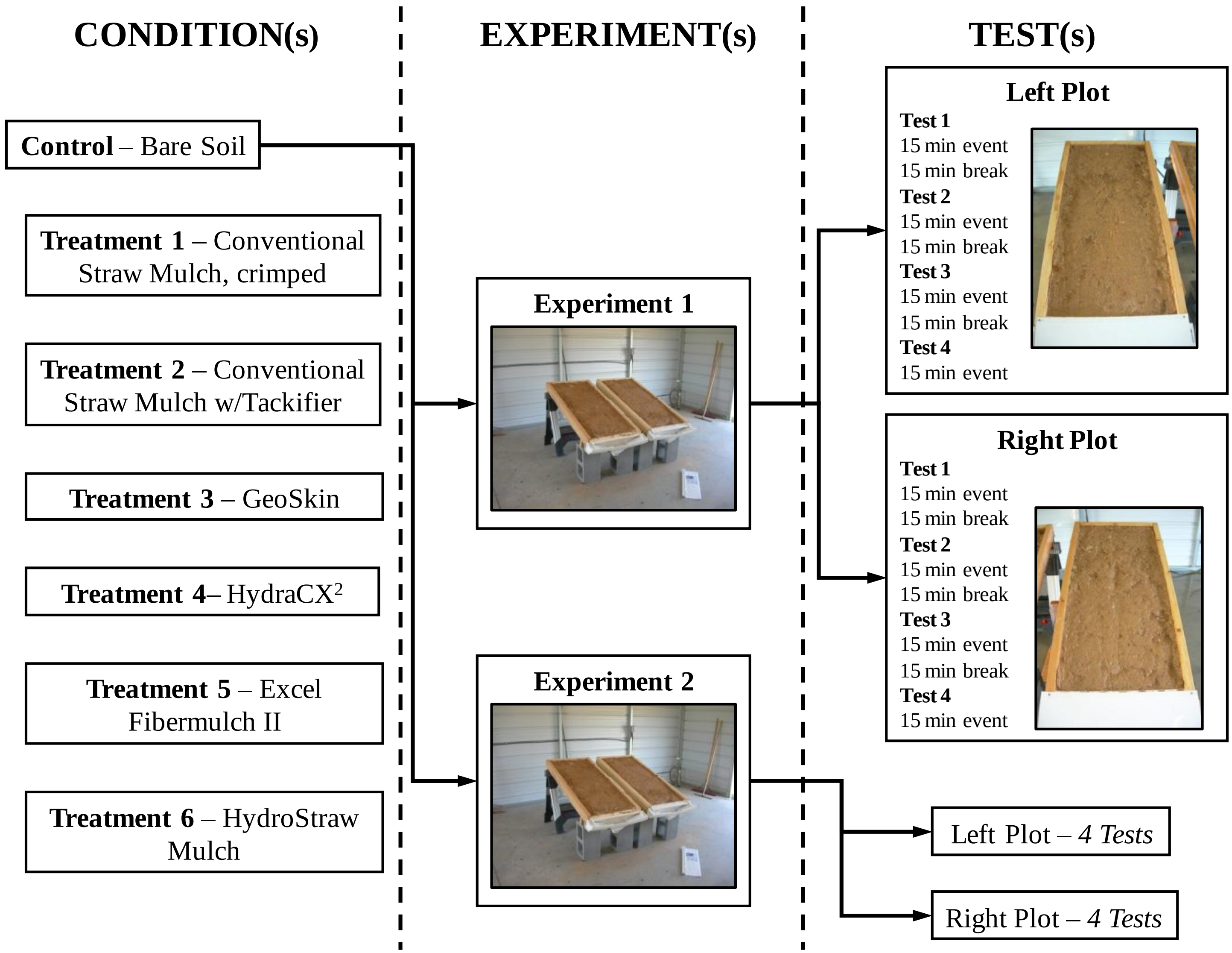


Figure 3.12 Flowchart of Experimental Organization.

3.4.5 Test Plot Preparation

The test plot preparation used for this research was modified from Shoemaker's (2009) research. Shoemaker (2009) developed a five step process for his test plot preparation; however due the different products tested, the test preparations were changed slightly. For this research effort, test plot preparation is divided into two sections: (1) test plot preparation prior to condition application, and (2) condition application test protocols and procedures.

3.4.5.1 Test Plot Preparation Prior to Condition Application

Section 3.4.2 described the method used to determine the number of drops required by a hand tamp to reach optimum compaction, and the MC necessary to achieve the required compaction. To assure the MC of the soil was within the limits of the minimum dry unit weight of 105 pcf (1,682 kg/m^3), a small sample of the stockpile was dried using a double hotplate electric stove provided by the NCAT facility. After determining the MC of the soil, if the stockpile is above 23% it is left to dry until within the minimum MC for the acceptable 95% compaction. If the soil happened to be too dry, water was added until the proper MC was obtained.

In Shoemaker's research effort, after the moisture content was determined, two, 5 gallon buckets of soil were loaded into a wheelbarrow, added the proper amount of water, if necessary and compacted a one inch layer of soil. This step was repeated to obtain two compacted 1 inch layers of soil (2009). In this research effort, we used one, 3 inch (7.62 cm) layer of compacted soil and a scoured surface to simulate a more realistic highway embankment that has been prepared for seeding. Therefore, it was determined that six, 5 gallon (18.9 L) buckets or 10, 3 gallon (11.4 L) buckets of the previously tested soil illustrated in Figure 3.13 was necessary to achieve 3 inches of compacted soil. The box plots were loaded with soil in two steps: the first step consisted of 18 gallons of soil and the second with 12 gallons (45.4 L) of soil. After the first 10 gallons (37.9 L) were loaded into the box plots, the soil was spread evenly in the box plots and lightly tamped once or twice to prepare for the final load. Once the final load was poured onto the first layer, the soil was evenly distributed amongst the box to assure a flat surface for a level, optimum compaction with hand tamps.

Figure 3.13 Five and Three Gallon Bucket Used to Load Test Plots.

As designed by Shoemaker (2009), the uncompacted layer of soil was broken into 8 subsections and hand tamped individually as shown in Figure 3.14. After completing the compaction effort, the 3 inch (7.62 cm) compacted surface was then scoured with a rake approximately ¼ inch (6.35 mm) in depth, as shown in Figure 3.15.

Figure 3.14 8 Sections to Compact Approximately 80 Times.

Figure 3.15 Uniform Tilling of Surface Approximately ¼ inch in Depth.

Although this research effort does not test longevity or seedling germination, the purpose of scouring the surface of the compacted soil was to simulate a realistic ALDOT highway embankment, which generally includes tilling for spreading seed and fertilizer. Once the tilling effort was completed, the box plots were ready for condition applications (i.e., hydromulch or conventional straw).

3.5 Condition Application Experimental Procedures

Consistent test methods and procedures, while also ensuring that this research adheres to the manufacturers' specification for proper application rates on a 3H:1V slope, are vital to the integrity of the research. Thus, each condition was evaluated separately and an application process was developed specifically for each test.

A bare soil test was initially chosen as the control condition for this testing, however ALDOT became interested in testing an application of conventional straw mulch that was either crimped or sprayed with a tackifier. The first section will entail the application process of conventional straw applied at ALDOT specified 4,000 lbs/acre (4,480 kg/ha) that has been crimped or sprayed with a tackifier.

Different hydromulch products are comprised of diverse materials, as explained in the 'literature review' portion of this research; therefore different application rates are required, dependent upon steepness of slope. For a 3H:1V slope, the hydromulch application rates ranged from 2,000 lbs/acre to 3,500 lbs/acre (2,240 to 3,920 kg/ha). The section following the conventional straw conditions' experimental procedures will report the test protocols and procedures for the following hydromulch conditions: (1) GeoSkin®; (2) HydraCX^2®; (3) Excel® Fibermulch II; and (4)HydroStraw® BFM.

3.5.1 Conventional Straw, Crimped or with Tackifier Test Protocol

According to ALDOT's *Standard Specifications for Highway Construction* (2008), conventional straw or hay that has been crimped and is placed on a 3H:1V or flatter slope is considered a 'Class A, Type 1' mulch. 'Class A, Type 2' mulch is described as hay mulch or conventional straw that uses an adhesive or tackifier. This section will describe the necessary steps and test procedures required to produce an intermediate-scale test for conventional straw crimped or tackified.

3.5.1.1 Conventional Straw, Crimped Test Protocol and Procedures

Conventional straw's typical form of application is mechanically, using a machine to chop and blow the straw onto the slope to 75% or greater coverage, as shown in Figure 3.16, or it can be laboriously spread by hand.

Figure 3.16 Mechanically Blown Straw.
(Source: http://www.clintontractor.net)

After the straw is spread, for slopes 3H:1V or flatter, the straw is typically crimped or embedded into the soil by a mulch crimper to reduce the chance of the straw being blown away by wind or moved due to excess runoff volumes. ALDOT (2008) requires the crimper to be a roller type device equipped with flat, uncapped, dull edge disks with a minimum width of ¼ inch (6 mm) and placed a maximum of 2 inches (5.1 cm) apart along the axle or shaft, as shown in Figure 3.17.

Figure 3.17 Mulch Crimper.
(Source: http://www.proseriesproducts.com/procrimper.htm)

ALDOT also specifies that the diameter shall be large enough to prevent the axle or shaft from dragging or in any way disturbing the mulch or soil (2008). Crimpers should be designed to apply enough force to embed the straw approximately 2 inches (50 mm) into the soil (ALDOT, 2008).

Typically, conventional straw blowers and crimpers are used for application on large areas or acres of land. Therefore, modifications to typical application of straw were necessary for the intermediate-scale plots. The first modification made was converting ALDOT's specified application rate of 4,000 lbs/acre (4,480 kg/ha) to the 2 ft x 4 ft (0.6 m by 1.2 m) test plot, which was equivalent to 333 grams/plot (0.333 kg/plot). Depicted in Figure 3.18(a), (b), and (c) below, the proper amount of dry, conventional straw was weighed and evenly applied by hand to the compacted and tilled test plot.

(a) Weighing Straw Prior to App.
(4,000 lbs/acre≈333 grams/plot)

(b) Application of Straw on Test Plots
(Minimum 70% cover)

(c) Plots after 4000 lbs/acre (333 grams/plot) Application and 70% Cover

Figure 3.18 Weighing and Applying Conventional Straw.

After proper application of the conventional straw, the next task was to crimp the conventional straw into the soil. A typical mulch crimper weighs several thousand pounds; therefore an intermediate-scale crimper was designed. To simulate a crimping wheel, a prototype was constructed from the basic performance of a wheel as it rolls over the soil; the thought process of the design is shown in Figure 3.19.

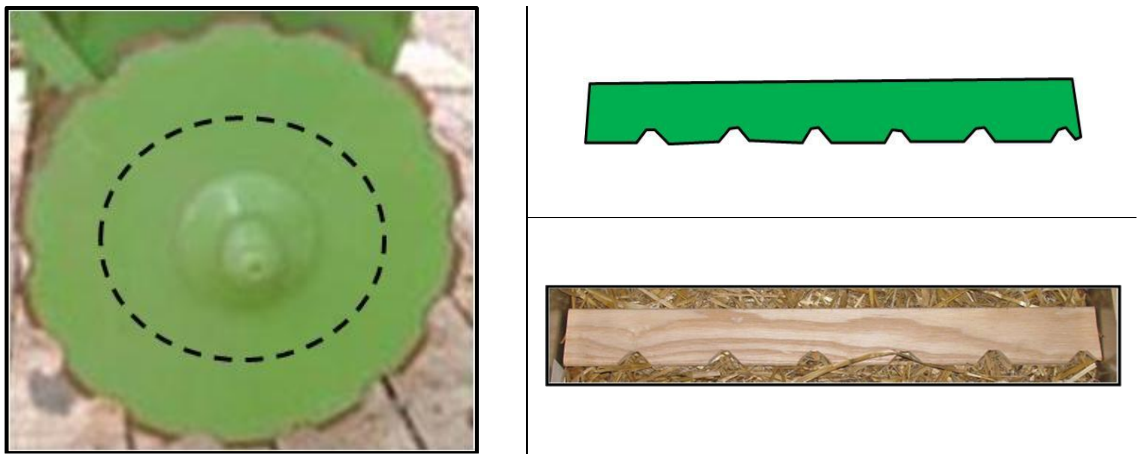


Figure 3.19 Intermediate-Scale Mulch Crimper Design and Construction Process.

The crimper constructed above is 2 ft (0.6 m) in length by 3.5 inches (5.1 cm) in height, and ¼ inch thick, which meets ALDOT specifications for a straw crimper. After constructing the intermediate-scale crimper, the next task was to crimp the conventional straw into the soil. Using a rubber mallet, the wooden crimper was positioned horizontally along the box plot and pounded uniformly into the soil until it was approximately 1 inch (25.4 mm) deep, as shown below in Figure 3.20.

Figure 3.20 Crimping Straw.

The conventional straw was crimped every two inches, as specified by ALDOT (2008). Experimental testing was commenced after each test plot was completely crimped.

3.5.1.2 Conventional Straw, with Tackifier

ALDOT (2008) specifies 'Class A, Type 2' mulching to be used on slopes steeper than 3H:1V, referred to herein as conventional straw with a tackifier. The type of tackifier tested in this research effort was *Hytac II* which is manufactured by Easy Lawn, Inc., mixed at a rate of 52.8 oz (1,497 grams) per 600 to 700 gallons (2,270 to 2,650 liters), and 1.1 oz/1,000 ft^2;(31 grams/cm^2) this converts to approximately 0.088 to 0.075oz/gallon (0.66 to 0.56 grams/L), and 0.0088 oz/plot/0.1 gallons (¼ gram/plot/0.0.38 L). Test procedures for this section are identical to procedures outlined in Section 3.5.1; however, the tackifier replaced the crimping method. To properly apply the tackifier to the conventional straw, it was added to a Maruyama MS074 backpack sprayer with a built in agitator. Specifications for the backpack sprayer are in Appendix C. To avoid clogging of the backpack sprayer, the tackifier was added slowly to the tank. Illustrated in Figure 3.21(a) and (b), the tackifier contained a blue dye for application purposes.

(a) Hytac II

(b) 0.5 grams of Hytac (applicatin rate for both test plots)

Figure 3.21 Hytac II—Tackifier for Convetional Straw.

After approximately 20 minutes of mixing, the tackifier was equally applied to both plots, as shown in Figure 3.22 (a) and (b).

(a) Maruyama MS074 Backpack Sprayer with Tackifier Mixed


(b) Applying Tackifier to Prepared Test Plots

Figure 3.22 Mixing and Application of Hytac II Tackifier to Conventional Straw.

Once both plots were sprayed with Hytac II, they were placed under ultra-violet-ray heat lamps for 48 hours to allow the tackifier to bond and dry to the straw and soil, as shown in Figure 3.23.

Figure 3.23 Conventional Straw with Tackifier for 48 hr Drying Period.

3.5.2 Hydromulching Test Protocol and Procedures

Designing a protocol to efficiently and effectively apply the hydromulches at the manufacturer specified application rate repeatedly was an important task to ensure uniform coverage at the specific application rate. The first task was to determine how the hydromulch would be applied to the test plots. To ensure that intermediate-scale application of hydromulch simulated field applications, it was decided to use Auburn University's hydroseeder, the TurfMaker® 380, for applying each hydromulch product.

The second task of this procedure was to determine a method that would accurately and consistently ensure manufacturer specified application rates were achieved. The first step was to cut 8 pieces of treated plywood that replicate the size of the test plots (2ft x 4 ft [0.6 m x 1.2 m]), position each board at a 3H:1V slope as illustrated in Figure 3.24.

Figure 3.24 3H:1V Test Boards Pre-Application of Hydromulch.

Once the boards were placed, an experimental procedure was developed to allow the researcher performing the application to have the capability of quantifying the sprays necessary to achieve manufacturer specified application rate. The test boards were assigned a number, 1 through 8, from left to right which corresponded accordingly with the number of sprays it would receive. The procedure was as follows: (1) each board was sprayed with one equal spray, shown in Figure 3.25; (2) from left to right, test boards 2 through 8 were sprayed a second time, shown in Figure 3.26; (3) after boards 1 through 8 were sprayed with their representative number of sprays, shown in Figure 3.27, the researcher proceeded to scrape the wet mulch from each individual board into a bucket, illustrated in Figure 3.28 and Figure 3.29; and (4) after all buckets were weighed, the wet hydromulch was placed in an oven to dry for 24 hours.

Figure 3.25 After One Spray to Each Test Board.

Figure 3.26 Applying Second Spray to Boards 2 through 8.

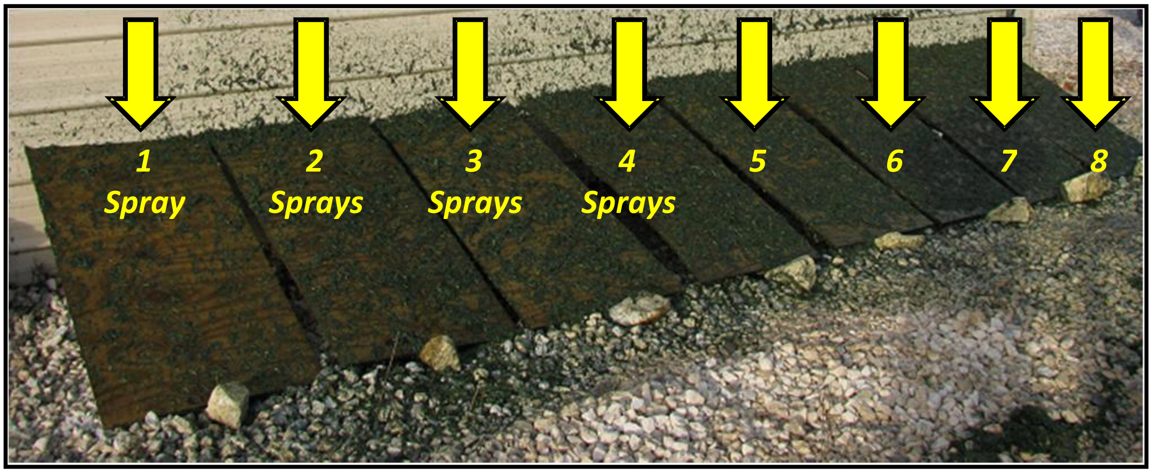


Figure 3.27 Post Application of 1-8 Sprays on Test Boards 1-8.

Figure 3.28 Post Application—Scraping Boards into Bucket for Weighing.

Figure 3.29 Hydromulch Scraped off of Test Boards into Corresponding Buckets.

Once the 8 hydromulch samples were dry, their dry weights were recorded. Table 3.4 shows the wet weight recorded after each spray, its corresponding dry weight, and the calculated wet/dry weight factor. GeoSkin® achieved the required application rate of approximately 5.9 oz (167 grams) by spray 6. HydraCX^2®, Excel® Fibermulch II, and HydroStraw® BFM reached the required application rates of 10.3 oz (292 grams), 5.9 to 7.4 oz (167 to 209 grams), and 8.8 oz (250 grams) by spray 7, 9, and 3 respectively. Figure 3.30(a) through (d) illustrate the plots of wet unit weight versus the number of sprays for the four hydromulch treatments reported in Table 3.4.

Table 3.4 Determination of Number of Sprays for Required Application Rate

No. of Sprays	Wet Weight (g)	Dry Weight (g)	Factor*
GeoSkin®			
1	350	34	10.3
2	851	84	10.1
3	984	95	10.4
4	1356	139	9.8
5	1480	150	9.9
6	**1725**	**174**	**9.9**
7	2140	212	10.1
8	2309	229	10.1
		Average =	**10.06**
HydraCX®^{2}			
1	181	19	9.5
2	522	61	8.6
3	1238	113	11.0
4	1581	159	10.0
5	2148	203	10.6
6	2552	251	10.2
7	**2820**	**295**	**9.6**
8	3026	327	9.3
		Average=	**9.82**
Excel® Fibermulch II			
1	190	24	8
2	378	56	6.77
3	572	72	7.94
4	707	91	7.74
5	847	127	6.64
6	984	126	7.81
7	1245	134	9.3
8	1236	136	9.12
9	**1392**	**180**	**7.73**
10	1766	196	9.01
11	1837	203	9.05
12	2066	225	9.18
13	2183	247	8.84
		Average=	**8.76**
HydroStraw® BFM			
1	910	118	7.74
2	1997	242	8.26
3	**3036**	**358**	**8.49**
4	3007	363	8.28
5	2989	354	8.44
6	3011	359	8.39
7	3552	434	8.19
8	3563	447	7.97
		Average=	**8.22**

Note: '*' Factor calculated by dividing the wet weight by the dry weight.

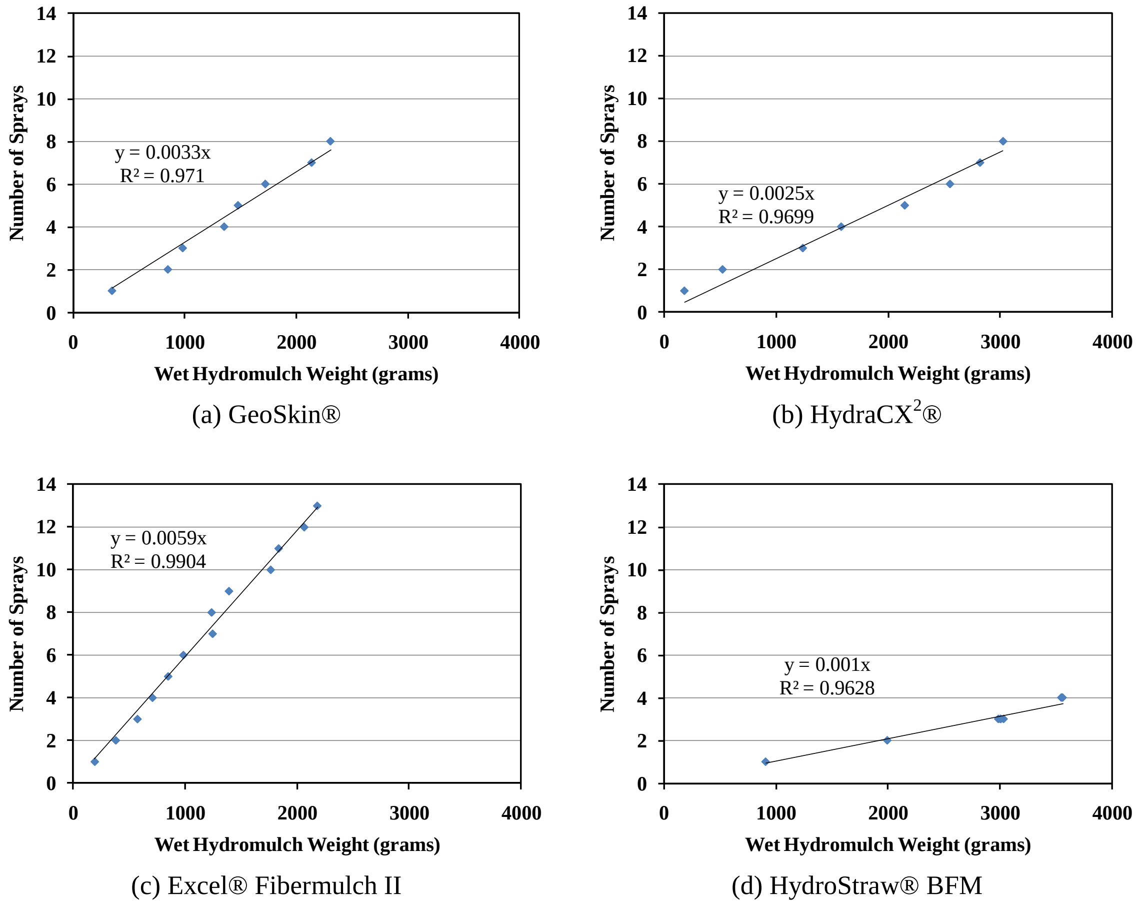


Figure 3.30 Scatter Plots of Wet Unit Weight vs. Number of Sprays for Hydromulch Treatments.

Table 3.4 indicates that a minimum of 6 sprays was necessary to meet the GeoSkin manufacturer requirement for 2,000 lbs/acre (2,240 kg/ha), equivalent to approximately 5.9 oz/plot (167 grams/plot). An average factor was determined, which is the wet weight divided by the dry weight; enabling researchers to determine if the plots achieved the minimum application rate. This was completed by simply dividing the wet weight by the averaged factor, which yielded a calculated dry weight. The calculated dry weight was then compared to the manufacture specifications for application rate. This test was replicated for each hydromulch product tested. Table 3.5 shows a summary of the number of sprays determined for each hydromulch products manufacturer specified application rate.

Table 3.5 Determined Number of Sprays For Hydromulch Products Tested

Hydromulch Product	Manufacturer Required Dry Application Rate (lbs/acre)	Equivalent Test Plot Required Dry Application Rate (g/plot)	Averaged Factors	Minimum # of Sprays Required
GeoSkin®	2,000	~167	10.1	6
HydraCX^2®	3,500	~292	9.7	7
Excel® Fibermulch II	2,000-2,500	~167-209	9.3	9
HydroStraw® BFM	3,000	~250	8.9	3

Once the minimum number of sprays was determined for each hydromulch product, each product was ready to be applied to test plots and tested accordingly. Although the minimum number sprays were already determined, to ensure consistency, the test boards were also sprayed during test plot applications. After the minimum number of sprays was applied to the eight test boards and the two test plots, two of the test boards were scraped and weighed to check for consistency, shown in Figure 3.31 and Figure 3.32.

Figure 3.31 Scraping First Two Test Boards.

Figure 3.32 First Two Plots Scraped For Weighing.

The wet weight was then divided by the averaged factor to determine the calculated dry weight of the hydromulch. If the calculated weight was under the minimum required application rate, the remaining test boards and the test plots were sprayed once more, and two additional test plots were scraped and weighed. This procedure continued until the manufacturer specified application rate was achieved.

After the test plots were sprayed with the manufacturer specified application rate of the hydromulch, the test plots needed ample time to dry. Some manufacturers claim zero drying time necessary for their products; however this research focused on reducing variability in testing, and to achieve this goal, the same test procedure was applied to each hydromulch product. Therefore, after applying the product to the test plots, a structure was built, shown in Figure 3.33, to hold four, 250 Watt ultraviolet-ray bulbs for the purpose of simulating natural sunlight. To ensure consistent drying, the structure was built to allow for the bulbs to hang at a 3H:1V slope which mimics the test plot setup. Lastly, the distance (approximately 18 inches [45.7 cm]) between the bulbs and the hydromulch on the test plots were measured and adjusted to ensure all bulbs were equidistant to the hydromulch surface, as illustrated in Figure 3.34. The hydromulched test plots were left to dry for 48 hours.

Figure 3.33 Wooden Structure to Suspend Heat Lamps.

Figure 3.34 Heat Lamps Measured for Accurate Spacing.

The application process of each individual hydromulch product can be viewed in Appendix D of this report.

3.6 Data Collection

Data collection procedures for this research effort were adopted from Shoemaker et al (2009). Collected data included (1) soil loss, (2) runoff volume, (3) initial turbidity, and (4) turbidity over time. The focus was primarily on runoff generated from test plots during rainfall events. Runoff volume, mass, and initial turbidity were collected every minute during experimentation. Clear, five quart buckets with volume markings, shown in Figure 3.35 were used to collect runoff volume and mass for each 'left' and 'right' test plot. Instantaneous turbidity was recorded with an ANALITE NEP 160 turbidity meter with an ANALITE NEP 260 probe, illustrated in Figure 3.36. Detailed specifications for this meter can be found in Appendix C. Along with instant turbidity, this meter was used to record turbidity over time. Grab samples at 5 and 10 minute intervals for each of the four tests on each plot were collected in one quart cups and used to record turbidity over time, shown in Figure 3.36. Turbidity in the one quart cups was recorded every 10 seconds over a 3 minute period.

Figure 3.35 Collection of Runoff.

Figure 3.36 Turbidity Over Time.

After each test run, surface runoff samples were poured into Hayward single-length bags with one micron size pores, as pictured in Figure 3.37. A total of 40 bags were used to collect samples, divided into 5 bags consisting of 3 samples per bag. Once all samples were filtered, the bags were place in an oven at 160° F (71.1° C) and dried for 24 hours. After drying, the bags were compared to the weight of the empty bags recorded prior to filtering to determine the amount of eroded soil from each test plot contained within each bag.

Figure 3.37 Filtering Process.

Following the above mentioned experimental data collection procedures allowed for the collection of large samples of data. Illustrated in Table 3.6, a total of 1,680 observations were recorded during experiments (e.g. 7 conditions x 4 test plots x 4 test x 15 observations per test = 1,680 total recorded measurements). Surface runoff volume, mass, and initial turbidity were recorded every minute during a 15 minute test, and soil loss samples were recorded every 3 minutes, resulting in 5 observations per test plot.

Table 3.6 Breakdown of Collected Data Totals

Conditions	Test Plots	Tests	Observations per Test	Runoff Observations[1]	Turbidity Observations[1]	Soil Loss Observations[2]
7	4	4	15	1,680	1,680	560

Notes: 1. Observations were recorded every minute
2. Observations were recorded every 3 minutes

3.7 Statistical Analyses

The Tukey-Kramer method, a single-step multiple comparison procedure and statistical test, was used in this research effort to conduct a proper statistical analysis of the recorded data, and establish statistical significance between treatments. The Tukey-Kramer method is generally used in conjunction with a one-way analysis of variance (ANOVA) to find which means are significantly different from one another. The one-way ANOVA tool provided by Microsoft's Excel™ 2007 was used for statistical analyses in this report. A typical null and alternative hypothesis used during this research for ANOVA analysis is illustrated in Equation 1 and 2, respectively (Shoemaker, 2009).

$$H_o: \mu_0 = \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_6 = \mu_7 \quad (1)$$

$$H_a: \text{all means are different} \quad (2)$$

where,

H_o = null hypothesis
H_a = alternative hypothesis
μ_i = mean values of each data set 'i',
i = independent groups [i.e. (0) control, (1) GeoSkin®, (2) HydraCX^2®, etc]

The null and alternative hypothesis statements for ANOVA are not sufficient to discern statistical significant differences between individual pairs. Therefore, to determine statistical significance between pairs, a confidence interval (CI) was calculated using the following equations, adopted from the Tukey-Kramer method (Shoemaker, 2009):

$$CI_{95\%} = (\mu_i - \mu_j) \pm TukeyKramermultiplier \times s_p \sqrt{\left(\frac{1}{n_i} + \frac{1}{n_j}\right)} \quad (3)$$

where,

$CI_{95\%}$ = 95% confidence interval,

μ_i - μ_j = difference of means for ‘i’ and ‘j’ groups,

s_p = pooled standard deviation, and

$n_{i,j}$ = sample sizes of ‘i’ and ‘j’ groups

The pooled standard deviation as shown in Equation 3 can be derived from taking the square-root of the Mean Square Error (MSE), which is calculated during creation of an ANOVA table. A Tukey-Kramer multiplier can be determined using Equation 4 (Shoemaker, 2009):

$$Tukey\,Kramer\,multiplier = \frac{q_{a,n-a,\alpha}}{\sqrt{2}} \tag{4}$$

where,

q = upper percentile for a studentized range distribution,

a = total number of groups,

n = sample size, and

α = level of significance (5%)

The calculated confidence interval was then examined to determine if the two test groups were statistically significant; if zero was contained within the upper and lower bounds of the interval, then the two groups were not statistically significant.

3.8 Summary

A total of 14 intermediate-scale experiments were conducted to examine the erosion control performance of the 4 hydromulch treatments: (1) GeoSkin®, (2) HydraCX^2®, (3) Excel® Fibermulch II, and (4) HydroStraw® BFM in comparison to bare soil treatments and the 2 conventional straw treatments: (1) conventional straw crimped and (2) conventional straw, tackified. Experimental procedures for this research effort were adopted from Shoemaker (2009), and modifications were made as necessary. One modification was the construction of a flume to collect surface runoff from the plots. The intermediate-scale test plots allowed for an experimental setup that required less time to prepare, allowing researchers the ability to conduct more experiments and collect copious amounts of data.

Test preparations pre-application of the ESC practices involved obtaining the OMC of the soil in order to effectively compact the test soil to a rate of 95% using hand-tamps. Once plots were compacted and prepared, ESC practices were applied. To achieve the minimum required application rate of each treatment, researchers designed a new test method to assure uniformity and accuracy of applications. The new test method ensured ALDOT regulations were met regarding the spread of conventional straw on 3H:1V highway embankments, and also assured researchers that manufacturer specified application rates were achieved with the hydromulch treatments.

Data collection in this research effort consisted of runoff mass and volume to account for consistency between experiments, and initial turbidity and eroded soil to validate the performance of each treatment. An abundant amount of data enabled t an ANOVA analysis to be conducted to determine statistical significance between treatments. Also, recorded soil loss allowed for the computation of a cover-factor, which allowed researchers to numerically specify the performance of treatments in comparison to the bare soil treatment.

Chapter 4 Intermediate-Scale Experiments Results and Discussion

4.1 Introduction

The use of intermediate-scale experiments to test the performance of ESC practices provide means to perform multiple tests with fewer resources when compared to field-scale experiments, and also allows for a large amount of data to be collected and analyzed. This chapter presents the data recorded from experiments and statistical analysis tests used to analyze the performance of the following four hydromulch practices: (1) GeoSkin®, (2) HydraCX^2®, (3) Excel® Fibermulch II, and (4) HydroStraw® BFM in comparison to a bare soil control and two conventional straw practices, either crimped or tackified.

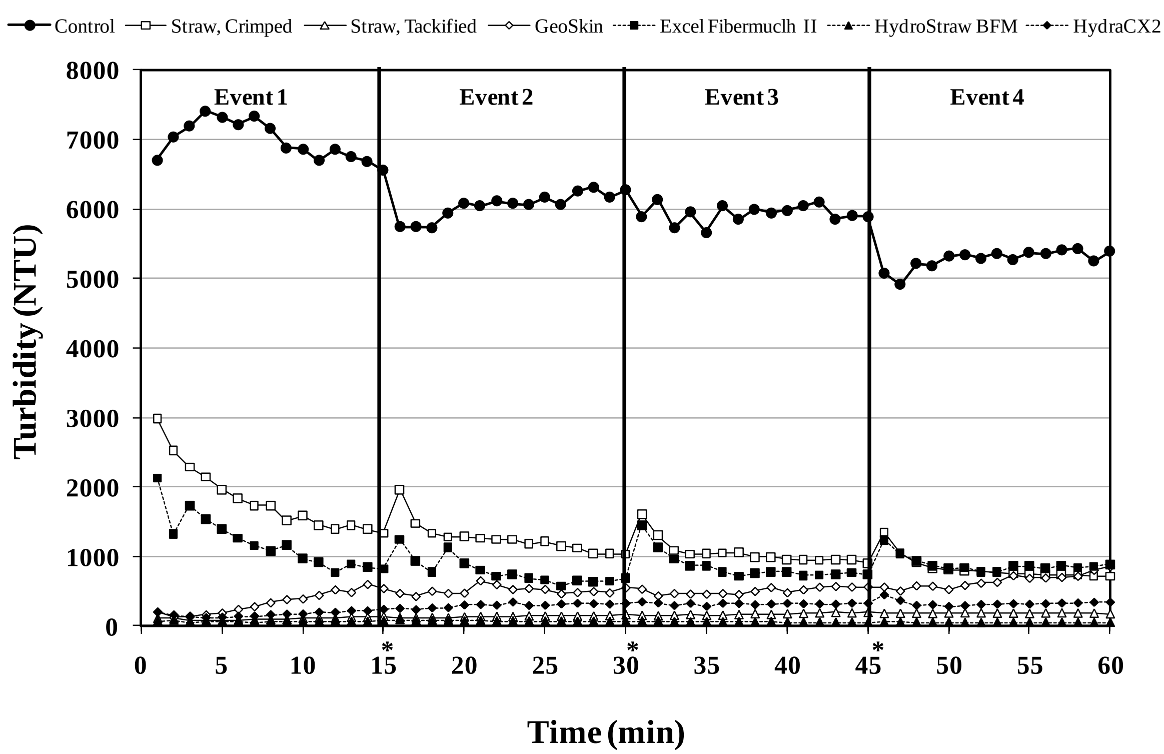
4.2 Experimental Results

Data collection procedures, outlined in Section 3.6 provided researchers with a copious amount of raw data. The data collected and recorded included: (1) surface runoff volume and mass, (2) initial turbidity, (3) runoff samples (turbidity versus time) and, (4) amount of soil eroded from test plots. All raw data collected for the research herein can be found in Appendix F. Surface runoff volume and mass quantities were collected to ensure consistent runoff between test plots and test runs, and can be found in Appendix F.

This chapter will include the experimental results and statistical analyses performed for the following sets of data: (1) initial turbidity, (2) turbidity over time, (3) soil loss, and (4) cover factor.

4.2.1 Initial Turbidity

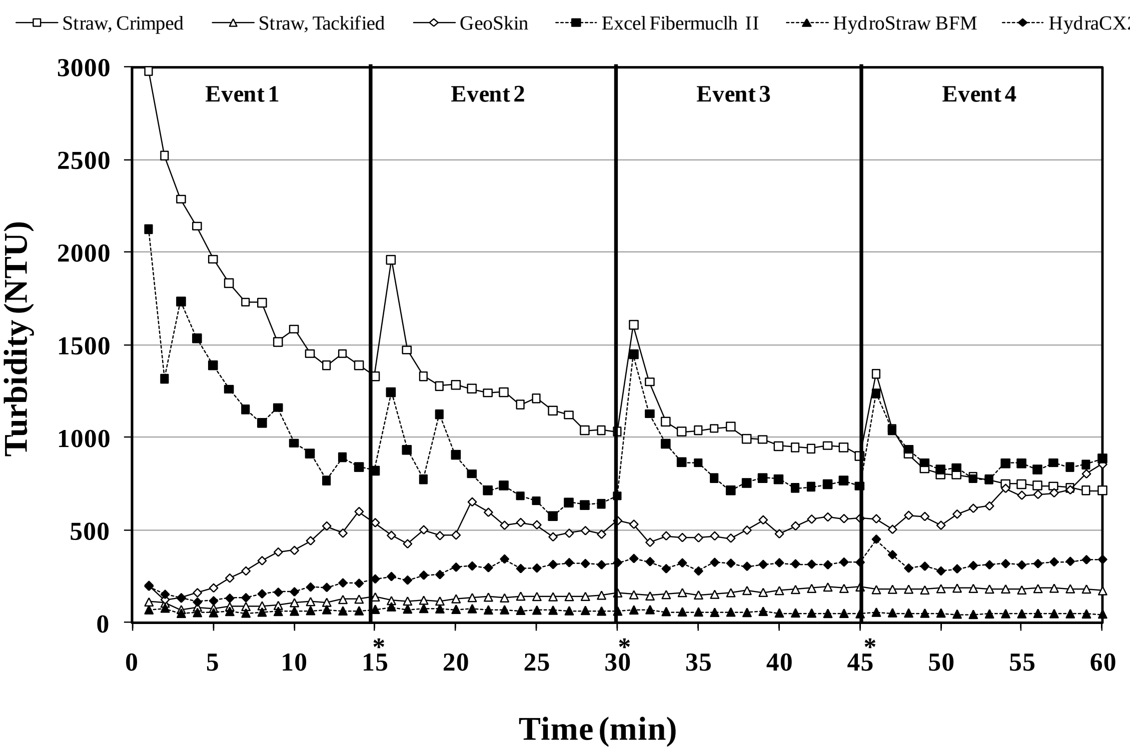
Initial turbidity measurements were recorded from a thoroughly stirred, 5 quart bucket of runoff collected at 1 minute intervals. A total of 1,608 initial turbidity measurements were recorded for this research effort, and averaged for each condition, as illustrated in Figure 4.1. Normalized to the bare soil treatment, labeled 'Control', turbidity values were reduced by at least a factor of 8 for all treatments by the end of 'Event 4'.



Note: '*' denotes 15 minute break in between tests

Figure 4.1 Average Initial Turbidity of Surface Runoff vs. Time.

Figure 4.2 allows for a closer investigation of initial turbidity values for the different conditions without showing the bare soil control as in Figure 4.1. As shown in Figure 4.2, each hydromulch with the exception of Excel® Fibermulch II and GeoSkin® were capable of reducing turbidity levels to under 500 NTUs. Two observations can be made from Figure 4.2: (1) the treatments without a polymer-enhanced tackifier had higher turbidity values from ‘Event 1’ to ‘Event 2’, and remained constant during the last two rainfall events in comparison to treatments with a tackifier; (2) the treatments with tackifiers started with very low turbidity values and steadily increased over the four, 15 minute rainfall events. HydroStraw® BFM was able to maintain a steady turbidity of about 60 NTUs throughout the four rainfall events.



Note: ‘*’ denotes 15 minute break in between tests

Figure 4.2 Average Initial Turbidity of Surface Runoff vs. Time w/o Control.

Table 4.1 shows average turbidity measurements, standard deviation of the average turbidity, and a percent reduction, normalized for the control condition. Results indicate HydroStraw® BFM has the potential to reduce initial turbidity of nearly 99%, followed by 'Straw, Tackified', HdraCX^2®, GeoSkin®, Excel® Fibermulch II, and 'Straw, Crimped' with percent reductions of 98%, 95%, 92%, 85%, and 80% respectively.

Hydromulches typically include tackifying or bonding agents to bond the mulch particles to the soil surface. Once the hydromulch dries on the soil surface, a crusted, rough surface is formed. The crusted surface is designed to absorb the rainfall, and serve as a filtration system to capture soil particles suspended in the stormwater runoff. When the tackifier or bonding agents have been washed away or begins to degrade due to stormwater runoff, the performance of the hydromulch begins to decrease, as shown with the 'Straw, Tackified', HydraCX^2®, and GeoSkin® in Figure 4.2 above. However, products with stronger tackifying agents such as HydroStraw® BFM take longer to deteriorate.

The treatments without a tackifier, 'Straw, Crimped' and Excel® Fibermulch II, rely primarily on the mulch material to filter the runoff from the plots. An observation was made from Figure 4.2 during the first two rainfall events: the soil surface that was scoured prior to treatment application was partially removed due to the absence of a tackifying agent to bond the soil particles to the treatment. This initial large concentration of soil in the runoff at the beginning of a rainfall event is known as the 'first flush phenomenon'. The first-flush phenomenon has been widely researched

(Kayhanian and Stenstrom, 2008), and can be defined as the discharge of larger mass or higher concentrations of sediment runoff in the early part of a storm relative to the later part of the storm. As shown in Figure 4.2, the initial spikes in turbidity at the start of each event are due to this phenomenon. These observations are also reflected in percent reduction, shown in Table 4.1.

Table 4.1 Average Initial Turbidity Results for Surface Runoff

Condition	Average Turbidity[a] (NTU)	Standard Deviation[b] (NTU)	Percent Reduction[c]
Control	6,060	638	-
Straw, Crimped	1,240	468	80%
Excel® Fibermulch II	930	285	85%
GeoSkin®	501	150	92%
HydraCX^2®	277	71	95%
Straw, Tackified	148	35	98%
HydroStraw® BFM	59	10	99%

Notes: ‘a’ Average of initial turbidity vs. time
‘b’ Standard deviation for average initial turbidity vs. time
‘c’ Denotes values normalized by control condition

Although the ‘Straw, Tackified’ and HydroStraw® BFM treatments reduced average turbidity by approximately 98% and 99% and met the USEPA’s new stormwater ELGs of 280 NTUs, none of the observed treatments met the ADEM’s ELGs of 50 NTUs above background turbidity levels.

A statistical analysis was completed to confirm observed differences between the control and treatments for initial turbidity measurements of stormwater surface runoff. ANOVA tables were created using Tukey-Kramer comparison tests to determine statistical significance between individual pairs of groups, as illustrated in Table 4.2. As observed, these tables demonstrated that the initial turbidities had statistically significant differences between the control and all treatments, proving that each treatment reduced initial turbidity to a certain degree when compared to the bare soil. However, GeoSkin® and HydraCX^2® showed no statistical difference in initial turbidity, similar to the behavior of 'Straw, Crimped' and Excel® Fibermulch II. Also, no significant statistical difference was observed between HydraCX^2® and HydroStraw® BFM, HydraCX^2® and 'Straw, Tackified', and HydroStraw® BFM and 'Straw, Tackified'. All other treatment comparisons proved to show a statistically significant difference in Table 4.2.

Table 4.2 Tukey-Kramer Comparison on Average Initial Turbidity

	Comparison	$\mu_i - \mu_j$	CI [LB]	CI [UB]	Significantly Different
Control	GeoSkin	5,559	5,218	5,901	Yes
	Straw, Crimped	4,820	4,478	5,162	Yes
	HydraCX^2	5,783	5,441	6,125	Yes
	Excel Fibermulch II	5,129	4,788	5,471	Yes
	HydroStraw BFM	6,001	5,660	6,343	Yes
	Straw, Tackified	5,912	5,570	6,254	Yes
Straw, Crimped	Control	4,820	4,478	5,162	Yes
	GeoSkin	739	398	1,081	Yes
	HydraCX^2	963	621	1,305	Yes
	Excel Fibermulch II	309	-32	651	No
	HydroStraw BFM	1,181	840	1,523	Yes
	Straw, Tackified	1,092	750	1,434	Yes
Straw, Tackified	Control	5,912	5,570	6,254	Yes
	GeoSkin	353	11	694	Yes
	Straw, Crimped	1,092	750	1,434	Yes
	HydraCX^2	129	-213	471	No
	Excel Fibermulch II	783	441	1,124	Yes
	HydroStraw BFM	89	-252	431	No
GeoSkin	Control	5,559	5,218	5,901	Yes
	Straw, Crimped	739	398	1,081	Yes
	HydraCX^2	224	-118	565	No
	Excel Fibermulch II	430	88	772	Yes
	HydroStraw BFM	442	100	784	Yes
	Straw, Tackified	353	11	694	Yes
HydraCX^2	Control	5,783	5,441	6,125	Yes
	Straw, Crimped	963	621	1,305	Yes
	GeoSkin	224	-118	565	No
	Excel Fibermulch II	654	312	995	Yes
	HydroStraw BFM	218	-124	560	No
	Straw, Tackified	129	-213	471	No
Excel Fibermulch II	Control	5,129	4,788	5,471	Yes
	Straw, Crimped	309	-32	651	No
	GeoSkin	430	88	772	Yes
	HydraCX^2	654	312	995	Yes
	HydroStraw BFM	872	530	1,214	Yes
	Straw, Tackified	783	441	1,124	Yes
HydroStraw BFM	Control	6,001	5,660	6,343	Yes
	Straw, Crimped	1,181	840	1,523	Yes
	HydraCX^2	218	-124	560	No
	Excel Fibermulch II	872	530	1,214	Yes
	GeoSkin	442	100	784	Yes
	Straw, Tackified	89	-252	431	No

Notes: [LB] signifies lower bound of confidence interval = -342
[UB] signifies upper bound of confidence interval = +342
$q_{crit} = 4.08$

4.2.2 Turbidity vs. Time

Turbidity was also recorded every 10 seconds over a period of 200 seconds to determine the rate at which suspended soil particles in the runoff settled. Samples were collected during each of the four tests at 5 and 10 minute intervals, providing researchers with 224 runoff samples (e.g. 7 conditions x 4 test plots x 4 tests x 2 samples = 224 runoff samples) to measure and record turbidity over time. Average recorded turbidities over 200 seconds are shown in Figure 4.3. For each ESC practice, turbidity values declined steadily until approximately 40 seconds, at which point turbidity rates became a constant value. As shown, at 200 seconds, the 'Control' was approximately 3,000 NTUs and still steadily declining. Shoemaker (2009) determined bare soil treatments do not fully settle until after approximately 10 minutes. Results show of the 4 hydromulch treatments and 2 conventional straw practices that HydroStraw® BFM was capable of obtaining ADEM's ELG of 50 NTUs from the limited number of replications within this research.

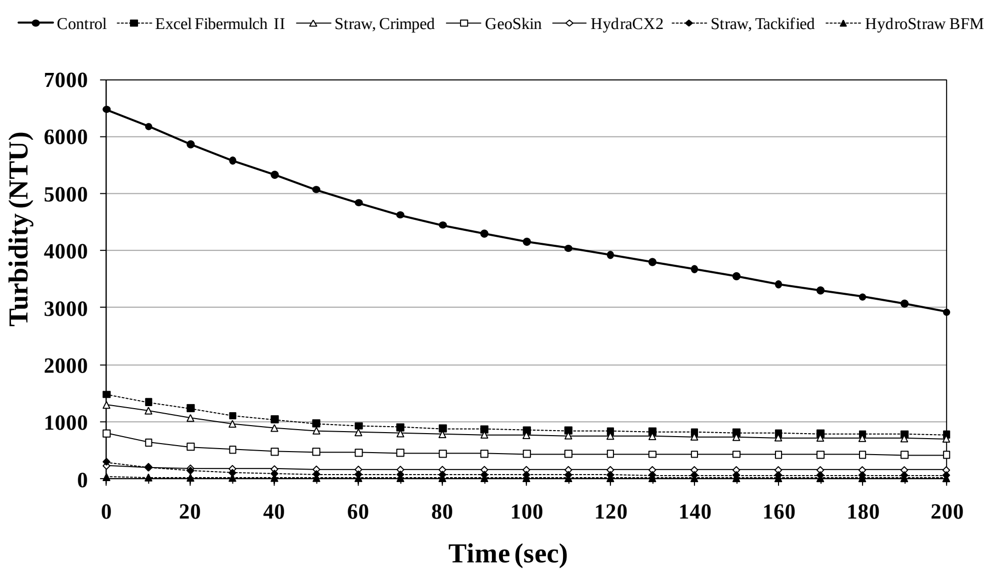
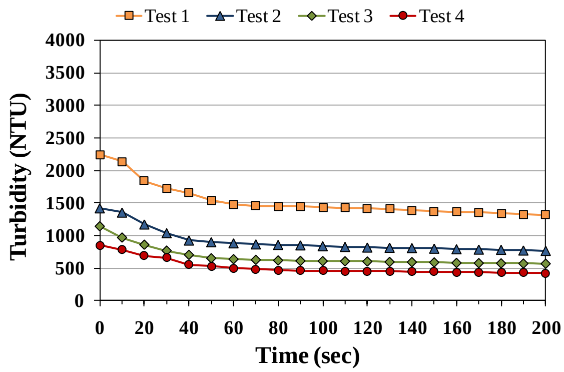
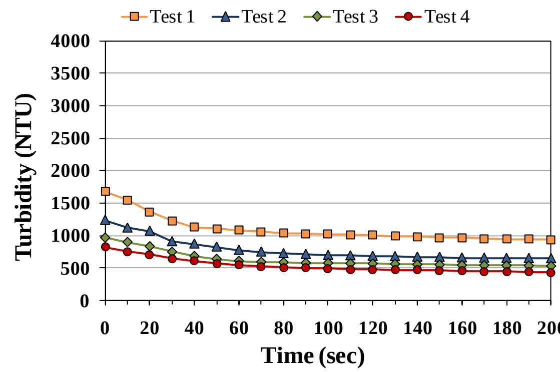


Figure 4.3 Average Recorded Turbidity for all Samples vs. Time.

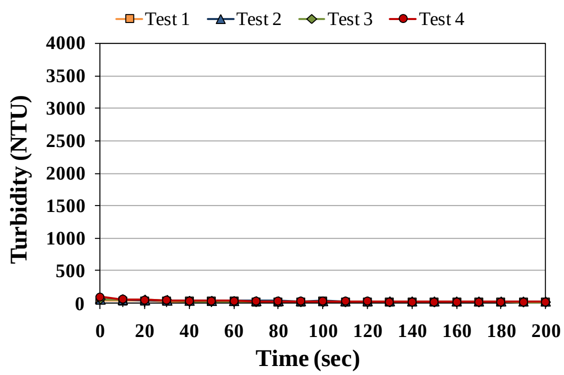
To further investigate the treatments' capability to reduce turbidity over time, treatments with similar compositions were compared. Figure 4.4 shows turbidity over time results for the treatments composed of straw. It can be observed that 'Straw, Tackified' consistently reduced turbidity over time; however the 'Straw, Crimped' and Excel® Fibermulch II treatments progressively decreased per rain event (i.e. test 1 through 4) in turbidity for both 5 and 10 minute collection times. Figure 4.5 shows turbidity over time results for the hydromulch treatments composed of a pre-mixed mulch and a tackifying agent. In comparison to HydraCX^2® and HydroStraw® BFM, GeoSkin® had different results for 5 and 10 minute samples. As Figure 4.5(a) and (b) show, the GeoSkin® hydromulch product's turbidity over time increased through an experiment's individual rainfall events. This confirms the observation that bonds of tackifying agents within hydromulches begin to deteriorate over time and hydromulches become less effective. However, as shown in Figure 4.5(c) through (f), hydromulches with tackifiers that have stronger bonding agents are capable of consistently controlling turbidity over time for all four rain events.



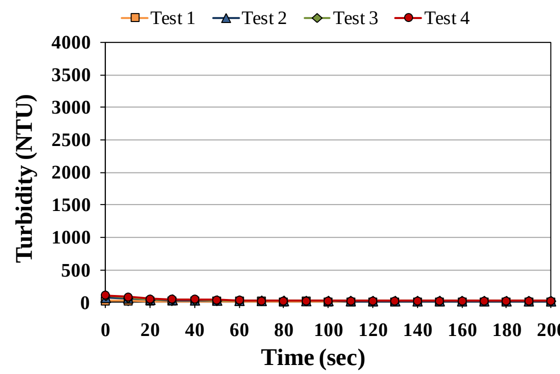
(a) Conventional Straw, Crimped at 5 Minutes



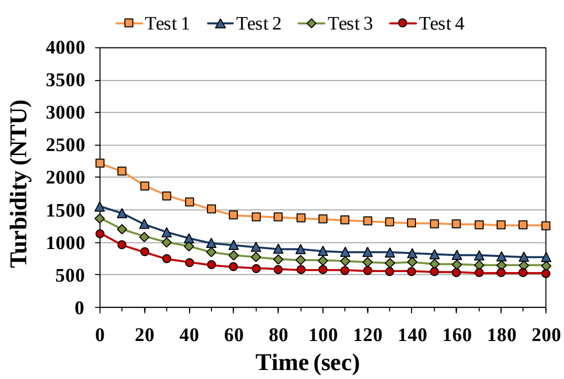
(b) Conventional Straw, Crimped at 10 Minutes



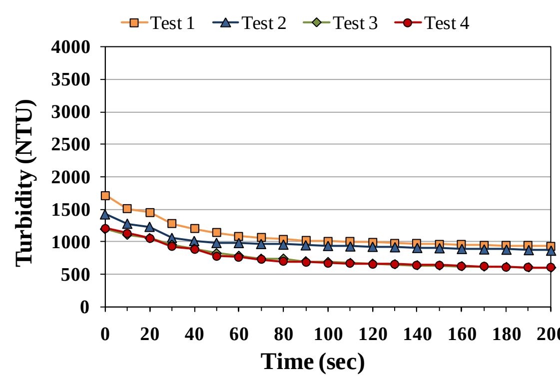
(c) Conventional Straw w/ Tackifier at 5 Minutes



(d) Conventional Straw w/ Tackifier at 10 Minutes

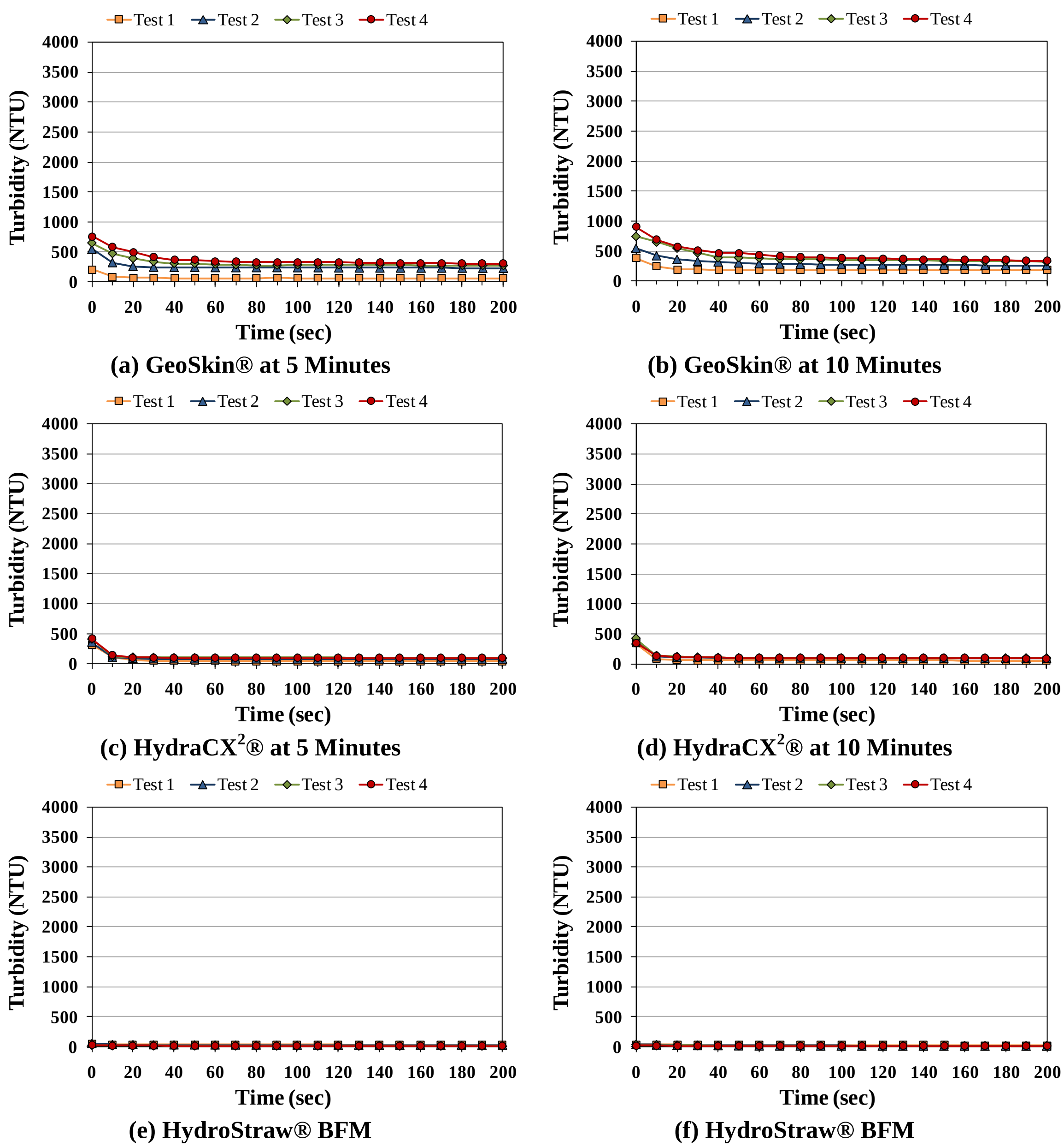


(e) Excel® Fibermulch II at 5 Minutes



(f) Excel Fibermulch II at 10 Minutes

Figure 4.4 Straw Treatments' Average Recorded Turbidity from 5 to 10 Minute Samples.



(a) GeoSkin® at 5 Minutes

(b) GeoSkin® at 10 Minutes

(c) HydraCX^2® at 5 Minutes

(d) HydraCX^2® at 10 Minutes

(e) HydroStraw® BFM

(f) HydroStraw® BFM

Figure 4.5 Hydromulch Treatments' Average Recorded Turbidity from 5 to 10 Minute Samples

Table 4.3 is a summary table to illustrate averaged turbidity measurements taken every 200 seconds for all four tests. These values are the final turbidity measurements observed while collecting turbidity over time. It can be observed that HydroStraw®

BFM was the only treatment to satisfy the ADEM ELGs of 50 NTUs over the 200 second settling period. ‘Straw, Tackified’ and HydraCX^2 were able to meet the USEPA new ELGs of 280 NTUs, recording 5 and 10 minute final values of 61.8 and 60.2 NTUs, and 17.5 and 14.4 NTUs, respectively for each treatment.

Table 4.3 Summary of Average Turbidity vs. Time Measurements

Condition	Average Turbidity (NTU)[1]	
	5 Minutes	10 Minutes
Straw, Crimped	768	636
Excel® Fibermulch II	802	749
GeoSkin®	397	440
HydraCX^2®	146	169
Straw, Tackified	61.8	60.2
HydroStraw® BFM	17.5	14.4

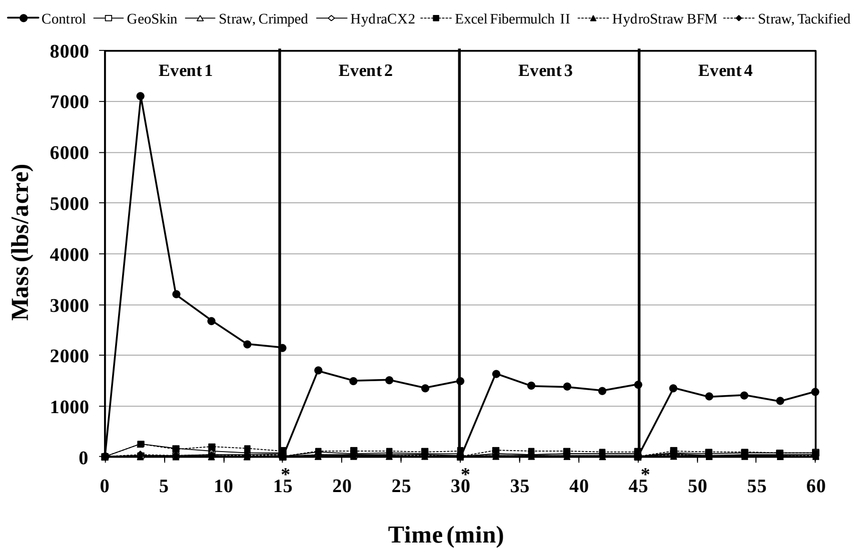
Note: 1. Average turbidity measurements at 200 seconds.

Figure 4.3 through Figure 4.5and Table 4.3 are illustrations of observed performance differences between each treatment in reducing sediment transport by increases in settling rates. For the treatments without a tackifying agent, ‘Straw, Crimped’, and Excel® Fibermulch II, turbidity rates decreased over time as well as over each of the four rainfall events. The steady decrease in turbidity over time and over each event is most likely due to a ‘flush effect’ of the topsoil that was tilled prior to treatment application. After the loose layer of soil was washed away, the rainfall was exposed to the underlying compacted soil, greatly reducing sediment runoff. Contrarily, GeoSkin® was observed to increase in turbidity over each rainfall event. This is observed to be due to a breakdown of the chemical bonds between the mulch and the soil produced by the pre-mixed tackifying agent in the hydromulch product. Manufacturers of HydroStraw® BFM require 60 lbs (27.2 kg) of dry mulch per 100 gallons (378.5 L) of water for a proper mix, compared to the 50 lbs (22.7 kg) per 100 gallons (378.5 L) for each other hydromulch treatment tested herein; therefore, an observation can be made that when applied to slopes, the HydroStraw® BFM product contains more mulch per volume sprayed, directly correlating with an increase performance in reducing sediment transport. The increased amount of dry mulch on a slope allowed for more absorption of soil in the runoff and a reduction in sediment transport. Overall sediment control effectiveness, from a sediment transport perspective, of the treatments observed herein was dependent upon three factors: (1) mulch composition (i.e. tackifier or no tackifier), (2) strength of tackifier, and (3) percent mulch per volume.

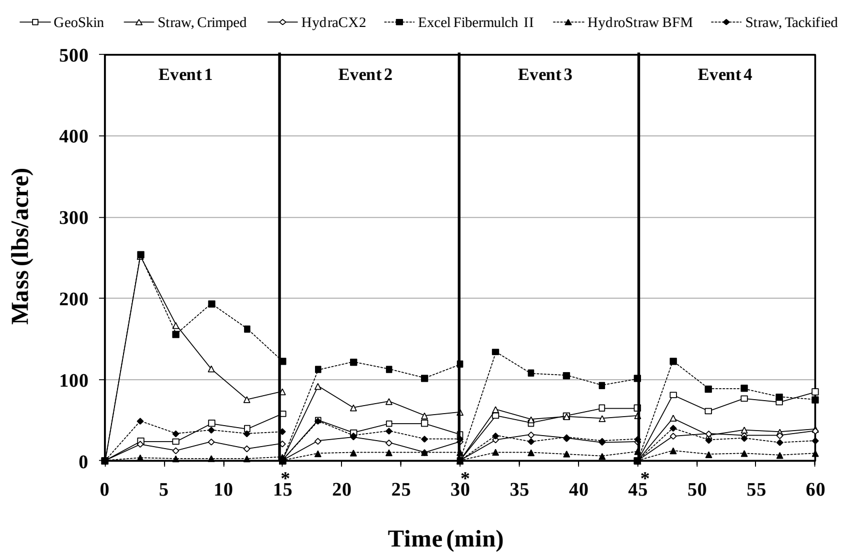
4.2.3 Soil Loss

Soil samples were collected from test plot runoff every 3 minutes for a total of 560 observations (e.g. 7 conditions x 4 test plots x 4 tests x 5 observations per test = 560 recorded measurements) for all experiments conducted. Figure 4.6(a) is representative of the average values of eroded soil for each treatment during an experiment's duration. It was observed that all treatments had significantly less levels of sediment when compared to the bare soil control. The control condition and the treatments without a tackifying agent (i.e. 'Straw, Crimped' and Excel® Fibermulch II) experienced an initial surge of sediment within the runoff, as discussed in Section 4.2.2. This is most likely due to a 'first flush effect' from the beginning of a rainfall event. However, the treatments with tackifiers did not experience this surge; a steady increase in soil loss over time for each rainfall event was observed for these treatments. As shown in Figure 4.6(b), the most effective treatments in reducing soil loss ranked in order of percent reduction were: (1) HydroStraw® BFM [~100%], (2) HydraCX^2 [99%], and (3) 'Straw, tackified' [98%].

Based upon a comparative statistical analysis performed, the abovementioned treatments were not statistical different in regards to erosion control performance. After the first rainfall event, it was observed that soil loss measurements remained consistent for the remainder of the experiment.



(a) All Treatments vs. Control

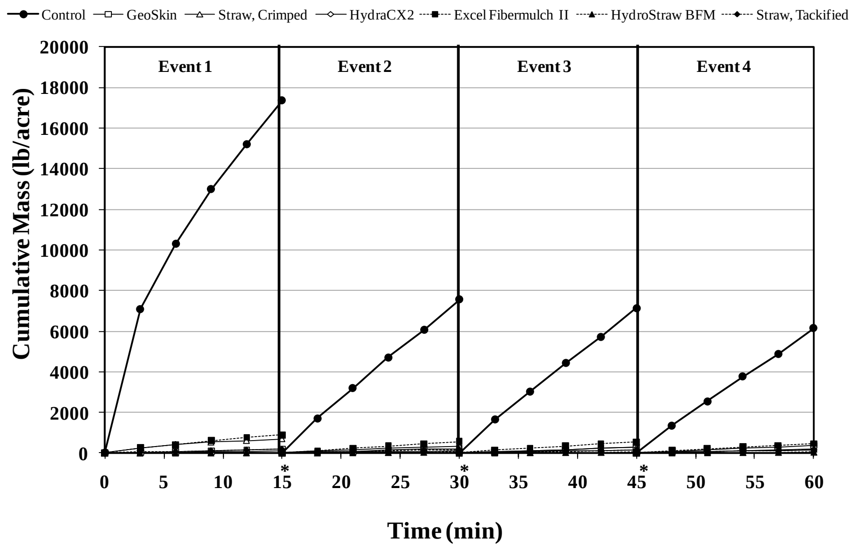


(b) All Treatments w/o Control

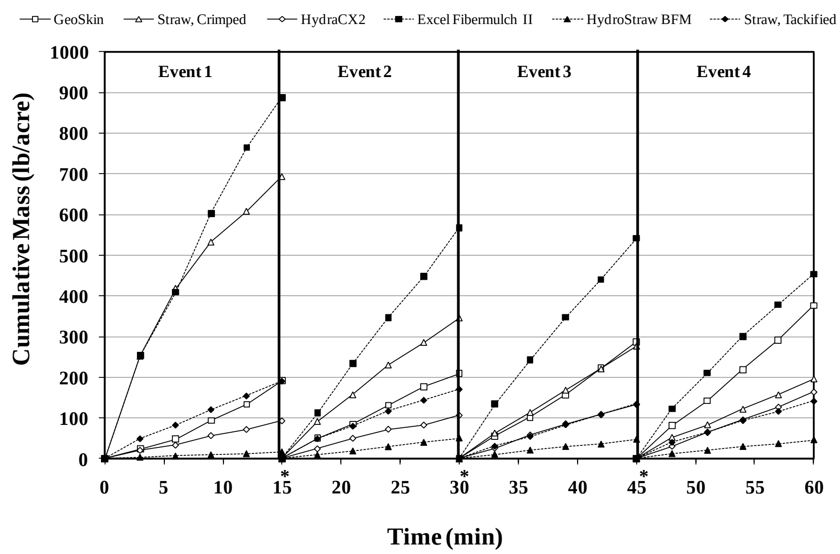
Note: '*' denotes 15 minute break in between tests [*applies to all figures*]

Figure 4.6 Average Soil Loss vs. Time.

Figure 4.7 illustrates the average cumulative amount of eroded soil for each 15 minute rain event. When compared to the control in Figure 4.7(a), all treatments are perceived to control soil loss equally; however, the control recorded more soil than all of the treatments in the first rainfall event by a factor of 17. Therefore, when soil loss is illustrated without the control, as shown in Figure 4.7(b), a clear distinction can be made between each treatment tested. As shown in Figure 4.7(b), the most consistent and effective erosion control treatment was HydroStraw® BFM, maintaining an average soil loss of approximately 10 lbs/acre (11.2 kg/ha) over the entire experiment. Excel® Fibermulch II was observed to produce the largest consistent amount of eroded soil, starting at approximately 900 lbs/acre (1008 kg/ha), and decreasing to approximately 450 lbs/acre (504 kg/ha) by the last rainfall event. GeoSkin® showed initial signs of strength in controlling erosion with 200 lbs/acre (224 kg/ha) of cumulative eroded soil, however steadily increased to almost 400 lbs/acre (448 kg/ha) by 'Event 4', nearly doubling its initial amount. It was also observed that 'Straw, Crimped' began with approximately the same amount of cumulative runoff as Excel® Fibermulch II; however after the first two rainfall events, steadily decreased to nearly 200 lbs/acre (224 kg/ha), which are soil loss levels similar to that of 'Straw, Tackified' and HydraCX^2®. 'Straw, Tackified' was observed to behave similarly in erosion control as 'Straw, Crimped', steadily decreasing over each rainfall event to the second most effective erosion control treatment by 'Event 4'. HydraCX^2® averaged 100 lbs/acre (112 kg/ha) over the entire experiment.



(a) All Treatments vs. Control



(b) All Treatments w/o Control

Note: '*' denotes 15 minute break in between tests [*applies to all figures*]

Figure 4.7 Average Cumulative Soil Loss vs. Time.

Table 4.4 and Table 4.5 present specific values of average soil loss, standard deviation, and percent reduction for each treatment during each rainfall event. The 'Straw, Crimped' treatment, when normalized to the control, reduced erosion during the first rainfall event by nearly 96% and increased in control to approximately 98.9% by the fourth rainfall event. Similarly, 'Straw, Tackified' and Excel® Fibermulch II increased in percent reduction from 'Event 1' to 'Event 4' by 98.9% to 99.2% and 94.9% to 97.4%, respectively. The hydromulches with tackifying agents reacted in a dissimilar way when normalized to the control. Over the rainfall events, percent reductions decreased from 98.9% to 97.8%, 99.5% to 99.1%, and 99.9% to 99.7% for GeoSkin®, HydraCX^2®, and HydroStraw® BFM, respectively. It was observed that this reduction was due to the degradation of the tackifying bonds between the soil and the mulch; contrarily, the increased performance of the non-tackified treatments was observed to be due to the 'flush effect' of the scoured surface in the first events, exposing the less erodible, compacted, underlying soil.

Table 4.4 Average Soil Loss due to Surface Runoff
[*Straw, Crimped or Tackified; Excel®Fibermulch II*]

Condition	Soil Loss [a] (lbs/acre)	Standard Deviation [b] (lbs/acre)	Percent Reduction [c]
Test 1			
Control	3469.8	2675.9	-
Straw, Crimped	138.6	96.3	96.0%
Straw, Tackified	38.2	35.3	98.9%
Excel® Fibermulch II	177.5	141.3	94.9%
Test 2			
Control	1511.3	211.0	-
Straw, Crimped	69.2	21.7	98.0%
Straw, Tackified	34.2	34.5	99.0%
Excel® Fibermulch II	113.4	75.6	96.7%
Test 3			
Control	1429.1	341.9	-
Straw, Crimped	55.3	12.0	98.4%
Straw, Tackified	26.9	23.8	99.2%
Excel® Fibermulch II	108.3	75.3	96.9%
Test 4			
Control	1228.6	185.0	-
Straw, Crimped	39.3	12.3	98.9%
Straw, Tackified	28.3	25.3	99.2%
Excel® Fibermulch II	90.8	69.6	97.4%

Notes: 'a' Average of eroded soil vs. time for each test
'b' Standard deviation for average soil loss vs. time
'c' Denotes values normalized by control condition

Table 4.5 Average Soil Loss due to Surface Runoff
[*GeoSkin®, HydraCX^2®, HydroStraw®*]

Condition	Soil Loss [a] (lbs/acre)	Standard Deviation [b] (lbs/acre)	Percent Reduction [c]
Test 1			
Control	3469.8	693.8	-
GeoSkin®	38.2	44.7	98.9%
HydraCX^2®	18.5	11.5	99.5%
HydroStraw® BFM	3.4	2.6	99.9%
Test 2			
Control	1511.3	189.7	-
GeoSkin®	41.8	35.2	98.8%
HydraCX^2®	21.2	15.1	99.4%
HydroStraw® BFM	10.0	3.3	99.7%
Test 3			
Control	1429.1	236.3	-
GeoSkin®	57.4	47.4	98.3%
HydraCX^2®	26.5	16.3	99.2%
HydroStraw® BFM	9.4	5.2	99.7%
Test 4			
Control	1228.6	194.0	-
GeoSkin®	75.2	50.2	97.8%
HydraCX^2®	32.7	21.9	99.1%
HydroStraw® BFM	9.2	3.3	99.7%

Notes: 'a' Average of eroded soil vs. time for each test
'b' Standard deviation for average soil loss vs. time
'c' Denotes values normalized by control condition

Continuing the statistical analysis used throughout this research effort, ANOVA procedures with Tukey-Kramer multiple comparison tests were used for the recorded amounts of soil. Table 4.6 illustrates statistically significant and insignificant results of average soil loss throughout the experiments. The statistical analysis compared all treatments to the control and each other. The control proved to be statistically different than all treatments; therefore each treatment had a significant effect in reducing soil loss when compared the bare soil. When the treatments were compared amongst each other all were capable of reducing soil loss significantly the same. Therefore it can be concluded from Table 4.6 that statistically, each treatment is capable of significantly reducing and controlling erosion on 3H:1V, compacted fill slopes.

Table 4.6 Tukey-Kramer Comparison on Average Soil Loss

	Comparison	μ_i - μ_j	CI [LB]	CI [UB]	Significantly Different
Control	GeoSkin	1,857	1,312	2,401	Yes
	Straw, Crimped	1,834	1,289	2,379	Yes
	HydraCX^2	1,885	1,340	2,430	Yes
	Excel Fibermulch II	1,787	1,242	2,332	Yes
	HydroStraw BFM	1,902	1,357	2,447	Yes
	Straw, Tackified	1,878	1,333	2,423	Yes
Straw, Crimped	Control	1,834	1,289	2,379	Yes
	GeoSkin	22	-522	567	No
	HydraCX^2	51	-494	596	No
	Excel Fibermulch II	47	-498	592	No
	HydroStraw BFM	68	-477	612	No
	Straw, Tackified	44	-501	589	No
Straw, Tackified	Control	1,878	1,333	2,423	Yes
	GeoSkin	21	-524	566	No
	Straw, Crimped	44	-501	589	No
	HydraCX^2	7	-538	552	No
	Excel Fibermulch II	91	-454	635	No
	HydroStraw BFM	24	-521	569	No
GeoSkin	Control	1,857	1,312	2,401	Yes
	Straw, Crimped	22	-522	567	No
	HydraCX^2	28	-516	573	No
	Excel Fibermulch II	69	-476	614	No
	HydroStraw BFM	45	-500	590	No
	Straw, Tackified	21	-524	566	No
HydraCX^2	Control	1,885	1,340	2,430	Yes
	Straw, Crimped	51	-494	596	No
	GeoSkin	28	-516	573	No
	Excel Fibermulch II	98	-447	643	No
	HydroStraw BFM	17	-528	562	No
	Straw, Tackified	7	-538	552	No
Excel Fibermulch II	Control	1,787	1,242	2,332	Yes
	Straw, Crimped	47	-498	592	No
	GeoSkin	69	-476	614	No
	HydraCX^2	98	-447	643	No
	HydroStraw BFM	114	-430	659	No
	Straw, Tackified	91	-454	635	No
HydroStraw BFM	Control	1,902	1,357	2,447	Yes
	Straw, Crimped	68	-477	612	No
	HydraCX^2	17	-528	562	No
	Excel Fibermulch II	114	-430	659	No
	GeoSkin	45	-500	590	No
	Straw, Tackified	24	-521	569	No

Notes: [LB] signifies lower bound of confidence interval = -545
[UB] signifies upper bound of confidence interval = +545
q_{crit} = 4.18

4.2.4 Initial Turbidity vs. Soil Loss

To determine the relationship between the average recorded initial turbidities (essentially indicative of reducing sediment transport or migration) and average measured soil loss (which is indicative of erosion control performance) values were plotted together, illustrated in Figure 4.8. Average soil loss and initial turbidity values for the control produced an outlying group of high sediment yield and turbidity values, shown on the far right side of the plot, making it difficult to distinguish the performance of the other treatments tested. Therefore Figure 4.9 was created without the control to present the other treatments in a more comparable manner.

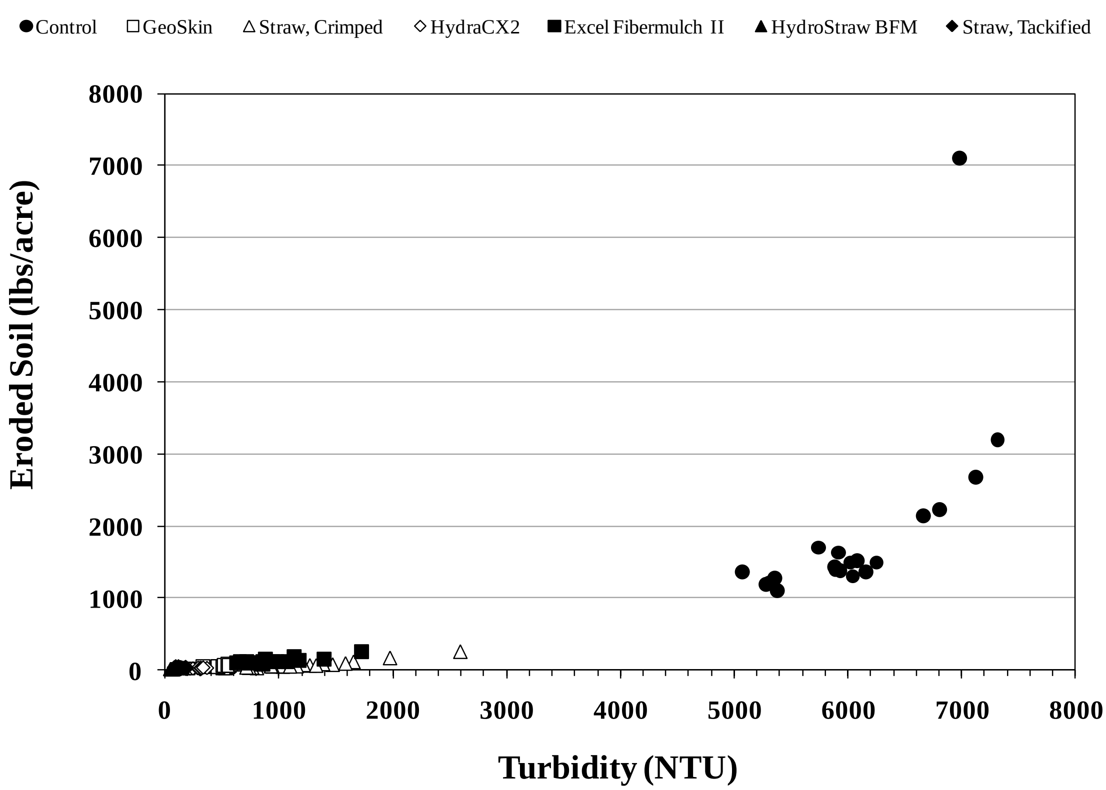


Figure 4.8 Average Initial Turbidity vs. Average Eroded Soil.

As illustrated in Figure 4.9, the three treatments that were not statistically different are ranked in order of percent reduction (i.e., soil loss and initial turbidity) in comparison to the control: (1) HydroStraw® BFM, (2) conventional straw with a tackifier, and (3) HydraCX^2®. The relationship between initial turbidities can be used as a method to determining overall performance of a treatment from an erosion and/or sediment transport perspective. Patterns and consistencies in erosion and sediment transport control are also revealed when using this method to plot treatments. For example, Excel® Fibermulch II and 'Straw, Crimped' have plotted values with a wider variability in comparison to the other treatments, showing signs of inconsistencies in product performance. Overall, significant reductions in both soil loss and initial turbidity are observed for each treatment when compared to the bare soil condition, as illustrated in Figure 4.8 and Figure 4.9.

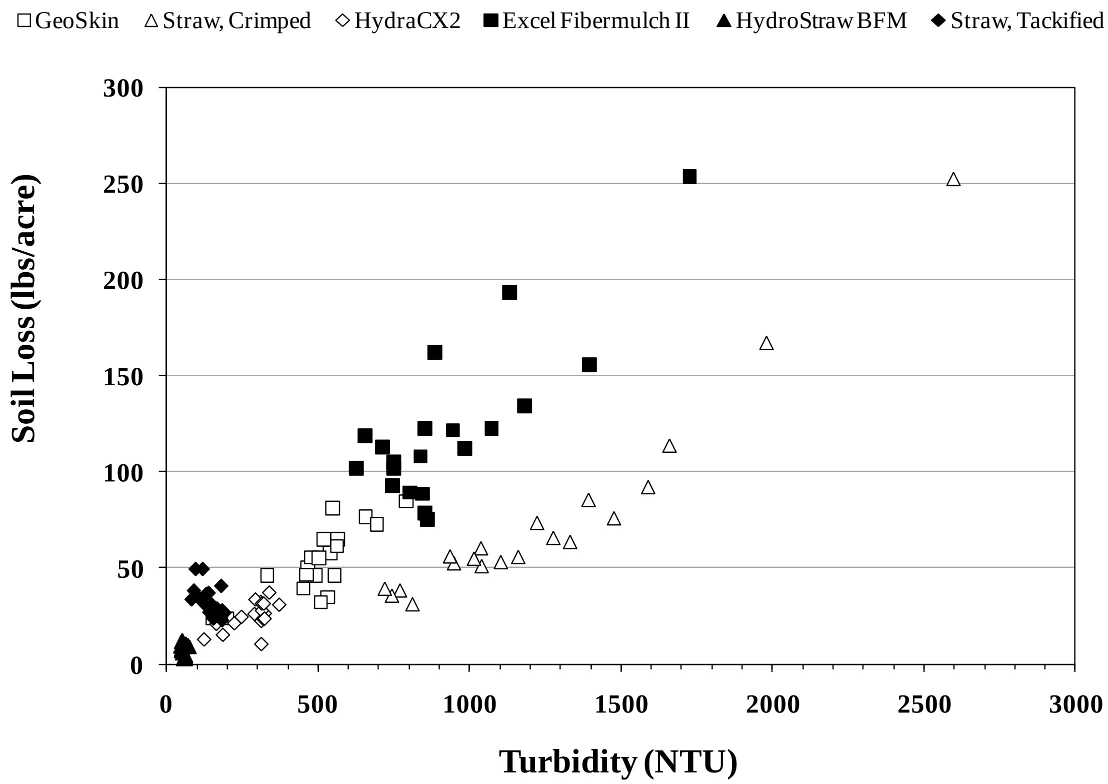


Figure 4.9 Average Initial Turbidity vs. Average Eroded Soil [*Excludes Control*].

4.2.5 Cover-Factor

Studies reviewed (Lipscomb et al., 2006; Holt et al., 2005; Landloch, 2002; Clopper et al., 2001; Buxton and Caruccio, 1979) used a 'cover-factor' to report erosion control performance. Cover factor is a parameter in the Revised Universal Soil Loss Equation (RUSLE) to represent a comparison of soil loss occurring with the treatment in place to that which occurs in the bare, unprotect condition (Clopper et al., 2001). The RUSLE allows researchers to calculate cover-factors for treatments without testing a bare soil using several different parameters based upon soil type, slope, and rain regimes; Lipscomb et al. (2006) and Clopper et al. (2001) mitigated the RUSLE to calculate cover-factors. However, if bare soil conditions are accounted for, the cover-factor is simply the ratio of sediment yield in the protected condition to sediment yield of the unprotected condition; Holt et al. (2005) effectively used this method to calculate c-factors. In 1979, Buxton and Caruccio used the Universal Soil Loss Equation (USLE) to calculate cover-factor values, which were at the time identified as 'VM factors'. In 1979, a VM factor represented a vegetative or maintenance erosion control practice and was a total soil loss ratio expressed as a decimal. Landloch (2002) calculated cover-factors using the Modified Universal Soil Loss Equation (MUSLE), which calculates erosive potential as a factor W, which is based on rainfall erosivity, peak runoff rate, total runoff, slope gradient and length, cover, etc.

Although there are several methods to calculating cover-factors, cover-factor remains simply a soil loss ratio (SLR) of treated to untreated (bare soil) conditions. Cover-factors numerically represent erosion control performance on a scale of 0.0 to 1.0, where a value of 0.0 means the erosion control practice has eliminated all erosion, and a cover-factor of 1.0 means the practice has done nothing to reduce erosion and is equivalent to a bare soil condition. Table 4.7 summarizes the cover-factors calculated in this research effort, normalized to bare soil conditions. According to calculated cover-factors of 0.004, 0.013, 0.017, 0.028 0.040, and 0.064 in Table 4.7, the hydromulches can be ranked from most to least effective erosion control practices accordingly: (1) HydroStraw® BFM, (2) HydraCX^2®, (3) Conventional Straw, Tackified, (4) GeoSkin®, (5) Conventional Straw, Crimped, and (6) Excel® Fibermulch II; however there are no statistical differences between practices.

Table 4.7 Cumulative Soil Loss (A) to Calculate Cover Factors (C) per Treatment

Treatment	Cumulative Soil Loss (A) (grams/plot)[1]	Cumulative Soil Loss (A) (tons/acre)[2]	*Calculated Cover Factor (C)[3]
HydroStraw® BFM	13	36	0.004
HydraCX^2®	41	112	0.013
Conventional Straw, Tackified	53	145	0.017
GeoSkin®	89	241	0.028
Conventional Straw, Crimped	126	343	0.040
Excel® Fibermulch II	204	556	0.064

Note: '1' Unit conversion: 1 gram/plot = 0.035 oz/plot.
'2' Unit conversion: 1 ton/acre = 2242 kg/ha.
'3' Cover factor normalized to a bare soil value of 8,662 tons/acre (19,420,204 kg/ha).
'*' Cover factor calculation: C=A/Control[3].

4.3 Summary

Data collection from intermediate-scale experiments allowed researchers to observe and evaluate the performance of conventional straw (crimped or tackified) and four hydromulches (Excel® Fibermulch II, GeoSkin®, HydraCX^2®, and HydroStraw® BFM) as an erosion control measure. Data collection included: (1) surface runoff, (2) initial turbidity, (3) turbidity versus time, and (4) soil loss. The collected data was analyzed using ANOVA and Tukey-Kramer statistical analysis procedures to determine the effect of different treatments and if any statistical significant results were observed.

At total of 1,680 runoff samples were recorded for 14 experiments in this research effort. This consisted of samples collected every minute for all four rainfall events per experiment. Initial turbidity measurements were recorded from every sample collected, allowing researchers to rank treatments; from most to least effective in reducing turbidity when normalized to bare soil (control) conditions, the ranked treatments in this research effort are (1) HydroStraw® BFM, (2) straw, tackified, (3) HydraCX^2®, (4) GeoSkin®, (5) Excel® Fibermulch II, and (6) straw, crimped, with reductions of 99%, 98%, 95%, 92%, 85%, and 80% respectively. The straw treatments without tackifiers, conventional straw, crimped and Excel® Fibermulch II, experienced the 'first-flush' phenomenon, receiving an initial surge of concentrated sediment in the runoff, which steadily reduced over time. Contrarily, the hydromulches and straw with tackifier were observed to slowly lose their effectiveness over the four rainfall events as the chemical bonds in the tackifying agents began to deteriorate.

In addition, soil loss samples were collected every 3 minutes from surface runoff, totaling 560 samples, to determine an amount of eroded soil from test plots. Samples were filtered and oven dried for 24 hours. Soil loss reduction results included 100%, 99%, 98%, 97%, 96%, and 94% for HydroStraw® BFM, HydraCX^2®, straw-tackified, GeoSkin®, straw-crimped, and Excel® Fibermulch II respectively. Figure 4.10 is a bar chart representing the average percent reduction of turbidity and soil loss for each treatment normalized to the bare soil control in this research effort.

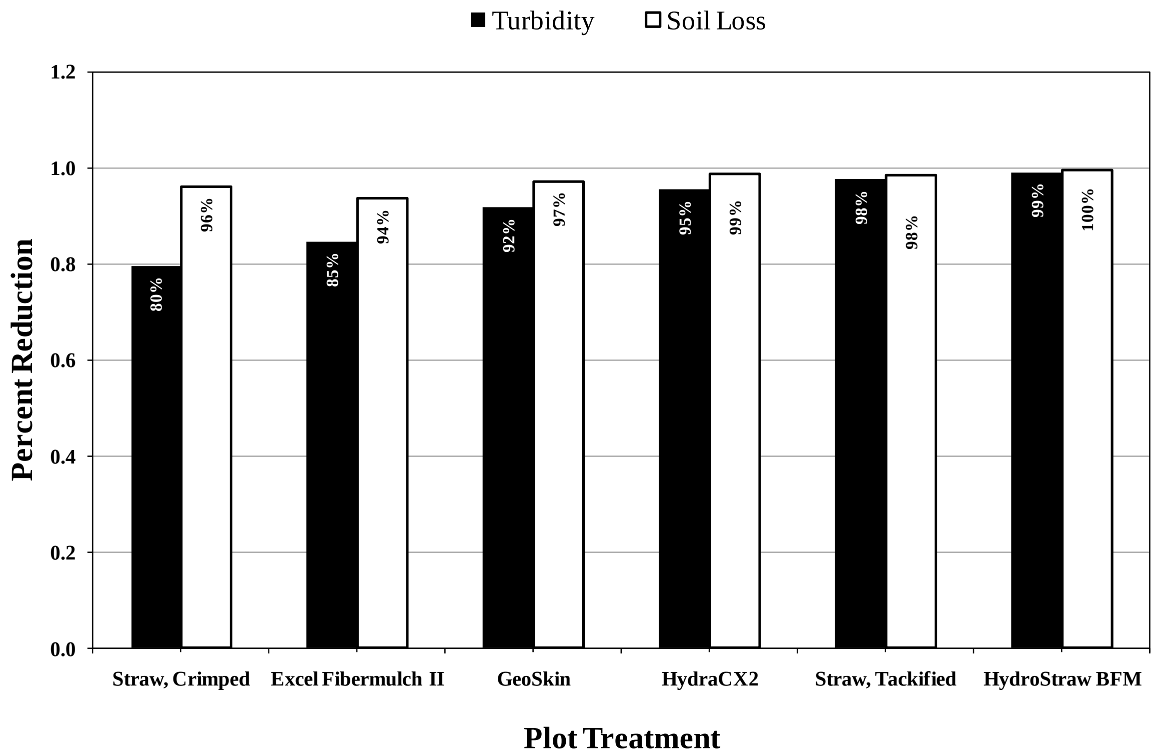


Figure 4.10 Average Percent Reduction of Treatments Compared to Control.

Cover-factors were calculated using SLRs between the control and the treatments. Calculated cover-factors mimicked performance results of soil loss percent reductions, indicating that HydroStraw® BFM, ‘Straw, Tackified’, and HydraCX^2® were the most effective erosion control measures and were not statistically different, while GeoSkin, Excel® Fibermulch II, and “Straw, Crimped” were the least effective treatments when compared as a group.

Grab samples were taken each test at 5 and 10 minutes to measure turbidity over time. This provided researchers with data showing treatment performance in reducing turbidity over time. All treatments were observed to reduce the time required for turbidity to decrease when compared to the control; however HydroStraw® BFM was capable of meeting ADEM ELGs of 50 NTUs, and straw, tackified and HydraCX^2® were capable of meeting the USEPA ELG of 280 NTUs.

Overall, according to experimental results, it was observed that there were no statistical differences in performance from an erosion control perspective between HydroStraw® BFM, ‘Straw, Tackified’, and HydraCX^2®, which all have potential to be effective erosion control practices. This was observed using recorded and analyzed turbidity measurements and soil loss masses collected from test plot runoff.

Chapter 5 Conclusions and Recommendations

5.1 Introduction

The purpose of this research effort was to evaluate the erosion control performance of the following four hydromulches: (1) Excel® Fibermulch II, (2) GeoSkin®, (3) HydraCX^2®, and (4) HydroStraw® BFM, in comparison to a bare soil control and two conventional straw practices that were either crimped or tackified. To achieve this, intermediate-scale experimentations were conducted to simulate conditions representative of a typical highway embankment with a fill slope of 3H:1V. The first objective involved the design and construction of a flume to modify Shoemaker's (2009) runoff collection device on the intermediate-scale (2 ft by 4 ft [0.6 m by 1.2 m]) plots. Once the flume was constructed, research and development of a uniform and consistent method of applying the 4 hydromulch and 2 conventional straw treatments was completed to ensure accurate, quantifiable, manufacture specified application rates. The second component of this research used the unified test procedures developed to evaluate the effectiveness of the 6 treatments. The data collected from the compacted, 3H:1V test plots was compared to a bare soil (control) condition and analyzed to provide recommendations for use of conventional straw (crimped or tackified) and hydromulches on highway construction sites.

5.2 Intermediate-Scale Test Methods and Procedures

Intermediate-scale experimental procedures and methods of data collection were adopted from Shoemaker (2009). A flume was designed and constructed to modify the collection runoff device used on the 2 ft (0.6 m) wide by 4 ft (1.2 m) long test plots. Uniform runoff was created by a rainfall simulator, verified by Shoemaker (2009) using the Christiansen Uniformity Coefficient to have an acceptable uniformity ranging between 84% and 88%. Experiments were divided into four 15 minute tests with 15 minute breaks in between for optimal data collection. The four tests produced a total rainfall of approximately 4.4 inches (1.1 inches per test) of rain, meeting the ALDOT's inspection guidelines that state ESC practices must be inspected following an accumulated amount of rainfall measuring 0.75 in. The rainfall event produced in this research effort was indicative of a 2-year, 24 hour storm event experienced in Auburn, AL with a total rainfall amount of 4.39 in/hr.

Another essential task to properly test the effectiveness of ESC practices in this research effort involved compacting the test soil to ALDOT's standard specified rate of 95%. It was determined by a soil and compaction analysis that hand-tamps were capable of compacting the test soil at an OMC of 14% to achieve the required rate of 105 pcf (1,682 kg/m^3) for compaction. Once the intermediate-scale test plots were compacted and scoured to simulate typical highway embankments, the plots were ready for ESC treatments to be applied.

A uniform and consistent method of applying each treatment was researched and evaluated individually to ensure proper, manufacture specified application rates.

Application procedures for applying conventional straw crimped or tackified to 3H:1V slopes was followed using methods developed by ALDOT (2008). However, applying the hydromulches was more involved therefore a procedure was developed to determine the application rate per spray (using a hydroseeder), allowing researchers to verify the application rate after a predetermined amount of sprays. Methods developed were used to ensure manufacturer specified application rates were achieved.

Once the treatments were uniformly applied and allowed a 48 hour drying period under ultra-violet ray heat lamps, testing could begin. A turbidity meter was used to record initial turbidity measurements as well as turbidity over time for all experiments, representative of controlling sediment migration in construction stormwater runoff from typical highway embankments. Runoff samples were filtered, dried for 24 hours, and weighed to account for sediment loss (erosion control). With the recorded data, researchers could properly evaluate the performance of each treatment.

5.3 Performance of Conventional Straw and Hydromulch

Fourteen experiments were conducted to examine the erosion control effectiveness of 4 hydromulch practices and 2 conventional straw surface cover practices: (1) Excel® Fibermulch II, (2) GeoSkin®, (3) HydraCX^2®, (4) HydroStraw® BFM, (5) conventional straw, crimped, (6) conventional straw, tackified. Performance was evaluated using data collection from experiments, which included surface runoff volume and mass, initial turbidity, and turbidity over time.

Initial turbidity measurements were recorded from samples that were collected every minute of each four, 15 minute rainfall events. Representative of initial sediment control, researchers were able to rank the 6 treatments in order from most to least effective according to an averaged percent reduction when normalized by the bare soil condition: (1) HydroStraw® BFM [99% reduction], (2) straw, tackified [98% reduction], (3) HydraCX^2® [95% reduction], (4) GeoSkin® [92% reduction], (5) Excel® Fibermulch II [85% reduction], and (6) straw, crimped [80% reduction]. The surface cover practices without tackifiers, conventional straw, crimped and Excel® Fibermulch II, experienced a heavy concentration of sediment in the runoff during the first two rainfall events, which is known as the 'first flush phenomenon'; however each treatment steadily improved sediment transport control over time. Contrarily, the surface cover practices with tackifying agents provided excellent initial sediment transport control, but over the four rainfall events the chemical bonds began to deteriorate, showing a steady decrease in performance.

Grab samples were collected from each test at 5 and 10 minutes to measure turbidity over time. Each treatment was observed to reduce the time required for turbidity to decrease when compared to the control. It was observed that the most effective treatment reducing turbidity over the 200 second settling period was the HydroStraw® BFM, which was also the only product to meet the ADEM effluent limitation guidelines (ELGs) of 50 NTUs. 'Straw, Tackified' and HydraCX^2 were able to meet the USEPA new ELGs of 280 NTUs, recording 5 and 10 minute final values of 61.8 and 60.2 NTUs, and 17.5 and 14.4 NTUs, respectively for each treatment.

Once initial turbidity measurements and turbidity over time grab samples were taken, collective runoff over a 3 minute period was filtered, oven dried for 24 hours, and weighed to provide quantitative erosion control results. Researchers observed approximately 100%, 99%, 98%, 97%, 96%, and 94% for HydroStraw® BFM, HydraCX^2®, straw-tackified, GeoSkin®, straw-crimped, and Excel® Fibermulch II respectively. Cumulative soil losses were also used in this research to calculate cover-factors, which are SLRs between treated and untreated conditions; calculated c-factors mimicked percent reduction performances, ranging in value from 0.004 for HydroStraw® BFM to 0.064 for Excel® Fibermulch II.

Literature reviewed and results from this research suggest that conventional straw crimped or tackified as well as hydromulches are very effective erosion control measures, when applied at the proper application rates. According to experimental results, HydroStraw® BFM was the only hydromulch practice that was able to satisfy both USEPA (280 NTUs) and ADEM (50 NTUs above background turbidity levels) ELGs. For all other treatments, sediment control additives such as polyacrylamide (PAM) are encouraged to be used in conjunction for optimal erosion and sediment transport control on construction sites with 3H:1V compacted fill slopes.

It is to be recognized that there are five qualifying experimental factors that have an impact on the conclusions drawn from the results reported from this research, which include: (1) soil type, (2) slope, (3) soil compaction, (4) rainfall simulator, and (5) rainfall intensity. These qualifying factors were designed into the experimental procedures and have the potential to create a biased outcome on some conclusions and recommendations that can be made for the erosion control practices tested. It should also be noted the intermediate-scale results reported herein may not be scale-able to field-scale or practical-scale performance on active construction sites.

5.4 Recommended Future Research

Results presented in this report show that conventional straw crimped or tackified and hydromulches are effective means of reducing erosion and sedimentation caused by sediment laden runoff. However, conventional straw or hydromulches are rarely used on its own and is more commonly used in conjunction with additional sediment control additives such as PAM. Therefore, further research should be conducted to examine how the addition of PAM to these practices could potentially improve ESC performance.

Also, the conclusions discussed in this report are based on intermediate-scale test plots. It would be beneficial if the performance of these treatments were tested at field-scale conditions to validate intermediate-scale results provided in this research. Intermediate-scale experiments allow researchers to test the performance of ESC practices at a faster rate than most field-scale experiments; therefore, if field-scale results were found to be similar to intermediate-scale results, a larger quantity of products could be effectively evaluated in a shorter period of time.

Lastly, this research only tested the performance of 4 manufactured hydromulch products. Increased technologies over the years have allowed for the creation of many new hydromulches that claim to be the best product on the market. It is strongly encouraged to further investigate the performance of other hydromulch products on the market to create a more thorough analysis and to provide a more scientific realm of knowledge of the hydromulch industry.

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Appendix 1 Manufacturer's Specifications for Rainfall Simulator Components

NORGREN

R43

Water and Compressed Air Service Pressure Regulator 1/4", 3/8" and 1/2" Port Sizes

- Non-relieving models
- Brass body, corrosion resistant construction
- Balanced valve minimizes effects of inlet pressure variations on outlet pressure
- T-bar adjustment standard, nonrising knob adjustment optional
- Full flow gauge ports can be used as auxiliary outlets
- Panel mounting nut standard
- Can be disassembled without the use of tools or removal from the air or water line.

Ordering Information. Models listed have T-handle adjustment, 5 to 125 psig (0.3 to 8.5 bar) outlet pressure adjustment range*, and PTF threads. A gauge is not included.

Port	Model	Flow† U.S. gpm (lpm)	Weight lb (kg)
1/4"	R43-201-NNLA	6 (23)	2.4 (1.09)
3/8"	R43-301-NNLA	6 (23)	2.4 (1.09)
1/2"	R43-406-NNLA	9 (34)	2.4 (1.09)

Alternative Models R43 - ★★★ - ★★★★

Port Size	Substitute
1/4"	2
3/8"	3
1/2"	4

Adjustment	Substitute
Knob	00
T-handle with 1/4" and 3/8" ports	01
T-handle with 1/2" ports	06

Diaphragm	Substitute
Non relieving	N

Threads	Substitute
PTF	A
ISO Rc taper	B
ISO G parallel	G

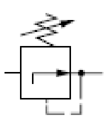
Outlet Pressure Adjustment Range*	Substitute
5 to 50 psig (0.3 to 3.5 bar)	E
5 to 125 psig (0.3 to 8.6 bar)	L
15 to 250 psig (1 to 17 bar)	S

Gauges	Substitute
With	G
Without	N

* Outlet pressure can be adjusted to pressures in excess of, and less than, those specified. Do not use these units to control pressures outside of the specified ranges.

† Typical flow with 150 psig (10 bar) inlet pressure, 90 psig (6.3 bar) set pressure and 15 psig (1 bar) droop from set.

ISO Symbols



Non relieving

See Section ALE-25 for Accessories

Pressure Regulator

Pilot Operated

General Service Solenoid Valves

Brass or Stainless Steel Bodies
3/8" to 2 1/2" NPT

2/2 SERIES 8210 **2-WAY**

Features

- Wide range of pressure ratings, sizes, and resilient materials provide long service life and low internal leakage
- High Flow Valves for liquid, corrosive, and air/inert gas service
- Industrial applications include:
  - Car wash
  - Laundry equipment
  - Air compressors
  - Industrial water control
  - Pumps

Construction

Valve Parts in Contact with Fluids		
Body	Brass	304 Stainless Steel
Seals and Discs	NBR or PTFE	
Disc-Holder	PA	
Core Tube	305 Stainless Steel	
Core and Plugnut	430F Stainless Steel	
Springs	302 Stainless Steel	
Shading Coil	Copper	Silver

Electrical

Standard Coil and Class of Insulation	Watt Rating and Power Consumption				Spare Coil Part Number			
		AC			General Purpose		Explosionproof	
	DC Watts	Watts	VA Holding	VA Inrush	AC	DC	AC	DC
F	-	6.1	16	40	238210	-	238214	-
F	11.6	10.1	25	70	238610	238710	238614	238714
F	16.8	16.1	35	180	272610	97617	272614	97617
F	-	17.1	40	93	238610	-	238614	-
F	-	20	43	240	99257	-	99257	-
F	-	20.1	48	240	272610	-	272614	-
H	30.6	-	-	-	-	74073	-	74073
H	40.6	-	-	-	-	238910	-	238914

Standard Voltages: 24, 120, 240, 480 volts AC, 60 Hz (or 110, 220 volts AC, 50 Hz). 6, 12, 24, 120, 240 volts DC. Must be specified when ordering.
Other voltages available when required.

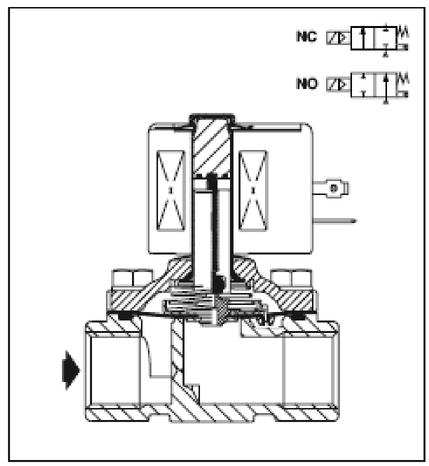
Solenoid Enclosures

Standard: RedHat II - Watertight, Types 1, 2, 3, 3S, 4, and 4X; RedHat - Type I.

Optional: RedHat II - Explosionproof and Watertight, Types 3, 3S, 4, 4X, 6, 6P, 7, and 9; Red-Hat - Explosionproof and Watertight, Types 3, 4, 4X, 7, and 9.

(To order, add prefix "EF" to catalog number, except Catalog Numbers 8210B057, 8210B058, and 8210B059, which are not available with Explosionproof enclosures.)

See Optional Features Section for other available options.



Nominal Ambient Temp. Ranges

RedHat II/
RedHat AC: 32°F to 125°F (0°C to 52°C)

RedHat II DC: 32°F to 104°F (0°C to 40°C)
RedHat DC: 32°F to 77°F (0°C to 25°C)
(104°F/40°C occasionally)

Refer to Engineering Section for details.

Approvals

CSA certified. RedHat II meets applicable CE directives.
Refer to Engineering Section for details.

Solenoid Valve (a)

Specifications (English units)

Pipe Size (ins.)	Orifice Size (ins.)	Cv Flow Factor	Operating Pressure Differential (psi) Min.	Max. AC Air-Inert Gas	Max. AC Water	Max. AC Light Oil @ 300 SSU	Max. DC Air-Inert Gas	Max. DC Water	Max. DC Light Oil @ 300 SSU	Max. Fluid Temp. °F AC	Max. Fluid Temp. °F DC	Brass Body Catalog Number	Brass Body Const. Ref. ④	Brass Body UL ⑤ Listing	Stainless Steel Body Catalog Number	Stainless Steel Body Const. Ref. ④	Stainless Steel Body UL ⑤ Listing	Watt Rating/ Class of Coil Insulation ⑦ AC	Watt Rating/ Class of Coil Insulation ⑦ DC
NORMALLY CLOSED (Closed when de-energized), NBR or PTFE ② Sealing																			
3/8	3/8	1.5	①	150	125	-	40	40	-	180	150	8210G073 ③	1P	●	8210G036 ③	1P	●	6.1/F	11.6/F
3/8	5/8	3	0	150	150	-	40	40	-	180	150	8210G093	5D	○	-	-	-	10.1/F	11.6/F
3/8	5/8	3	5	200	150	135	125	100	100	180	150	8210G001	6D	○	-	-	-	6.1/F	11.6/F
3/8	5/8	3	5	300	300	300	-	-	-	175	-	8210G006	5D	○	-	-	-	17.1/F	-
1/2	7/16	2.2	①	150	125	-	40	40	-	180	150	8210G015 ③	2P	●	8210G037 ③	2P	●	6.1/F	11.6/F
1/2	5/8	4	0	150	150	-	40	40	-	180	150	8210G094	5D	○	-	-	-	10.1/F	11.6/F
1/2	5/8	4	0	150	150	125	40	40	-	175	150	-	-	-	8210G087	7D	●	17.1/F	11.6/F
1/2	5/8	4	5	200	150	135	125	100	100	180	150	8210G002	6D	○	-	-	-	6.1/F	11.6/F
1/2	5/8	4	5	300	300	300	-	-	-	175	-	8210G007	5D	○	-	-	-	17.1/F	-
1/2	3/4	4	5	-	300	-	-	300	-	180	125	8210G227	5D	○	-	-	-	17.1/F	40.6/H
3/4	5/8	4.5	0	150	150	125	40	40	-	175	150	-	-	-	8210G088	7D	●	17.1/F	11.6/F
3/4	3/4	5	5	125	125	125	100	90	75	180	150	8210G009	9D	○	-	-	-	6.1/F	11.6/F
3/4	3/4	5	0	150	150	-	40	40	-	180	150	8210G095	8D	○	-	-	-	10.1/F	11.6/F
3/4	3/4	6.5	5	250	150	100	125	125	125	180	150	8210G003	11D	○	-	-	-	6.1/F	11.6/F
3/4	3/4	6	0	-	-	-	200	180	180	-	77	8210B026 ② ‡	10P	-	-	-	-	-	30.6/H
3/4	3/4	6	0	350	300	200	-	-	-	200	-	8210G026 ② ‡	40P	●	-	-	-	16.1F	-
1	1	13	0	-	-	-	100	100	80	-	77	8210B054 ‡	31D	-	8210D089	15D	-	-	30.6/H
1	1	13	0	150	125	125	-	-	-	180	-	8210G054	41D	●	8210G089	45D	●	16.1/F	-
1	1	13	5	150	150	100	125	125	125	180	150	8210G004	12D	○	-	-	-	6.1/F	11.6/F
1	1	13.5	0	300	225	115	-	-	-	200	-	8210G027 ‡	42P	●	-	-	-	20.1/F	-
1	1	13.5	10	300	300	300	-	-	-	175	-	8210G078 ②	13P	-	-	-	-	17.1/F	-
1 1/4	1 1/8	15	0	-	-	-	100	100	80	-	77	8210B055 ‡	32D	-	-	-	-	-	30.6/H
1 1/4	1 1/8	15	0	150	125	125	-	-	-	180	-	8210G055	43D	●	-	-	-	16.1/F	-
1 1/4	1 1/8	15	5	150	150	100	125	125	125	180	150	8210G008	16D	○	-	-	-	6.1/F	11.6/F
1 1/2	1 1/4	22.5	0	-	-	-	100	100	80	-	77	8210B056 ‡	33D	-	-	-	-	-	30.6/H
1 1/2	1 1/4	22.5	0	150	125	125	-	-	-	180	-	8210G056	44D	●	-	-	-	16.1/F	-
1 1/2	1 1/4	22.5	5	150	150	100	125	125	125	180	150	8210G022	18D	●	-	-	-	6.1/F	11.6/F
2	1 3/4	43	5	150	125	90	50	50	50	180	150	8210G100	20P	●	-	-	-	6.1/F	11.6/F
2 1/2	1 3/4	45	5	150	125	90	50	50	50	180	150	8210G101	21P	●	-	-	-	6.1/F	11.6/F
NORMALLY OPEN (Open when de-energized), NBR Seating (PA Disc-Holder, except as noted)																			
3/8	5/8	3	0	150	150	125	125	125	80	180	150	8210G033	23D	●	-	-	-	10.1/F	11.6/F
3/8	5/8	3	5	250	200	200	250	200	200	180	180	8210G011 ⑥ ⑧	39D	●	-	-	-	10.1/F	11.6/F
1/2	5/8	4	0	150	150	125	125	125	80	180	150	8210G034	23D	●	-	-	-	10.1/F	11.6/F
1/2	5/8	3	0	150	150	100	125	125	80	180	150	-	-	-	8210G030	37D	●	10.1/F	11.6/F
1/2	5/8	4	5	250	200	200	250	200	200	180	180	8210G012 ⑥ ⑧	39D	●	-	-	-	10.1/F	11.6/F
3/4	3/4	5.5	0	150	150	125	125	125	80	180	150	8210G035	25D	●	-	-	-	10.1/F	11.6/F
3/4	5/8	3	0	150	150	100	125	125	80	180	150	-	-	-	8210G038	38D	●	10.1/F	11.6/F
3/4	3/4	6.5	5	-	-	-	250	200	200	-	180	8210D013	24D	●	-	-	-	-	16.8/F
3/4	3/4	6.5	5	250	200	200	-	-	-	180	-	8210G013	46D	●	-	-	-	16.1/F	-
1	1	13	0	125	125	125	-	-	-	180	-	8210B057 ⑥ ⑩	34D	●	-	-	-	20/F	-
1	1	13	5	-	-	-	125	125	125	-	180	8210D014	26D	●	-	-	-	-	16.8/F
1	1	13	5	150	150	125	-	-	-	180	-	8210G014	47D	●	-	-	-	16.1/F	-
1 1/4	1 1/8	15	0	125	125	125	-	-	-	180	-	8210B058 ⑥ ⑩	35D	●	-	-	-	20/F	-
1 1/4	1 1/8	15	5	-	-	-	125	125	125	-	180	8210D018	28D	●	-	-	-	-	16.8/F
1 1/4	1 1/8	15	5	150	150	125	-	-	-	180	-	8210G018	48D	●	-	-	-	16.1/F	-
1 1/2	1 1/4	22.5	0	125	125	125	-	-	-	180	-	8210B059 ⑥ ⑩	36D	●	-	-	-	20/F	-
1 1/2	1 1/4	22.5	5	-	-	-	125	125	125	-	180	8210D032	29D	●	-	-	-	-	16.8/F
1 1/2	1 1/4	22.5	5	150	150	125	-	-	-	180	-	8210G032	49D	●	-	-	-	16.1/F	-
2	1 3/4	43	5	-	-	-	125	125	125	-	150	8210 103	30P	●	-	-	-	-	16.8/F
2	1 3/4	43	5	125	125	125	-	-	-	180	-	8210G103	50P	●	-	-	-	16.1/F	-
2 1/2	1 3/4	45	5	-	-	-	125	125	125	-	150	8210 104	27P	●	-	-	-	-	16.8/F
2 1/2	1 3/4	45	5	125	125	125	-	-	-	180	-	8210G104	51P	●	-			16.1/F	-

① 5 psi on Air; 1 psi on Water.
② Valve provided with PTFE main disc.
③ Valve includes Ultem (G.E. trademark) piston.
④ Letter "D" denotes diaphragm construction; "P" denotes piston construction.
⑤ ○ Safety Shutoff Valve; ● General Purpose Valve.
Refer to Engineering Section (Approvals) for details.
⑥ Valves not available with Explosionproof enclosures.
⑦ On 50 hertz service, the watt rating for the 6.1/F solenoid is 8.1 watts.
⑧ AC construction also has PA seating.
⑨ No disc-holder.
⑩ Stainless steel disc-holder.
‡ Must have solenoid mounted vertical and upright.

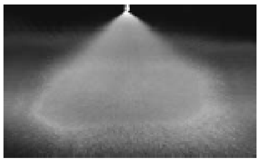
Solenoid Valve (b)

FULL CONE NOZZLES

B

FullJet® Spray Nozzles • Wide Angle Square Spray

Small Capacity



HH-WSQ

One-piece body
1/4"-1/2" NPT or BSPT (M)

DESIGN FEATURES

Wide angle square spray FullJet nozzles feature a solid cone-shaped spray pattern with a square impact area and spray angles of 93° to 110°.

Their uniform spray distribution of medium to large drops is the result of the unique FullJet nozzle vane design, exacting internal proportions, and precision machining. The nozzles are ideal for installations requiring uniform coverage of rectangular and/or square areas.

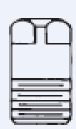
PERFORMANCE DATA

Nozzle Inlet Conn. NPT or BSPT (M)	Capacity Size	Orifice Dia. Nom.	Max. Free Passage Dia.*	Capacity (gallons per minute)									Spray Angle		
				5 psi	7 psi	10 psi	15 psi	20 psi	30 psi	40 psi	60 psi	80 psi	5 psi	10 psi	80 psi
1/4	14WSQ	.141"	.063"	1.0	1.2	1.4	1.7	1.9	2.3	2.6	3.1	3.5	99°	101°	93°
3/8	17WSQ	.156"	.063"	1.3	1.5	1.7	2.0	2.3	2.8	3.1	3.7	4.2	99°	101°	93°
	20WSQ	.172"	.094"	1.5	1.7	2.0	2.4	2.7	3.2	3.7	4.4	5.0	104°	110°	94°
	24WSQ	.188"	.094"	1.8	2.1	2.4	2.9	3.3	3.9	4.4	5.3	6.0	104°	110°	94°
	27WSQ	.203"	.109"	2.0	2.3	2.7	3.2	3.7	4.4	5.0	5.9	6.7	104°	110°	98°
1/2	30WSQ	.219"	.109"	2.2	2.6	3.0	3.6	4.1	4.9	5.5	6.6	7.5	104°	110°	102°
	35WSQ	.234"	.125"	2.6	3.0	3.5	4.2	4.8	5.7	6.4	7.7	8.7	104°	110°	102°
	40WSQ	.250"	.125"	3.0	3.4	4.0	4.8	5.4	6.5	7.4	8.8	10.0	104°	110°	102°
	45WSQ	.250"	.141"	3.3	3.9	4.5	5.4	6.1	7.3	8.3	9.9	11.2	104°	110°	102°
	50WSQ	.266"	.156"	3.7	4.3	5.0	6.0	6.8	8.1	9.2	11.0	12.5	104°	110°	102°

* Foreign matter with maximum diameter as listed can pass through nozzle without clogging.

DIMENSIONS & WEIGHTS

HH-WSQ



Nozzle Inlet Conn. NPT or BSPT (M)	Length	Dia.	Net Weight
1/4	29/32"	17/32"	1/2 oz.
3/8	1-3/16"	21/32"	1 oz.
1/2	1-3/8"	13/16"	1-1/2 oz.

Based on largest/heaviest version of each type.

ORDERING INFO

STANDARD SPRAY NOZZLE

1/4 HH – SS 14WSQ

Inlet Conn. | Nozzle Type | Material Code | Capacity Size

MATERIALS

Material	Material Code	Nozzle Type HH-WSQ
Brass	(none)	•
Mild Steel	I	•
303 Stainless Steel	SS	•
316 Stainless Steel	316SS	•
Polyvinyl Chloride	PVC	•

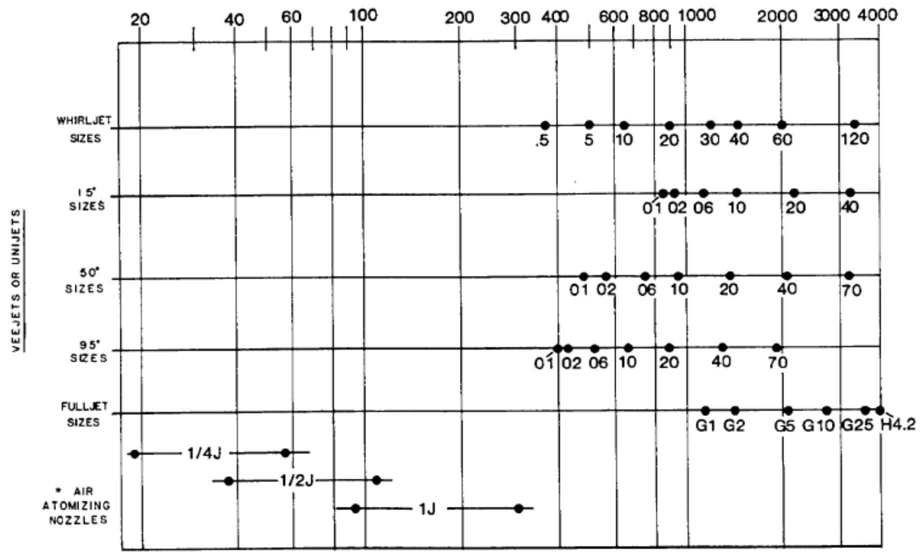
Other materials available upon request.

Spraying Systems Co.®
Phone 1-800-95-SPRAY, Fax 1-888-95-SPRAY
Outside the U.S., Phone 1(630) 665-5000, Fax 1(630) 260-0842
Visit our Web Site: www.spray.com, email: info@spray.com

Rainfall Simulator Nozzle

ESTIMATED M.V.D. PARTICLE SIZE-(MICRONS)-FOR STANDARD SSCO NOZZLES

(Nozzles spraying water at 10 PSIG at room temperature under laboratory conditions)



M.V.D. particle size data is based on volumetric measurements where 50% of the liquid sprayed is in drops smaller than the given number and 50% of the liquid is in drops larger than the given number.

EXAMPLE: To determine the approximate M.V.D. of a 5010 Veejet Nozzle:

1. Find 50°--series line for Veejets.
2. Locate--10 position in row of dots.
3. Read the particle diameter directly from the scale above.

Answer: 940 Microns (approx.)

*Air Atomizing Nozzle particle size ranges shown are generalized only. for more specific information, please write Wheaton.

Data is based on spraying water under laboratory conditions using Spraying Systems Co. Imaging Particle Analyzer.

PARTICLE SIZE RANGE (MICRONS) MEDIAN VOLUME	COMPARATIVE SUBJECT IN PARTICLE SIZE	TIME FOR PARTICLE TO FALL 10 FEET (SECONDS)
5000 to 2000	Heavy Rain	0.85 0.9
2000 to 1000	Intense Rain	0.9 1.1
1000 to 500	Moderate Rain	1.1 1.6
500 to 100	Light Rain	1.6 11
100 to 50	Misty Rain	11 40
50 to 10	Wet Fog	40 1020
10 to 2.0	Dry Fog	1020 25400
1.0 to .01	Fumes	Suspended** in air
.01 to .001	Smoke	Suspended** in air
Below .001	Molecular Dimensions	-

One Micron = 1/25400 of an inch
25.4 Microns = .001" (one thousandth of an inch)
1000 Microns = 1 millimeter

**Below 0.1 microns, particles are suspended in air due to molecular shock (Brownian Motion)

DESCRIPTION

COMPARATIVE PARTICLE SIZE DATA FOR SSCO SPRAY NOZZLES AND RAIN DROP PARTICLE SIZE TAB. (10 P.S.I.)

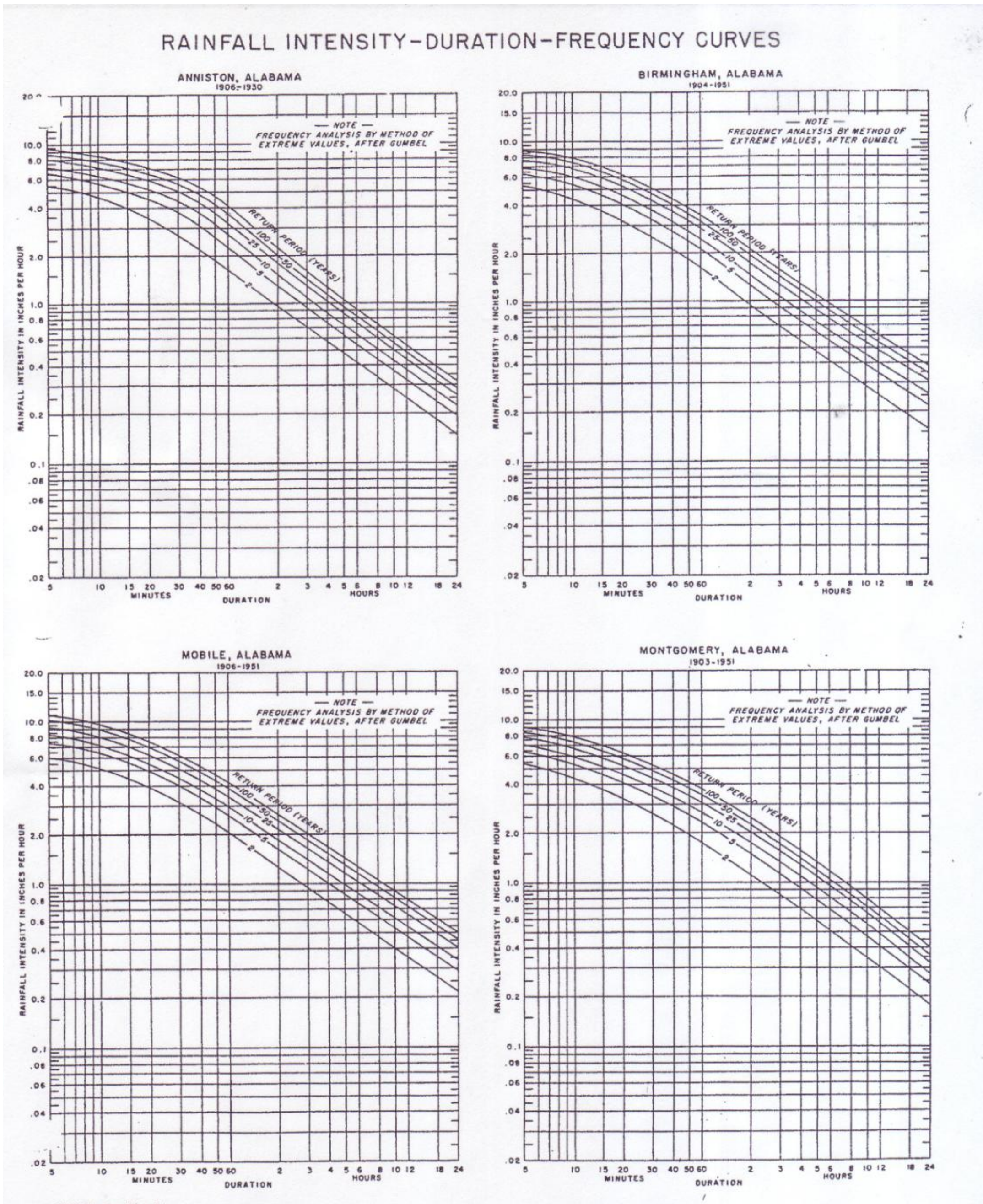
SPRAYING SYSTEMS CO.
Engineers and Manufacturers
NORTH AVENUE AT SCHMALE ROAD WHEATON, ILL.

DR. BY K.S.
DATE 10/29/81
DWG. NO. 13911-2

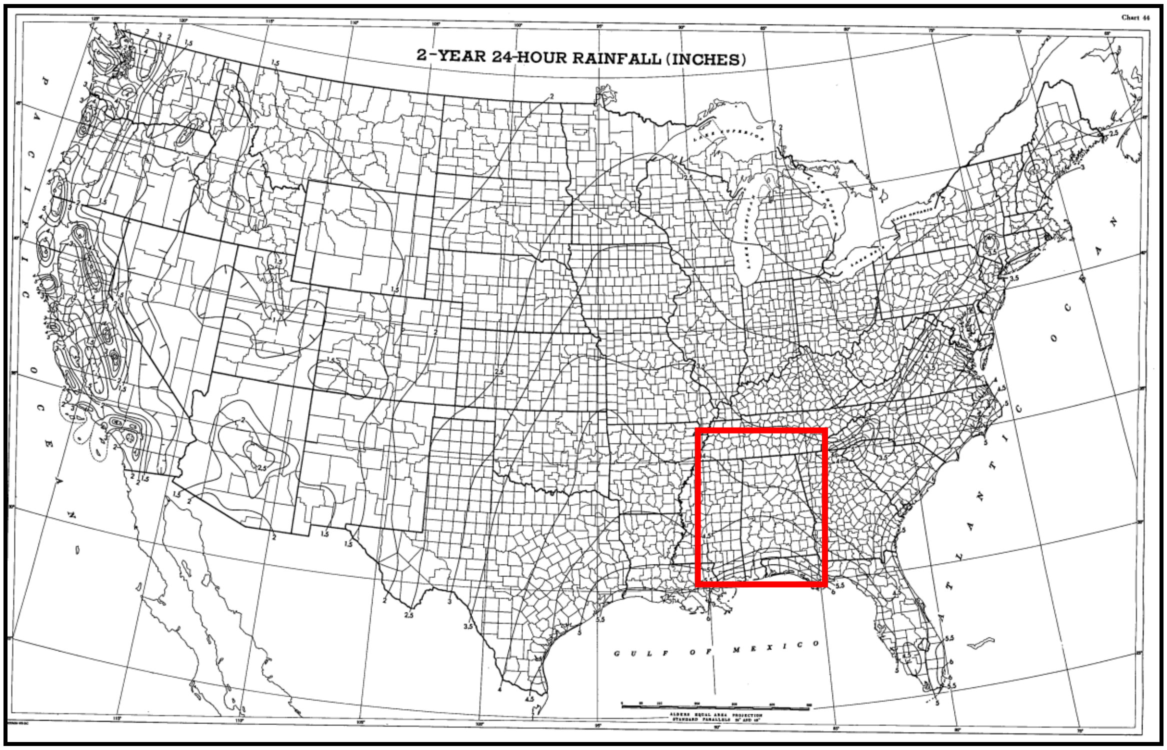
S-B

Raindrop Sizes

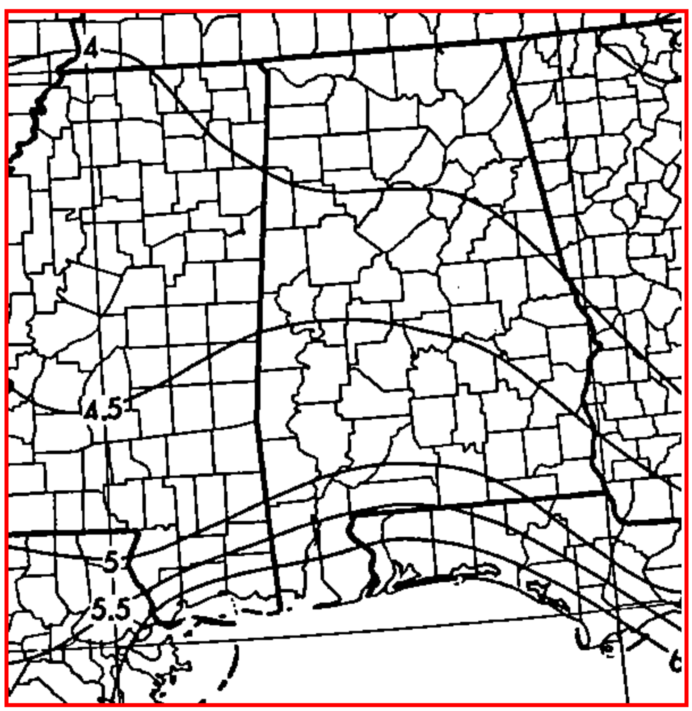
Appendix 2 Rainfall Intensity-Duration-Frequency Curves for Alabama.



IDF Curves for Alabama



(a) 2-yr, 24-hr Cumulative rainfall for the United States



(b) 2-yr, 24-hr Cumulative rainfall for Alabama

Appendix 3 Manufacturer's Specifications for Equipment Used During Experimentation

MARUYAMA TRUE COMMERICAL OUTDOOR POWER EQUIPMENT

COMPACT POWER SPRAYERS

LOW PRESSURE EXTREME-DUTY

1. Driven by commercial-grade, high performance, low weight engines. 2. The superior quality, positive displacement duplex piston pump provides remarkable performance and extreme durability, up to 1.9 gallons per minute volume at 356 psi. 3. A wide variety of optional nozzles, wands, extensions, guns and booms offer extraordinary flexibility and productivity. 4. Compact, highly portable designs. 5. Five year commercial warranty.

MARUYAMA IRON 5 YEAR COMMERCIAL WARRANTY

SPECIFICATIONS

MODEL	MSØ74	MSØ72EH
ENGINE	Maruyama	Honda
DISPLACEMENT (cc)	22.5	25.0
APPROX. WEIGHT (lbs)	18.7	16.3
TANK CAPACITY (gal)	6.1	-
PUMP TYPE	duplex piston	duplex piston
MAXIMUM VOLUME (gpm)	1.9	1.9
PRESSURE (psi)	356	356
TRANSPORT	backpack	barrel-top
AGITATION	liquid bypass	liquid bypass
COMMERCIAL WARRANTY	5 year	5 year
STANDARD ACCESSORY	dual head nozzle	U2L gun

Maruyama. extraordinary.

MARUYAMA U.S., INC. | DENTON, TEXAS | PH 94Ø.383.74ØØ | FX 94Ø.383.7466
EMAIL MARUYAMA@MARUYAMA-US.COM | WWW,MARUYAMA-US.COM

Backpack Sprayer

ANALITE NEP160
TURBIDITY METER
for Field and Laboratory Applications

The ANALITE NEP160 is a truly portable turbidity meter. Readings are taken by simply inserting the probe into the steam or media to get an immediate result truly representative of the turbidity level at that point and time. It allows for easy and fast multiple readings at a site to ascertain the real turbidity profile of a stream or water body.

The ANALITE 160 turbidity meter allows the user to set up measurement parameters through a user-friendly menu system displayed on the in-built 2 line alphanumeric display.

Three probes are currently available to suit the ANALITE NEP160 display unit, the NEP260 (ISO7027 to 3,000NTU), NEP280 (retro-scatter to 30,000NTU) and the high temperature rated NEP285 (retro-scatter to 30,000NTU). Other probes may be added to the range from time to time. The probes have a depth rating of 100 meters and the display unit is IP65 rated.

All ANALITE NEP160 compliant probes are "hot swappable" and contain their calibration data in the probe proper thereby avaoiding the need to calibrate every time another probe is connected. The NEP160 (and its probes) comes supplied precalibrated however the user can calibrate a probe at any time using the simple menu driven interface. Both 2 and 3 point calibrations can be preformed.

Measurements can be read directly from the display at any time or downloaded to a computer/printer through the RS232 output at user selectable periodic intervals.

The ANALITE NEP160 will power up automatically to its last settings whenever external power is applied making it ideal for logging applications when using the analogue output or RS232 port.

The NEP160 comes complete in a convenient carry case. The carry case can accommodate a probe with a cable length of up to 10 meters, an ac adapter, the display unit, the RS232 cabling and the User Manual.

Turbidity Meter (a)

Specifications:

Range:	0 to 30,000NTU (3,000NTU limit on NEP260, 90° probe) over four ranges automatically determined.
Display:	2 line, 16-character dot matrix alphanumeric liquid crystal display.
Displayed:	Turbidity (NTU) - default Relative Turbidity Reference (NTU) Relative Turbidity REL (Turbidity - Relative Turbidity Reference) Date/Time - default
Reading:	Updated approximately every 1 second.
Averaging period:	0.5 second or 8 seconds nominal – user selectable.
Range Steps:	1 <0.1 to 20NTU 2 <1 to 200NTU 3 <10 to 2,000NTU 4 <100 to 20,000NTU
Resolution	1 0.02NTU 2 0.1NTU 3 1NTU 4 10NTU
Repeatability:	2% ± 1 digit on all ranges.
Data Logging:	User set for one reading every 1 to 90 seconds or minutes. All readings stored in the Notepad.
Notepad:	100 readings each with time and date.
Setup :	Menu driven, including: – Calibration – Automatic Logging – Analogue Output range selection – Reference Turbidity value – Setting date and time.
Setup Memory:	Non volatile EEPROM.
Clock:	Calendar clock displays date and time.
GLP:	Good Laboratory Practice. All readings as well as calibration constants are stored together with the Time and Date and can be recalled at any time.
Analogue Output:	0 – 2 volts full scale corresponding to preset measurement range. Output impedance 600 ohms nominal.
Power:	***Internal:*** 6V NiMH rechargeable battery. ***External:*** 10 to 16V dc, 400mA max. incl. NiMH Charge current. External power connection is via jack plug male with 2.5mm pin. Centre pin is NEGATIVE polarity.
Power Manag't:	Automatic power down perating from batteries after approx. 5 minutes may be selected. Automatic power up when powered externally. Continuous operation of at least 5 hours on a fully charged battery. For normal intermittent operation a full charge may last several days. Low battery indication prior to shut down.

Outputs:	Inbuilt LCD, analogue output and RS232 port.
RS232 Port :	The RS232 port can output readings on request or at preset intervals of time from 1 to 99 seconds or minutes. The Notepad memory can also be downloaded on request. 4800 baud rate, 8 bits, no parity, 1 stop bit, Xon/Xoff protocol.
Dimensions:	187mm x 110mm x 51mm (display unit). 238mm x 32mm dia (probes incl gland).
Weight:	Display Unit 0.5kg. 180° Probe 0.4kg with 5m lead. 90° Probe 0.4kg with 5m lead.
Operating Temp':	0° to 50°C. Operating -10° to 60°C Storage
Humidity:	0 to 90% R.H. operating
Case Rating:	IP65 with all connectors sealed with dust caps (supplied) or probe properly connected and dust caps on remaining two connectors.
Probe Rating:	100 meters water column.
Ordering Info:	
NEP160-1-05R	NEP160 with **NEP280** - 180° general purpose probe.
NEP160-2-05R	NEP160 with **NEP285** - 180° hi-temp probe.
NEP160-3-05R	NEP160 with **NEP260** - ISO7027 90° probe.
NEP160R	Display unit only.

All probes are supplied with 5 meters of cable unless otherwise indicated at time of order.

Specifications subject to change without notice.
File: NEP160 Series Brochure Mar 2004.indd

Turbidity Meter (b)

Appendix 4 Hydromulch Manufacturer Specifications

HYDROSTRAW® BONDED FIBER MATRIX - CERTIFICATE OF COMPLIANCE

CERTIFICATE OF COMPLIANCE

Patents Pending

Manufacturer: HydroStraw, LLC · 3676 W 9000N Rd · Manteno, IL 60950
Toll Free: 800-545-1755 · Fax: 815-468-7450 · www.hydrostraw.com · info@hydrostraw.com

HydroStraw, LLC certifies that HydroStraw® BFM contains the following properties and characteristics

DESCRIPTION-
HydroStraw® Bonded Fiber Matrix is designed to be more cost effective than blankets and cost less to apply per acre than conventional BFM mulches on difficult sites, slopes and adverse soil conditions where extra erosion prevention is needed.

The product includes long natural fibers for maximum matrix entanglement for improved performance.

The combination of fiber entanglement in conjunction with our cross linked high-strength polymer binders produce great erosion prevention and vegetation establishment.

HydroStraw® Bonded Fiber Matrix in field tests has shown that the annually renewable heat and mechanically treated straw fibers in this product improves seeds germination and vegetation establishment. Research has shown that vegetation is many times better than temporary mulches in erosion prevention. Thereby the ultimate goal is creating an environment for rapid vegetation establishment with seed friendly straw fibers.

HydroStraw® Bonded Fiber Matrix consists of annually renewable heat and mechanically treated straw fibers, environmentally safe, fibers that are biodegradable and a non-toxic green colorant to aid in application.

Field tests have shown HydroStraw® mulch protects soil and enhances seed germination and vegetation establishment as the fibers bio-degrades. (V.E.M. Vegetation Establishment Mulch)

Physical Characteristics	
Toxicity	Non-Toxic
Applied Color	Green
Sufrace Tension	Material will evenly disperse and suspend when agitated in water
Absorbancy	When sprayed uniformly at the recommended rate, the mulch fibers form an absorbent mulch cover which will allow percolation of water and increased water infiltration to the underlying soil matrix
Solubility	Mulch Fibers are non water soluble
PH	06.8 +/- 0.5
Average Fiber Length	1/2" +/- 1/4"

Packaging and Shipping Data	
Bag Size	11.5" x 17" x 25"
Bag Weight	50 lbs. - Compressed Bales
Pallet	40 bags (52W x 45D x 96H)
Full Truck	22 Pallets, 880 Bales
Packaging	Moisture resistant packaging

Composition	
Heat & Mechanically Treated Straw Fibers™ (HMT™)	67.0% +/- 1.0%
Cellulose Paper Mulch	2.5% +/- 1.0%
Natural Fibers for Matrix Entanglement	10% +/- 1.0%
Proprietary Tackifiers	10% +/- 1.0%
Moisture Content	10.5% +/- 1.5%

Mixture Rates	
Hose Work	60 lbs per 100 gallons
Tower Work	75 lbs per 100 gallons

WARRANTY
HydroStraw, LLC warrants that its products are free from defects and will perform as stated in this literature. If our product does not meet products specifications, notice of failure must be received within 15 days of failure. HydroStraw, LLC will not warrant that the product will perform under unlimited circumstances that are caused by soil conditions, installation, and/or weather variables.

Slope Gradient/Condition	lb/acre
≤ 3:1	3,000 lbs/ac
≤ 2:1	3,500 lbs/ac
≤ 1:1	4,500 lbs/ac
Soil Moisture Retention	2,000 - 3,500 lbs/ac

HydroStraw® BFM Specifications

NORTH AMERICAN GREEN
A tensar Company

MATERIAL SPECIFICATION

HydraCX^2

Extreme Slope Matrix

The North American Green HydraCX^2 Extreme Slope Matrix shall be a hydraulically-applied matrix composed of a patent-pending blend of mechanically processed straw fibers, reclaimed cotton plant material, performance-enhancing tackifiers, and other proprietary additives. The HydraCX^2 requires no curing for soil erosion protection, and establishes an intimate bond upon application with the soil's surface to create a continuous, porous, absorbent and flexible erosion control matrix that allows for rapid germination and accelerated plant growth. The HydraCX^2 mulch is biodegradable and consists of approximately 90% organic matter.

The all natural fiber mulch shall satisfy the control performance criteria set forth in the Ceriodaphnia dubia, Daphnia magna and Pimephales promelas tests as described in EPA documentation (USEPA 2002) and the Region VIII NPDES Whole Effluent Toxics Control Program (EPA Region VIII 1997); therefore illustrating no significant toxicity for the mulch.

Composition:

All components of the HydraCX^2 mulch shall be pre-packaged by the Manufacturer to assure material performance and in compliance with the following values. **Under no circumstances will field mixing of additives or components be accepted.**

Mechanically processed Straw – 65% ± 3%
Mechanically processed Reclaimed Cotton Plant Material– 25 % ± 3%
Proprietary Hydro-Colloid Tackifiers and Activators – 10% ± 1%

Specifications:

Content: Straw/Reclaimed Cotton Plant Material
Packaging: 50 lbs (23 kg) +/- 3%
Total Organic Matter: 90.0
Carbon to Nitrogen Ratio: 38:1*
Moisture Content: 12% ± 3%
Color: Natural Green

* Analysis concluded from a representative sample as the C:N Ratio may vary from sample to sample.

Packaging:

Bags are filled with 50 lbs (23 kg) of material and packaged in a UV and weather-resistant bag. Each pallet contains 40 bags or one ton with a plastic pallet cover for enhanced protection from rain and UV rays.

Manufacturing:

HydraCX^2 is manufactured exclusively for North American Green by Mulch & Seed Innovations, LLC, Centre, Alabama. HydraCX^2 is manufactured within a set of quality guidelines established after years of product development and rigorous testing in varying conditions.

Application Instructions*:

1. Fill tank of a mechanically agitated hydroseeding machine with sufficient water to suspend seed and fertilizers. Add soil amendments.
2. Continue to add water slowly while adding HydraCX2 at a steady rate. Use loading chart to determine the proper application rates. Mix at a rate of 50 lbs of HydraCX2 per 100 gallons of water.
3. Agitate for a minimum of 10 minutes after adding the last amount of water and HydraCX2.
4. Apply in a uniform layer from 2 opposing directions to ensure complete soil coverage. Irregular surfaces may need slightly higher application rates to obtain adequate coverage.
5. Clean equipment properly to ensure HydraCX2 is removed from the pump, tank, and hoses.

Not for use in channels, swales, or other areas where concentrated flows are anticipated, unless installed in conjunction with a temporary erosion control blanket or permanent reinforcement mat. HydraCX2 may be applied on saturated surfaces.
Do not allow foot traffic or grazing on treated areas until vegetated. Be cautious of slippery surfaces while applying.
Warning: Do not store near an open flame or heat source. Use caution when stacking units.
* See installation guide for more detailed information regarding application of the HydraCX^2

Updated 10/2008

HydraCX^2 Specifications

MATERIAL SPECIFICATION

GeoSkin®

Straw & Cotton Plant Material Hydromulch

The North American Green GeoSkin® Straw & Reclaimed Cotton Plant Material Hydromulch shall be hydraulically-applied mulch composed of a patent-pending blend of mechanically processed straw fibers, reclaimed cotton plant materials, performance-enhancing tackifiers, and other proprietary additives. GeoSkin hydromulch protects from erosion, and begins establishing an intimate bond upon application with the soil's surface to create a continuous, porous and absorbent mulch layer that allows for rapid germination and accelerated plant growth.

Composition:
All components of GeoSkin hydromulch shall be pre-packaged by the Manufacturer to assure material performance and compliance with the following values.

Mechanically Processed Straw – 84% ± 3%
Mechanically Processed Reclaimed Cotton Plant Material – 15% ± 3%
Proprietary Blend of Tackifiers, Activators and Additives < 1%

Specifications:
Content: Straw/Reclaimed Cotton Plant Materials
Total Organic Matter: 90.0
Moisture Content: 12% ± 3%
Packaging: 50 lbs (23 kg) +/- 3%
Carbon to Nitrogen Ratio: approximately 40:1
Color: Natural Green

Packaging:
Bags are filled with 50 lbs (23 kg) of material and packaged in a UV and weather-resistant bag. Each pallet contains 40 bags and weighs one ton. All pallets have a plastic pallet cover for enhanced protection from rain and UV rays.

Application Instructions:

1. Fill tank of a mechanically agitated hydroseeding machine with sufficient water to suspend seed and fertilizers. Add seed and soil amendments.
2. Continue to add water slowly while adding GeoSkin hydromulch at a steady rate. Use the loading chart to determine the proper application rates. Mix at a rate of 50 lbs of GeoSkin hydromulch per 100 gallons of water.
3. Agitate for a minimum of 10 minutes after adding the last amount of water and GeoSkin hydromulch.
4. Apply in a uniform layer from 2 opposing directions to ensure complete soil coverage. Irregular surfaces may need slightly higher application rates to obtain adequate coverage.
5. Clean equipment properly after application to ensure GeoSkin hydromulch is removed from the pump, tank and hoses.

Typical Application Rates		
Slope Conditions	Rate (English)	Rate (SI)
≤ 4:1	1,500 lbs/acre	1,700 kg/ha
> 4:1 ≤ 3:1	2,000 lbs/acre	2,250 kg/ha

*Refer to the GeoSkin® Series Application Chart found on mulchandseed.com for site-specific recommendations based on slope gradient and length.

Not for use in channels, swales, or other areas where concentrated flows are anticipated, unless installed in conjunction with a temporary erosion control blanket or permanent turf reinforcement mat. GeoSkin hydromulch may be applied on saturated surfaces. Do not allow foot traffic or grazing on treated areas until vegetated. Be cautious of slippery surfaces while applying.

Warning: Do not store near an open flame or heat source. Use caution when stacking units.

GeoSkin® Specifications

American
Excelsior
Company®
Earth Science Division

Excel® Fibermulch II
Hydraulic Mulch

Packaging

Excel Fibermulch II is available in 50 lb polyethylene bags and is palletized for applicator convenience.

Suggested Specifications

Fiber:
Great Lake Aspen (naturally seed free)

Fiber Length:
25% or more of fibers ≥ 0.40" (10.2 mm) long,
75% of fibers retained on #28 sieve

Moisture Content:
10% ± 3%

pH:
5.4 ± 0.1

Organic Matter:
99.3% ± 0.2

Ash Content:
0.7% ± 0.2

Water Holding Capacity:
1401% ± 10%

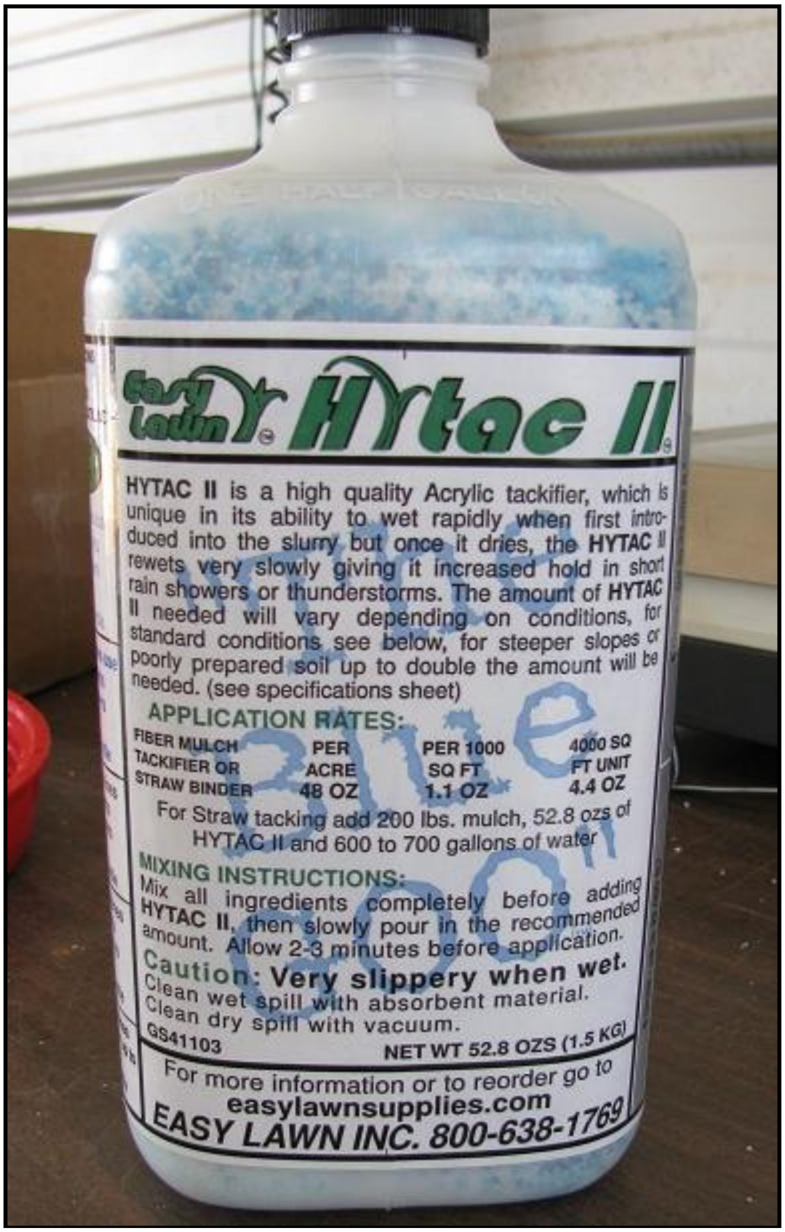
Installation

Before hydraulically applying Excel Fibermulch II, the finished grade 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. The contractor shall proceed when all satisfactory conditions are present. Each 50 lb bag of Excel Fibermulch II should be mixed with approximately 100 gallons of water and applied at a rate of 2,000 - 2,500 lb/acre. Mixing and application rates shall always be matched to project-specific specifications. Dri-Water Hydro mix tackifier (optional) and/or green tracer dye (optional) shall be mixed with water in tank of before being applied. Apply Excel Fibermulch II in multiple directions for best coverage results.

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

Excel® Fibermulch II Specifications



Hytac II Acrylic Tackifier

Appendix 5 Hydromulch Experimentation

EXCEL® FIBERMULCH II

Post-Application of Excel® Fibermulch II (a)

Post-Application of Excel® Fibermulch II (b)

EXCEL® FIBERMULCH II

Post-48 hour Drying Period

Post-Experimentation (2yr, 24 hr storm)

GEOSKIN®

Post-Application of GeoSkin® (a)

Post-Application of GeoSkin® (b)

GEOSKIN®

Post-48 hour Drying Period

Post-Experimentation (2yr, 24 hr storm)

HYDRACX^2®

Post-Application of HydraCX^2®

48-hr Drying Period

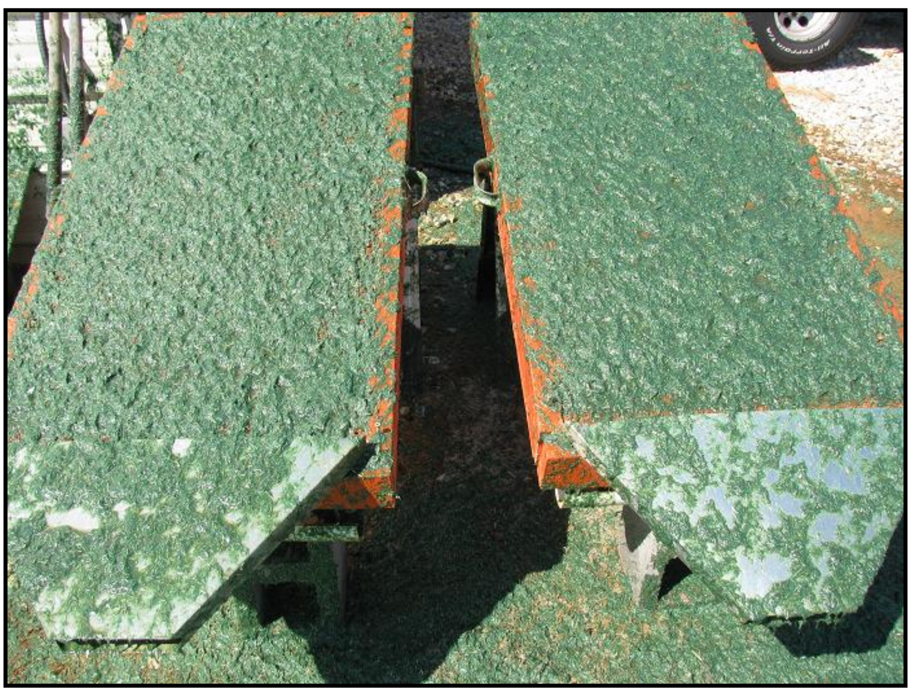
HYDRACX^2®

Post-48 hour Drying Period

Post-Experimentation (2yr, 24 hr storm)

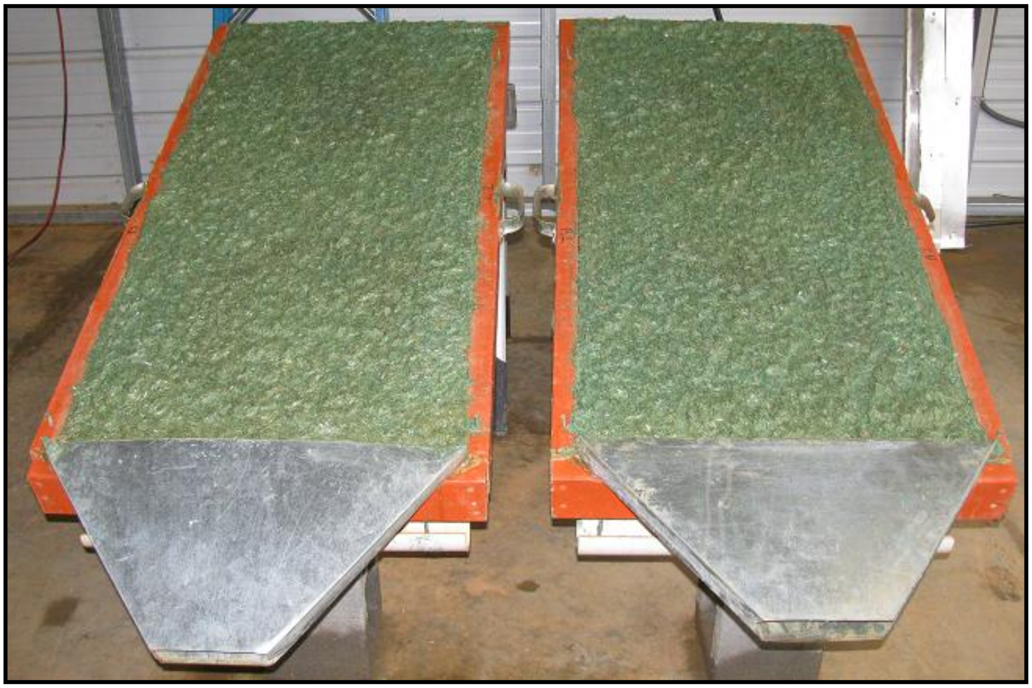
HYDROSTRAW® BFM

Post-Application of HydroStraw® BFM (a)



Post-Application of HydroStraw® BFM (b)

HYDROSTRAW® BFM

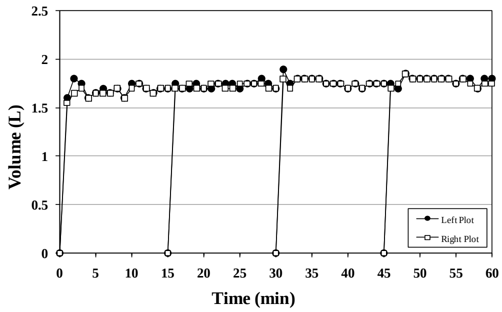


Post-48 hour Drying Period

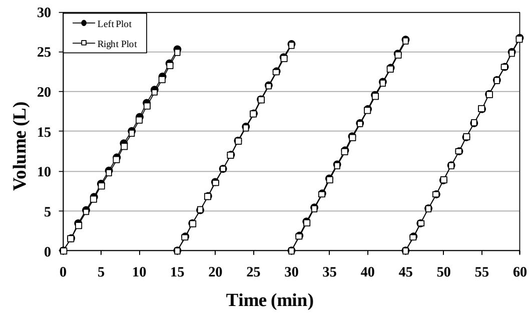
Post-Experimentation (2yr, 24 hr storm)

Appendix 6 Experimental Results

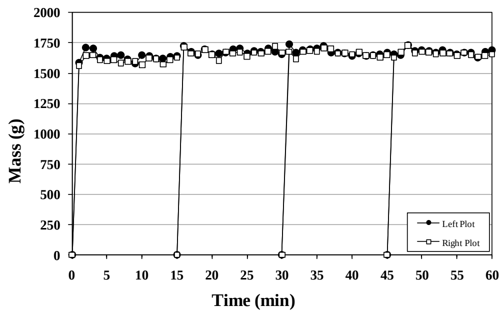
BARE SOIL (CONTROL) CONDITION
(AVERAGE DATA FROM EXPERIMENT 1 & 2)



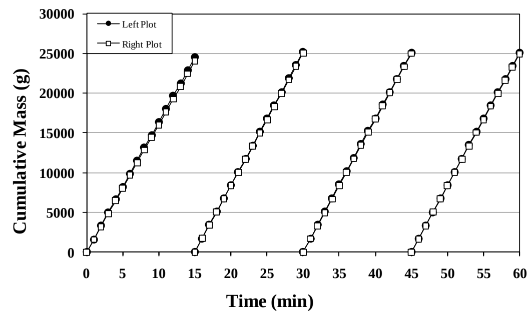
(a) Runoff Volume



(b) Cumulative Runoff Volume

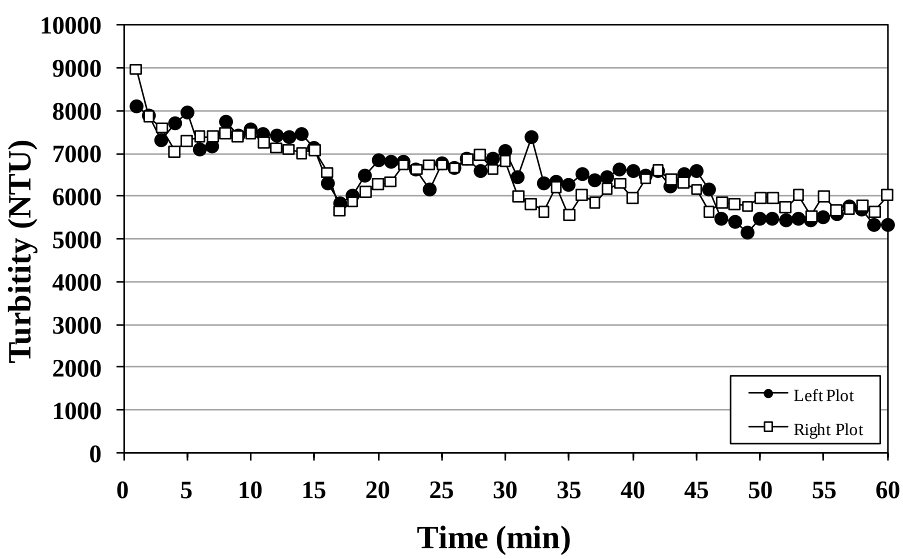


(c) Runoff Mass

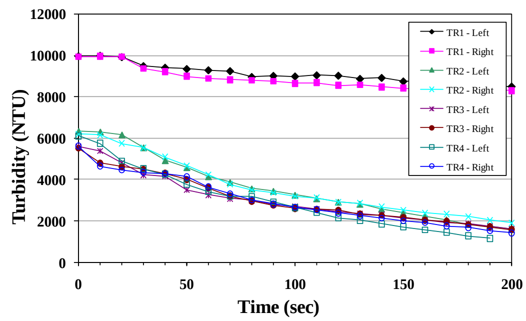


(d) Cumulative Runoff Mass

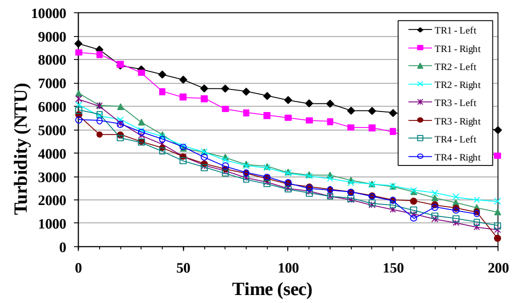
Surface Runoff Measurements vs. Time.



Surface Runoff Initial Turbidity vs. Time.

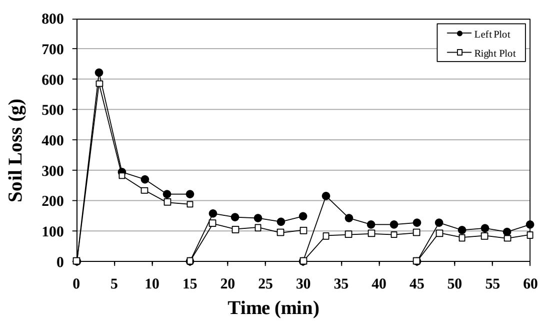


(a) Turbidity vs. Time at 5 Minutes

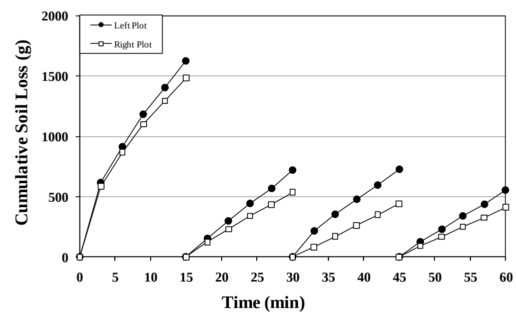


(b) Turbidity vs. Time at 10 Minutes

Turbidity vs. Time for Samples Collected at 5 and 10 Minutes.



(a) Soil Loss vs. Time

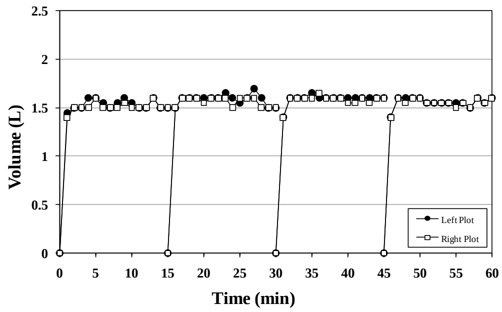


(b) Cumulative Soil Loss vs. Time

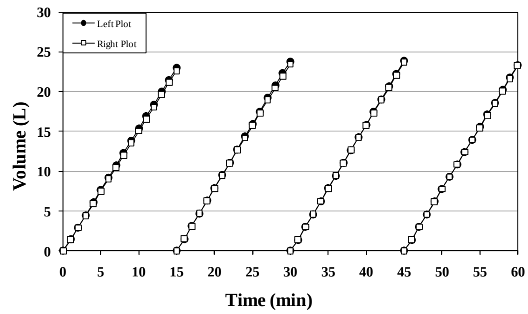
Soil Loss and Cumulative Soil Loss vs. Time.

Bare Soil Conditions, Post-Experimentation.

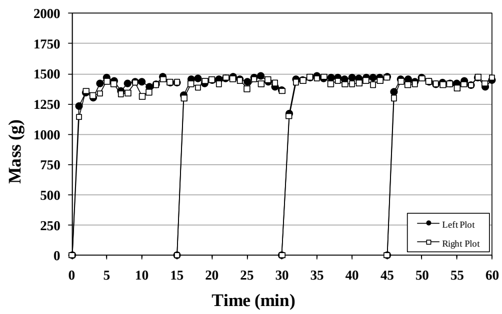
CONVENTIONAL STRAW, CRIMPED
(AVERAGE DATA FROM EXPERIMENT 3 & 4)



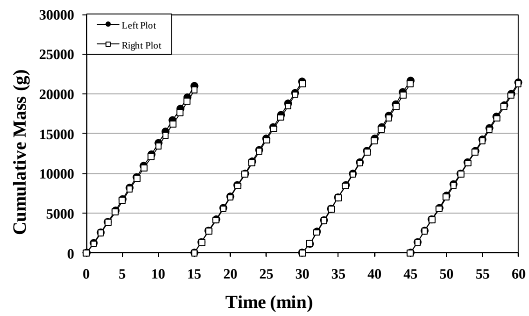
(a) Runoff Volume



(b) Cumulative Runoff Volume

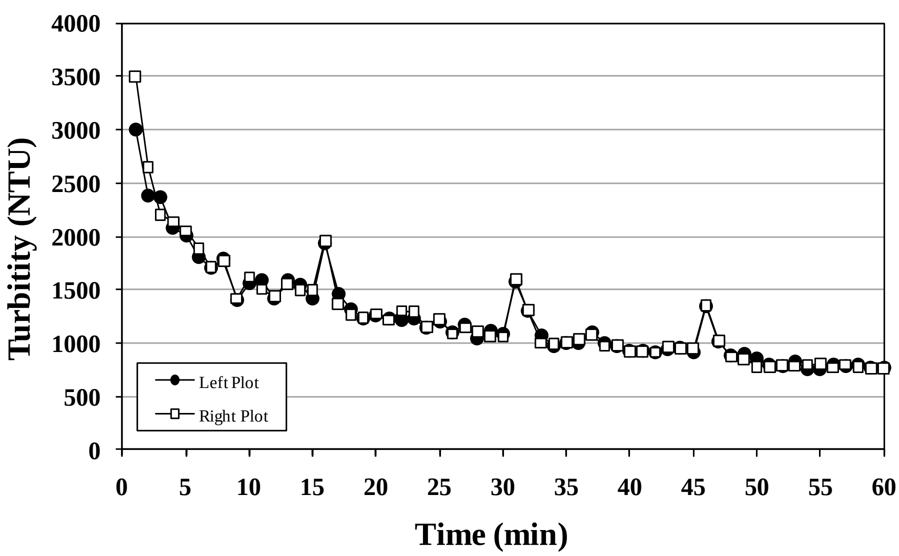


(c) Runoff Mass

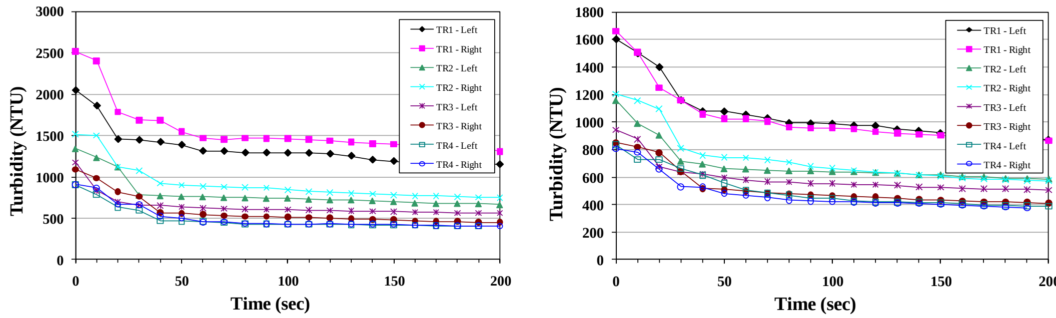


(d) Cumulative Runoff Mass

Surface Runoff Measurements vs. Time.

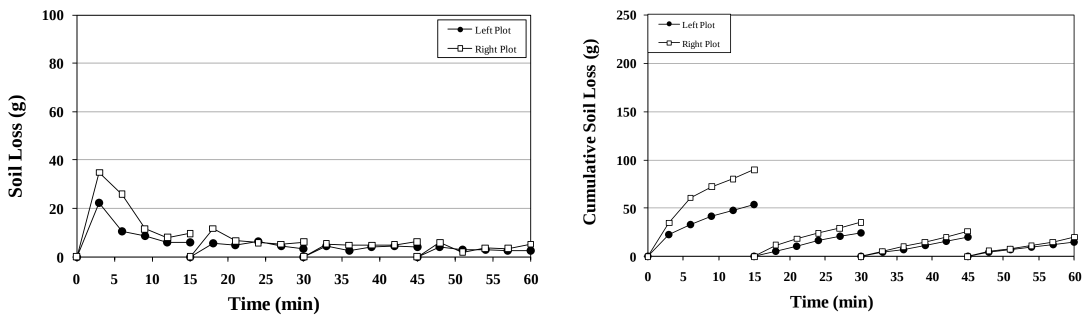


Surface Runoff Initial Turbidity vs. Time.



(a) Turbidity vs. Time at 5 Minutes **(b) Turbidity vs. Time at 10 Minutes**

Turbidity vs. Time for Samples Collected at 5 and 10 Minutes.

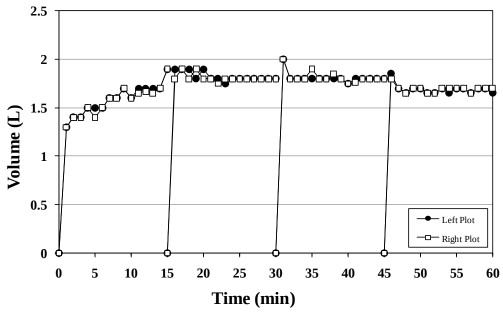


(a) Soil Loss vs. Time **(b) Cumulative Soil Loss vs. Time**

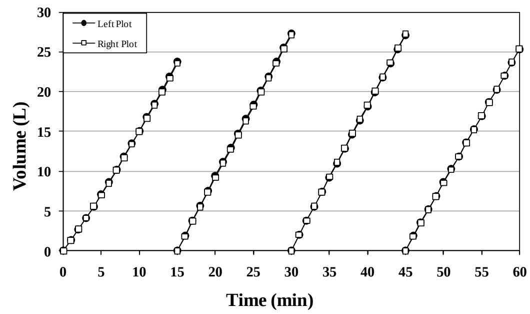
Soil Loss and Cumulative Soil Loss vs. Time.

Conventional Straw, Crimped, Post-Experimentation.

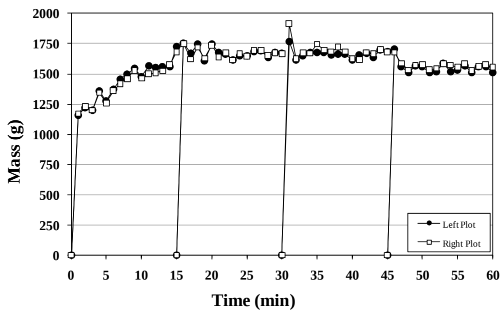
CONVENTIONAL STRAW, TACKIFIED
(AVERAGE DATA FROM EXPERIMENT 5 & 6)



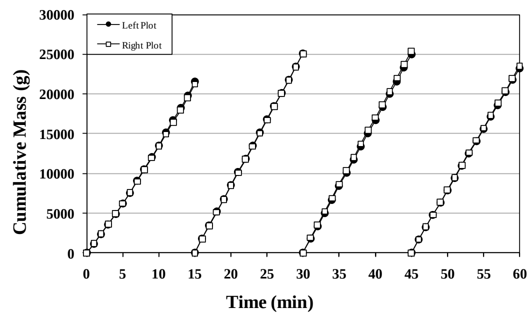
(a) Runoff Volume



(b) Cumulative Runoff Volume

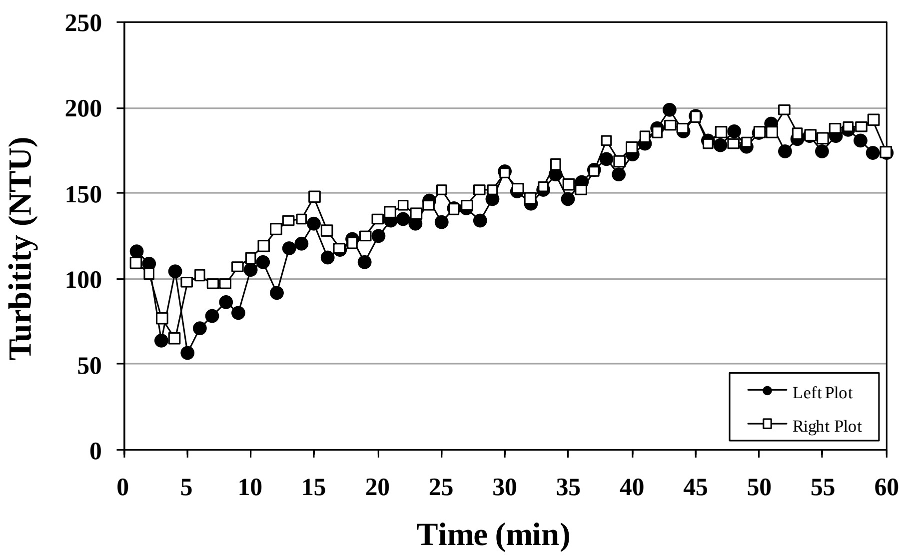


(c) Runoff Mass

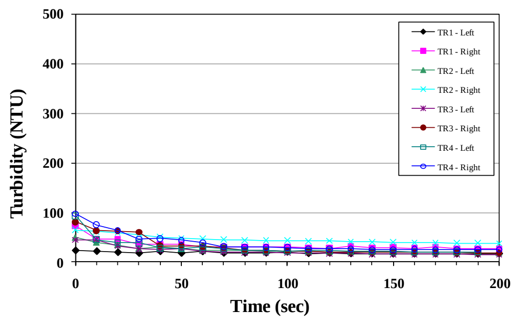


(d) Cumulative Runoff Mass

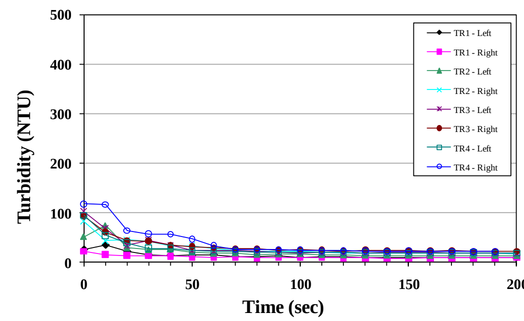
Surface Runoff Measurements vs. Time.



Surface Runoff Initial Turbidity vs. Time.

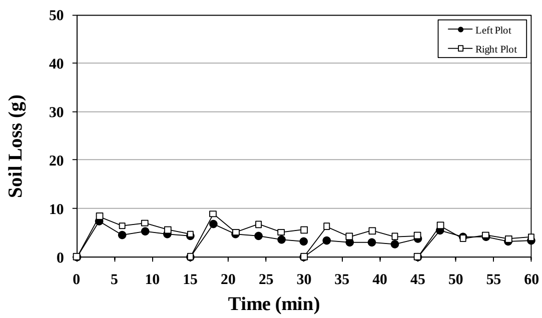


(a) Turbidity vs. Time at 5 Minutes

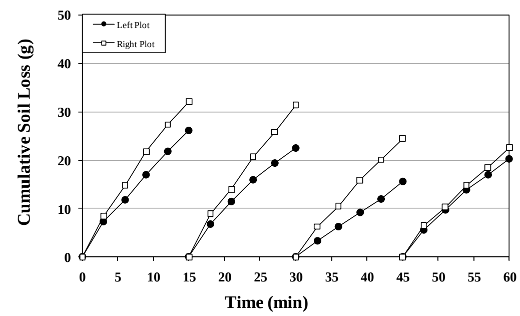


(b) Turbidity vs. Time at 10 Minutes

Turbidity vs. Time for Samples Collected at 5 and 10 Minutes.



(a) Soil Loss vs. Time

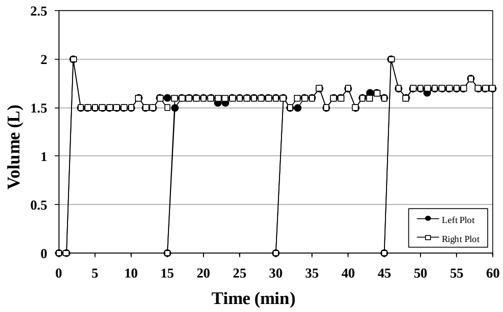


(b) Cumulative Soil Loss vs. Time

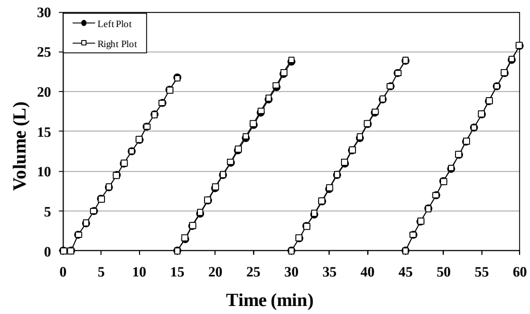
Soil Loss and Cumulative Soil Loss vs. Time.

Conventional Straw w/Tackifier, Post-Experimentation.

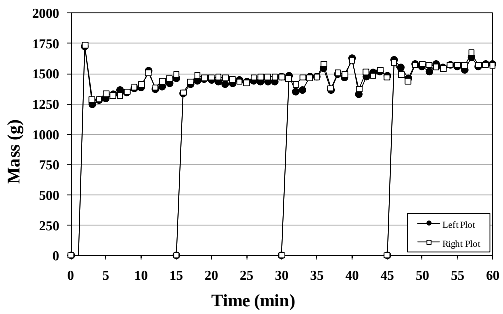
EXCEL® FIBERMULCH II
(AVERAGE DATA FROM EXPERIMENT 7 & 8)



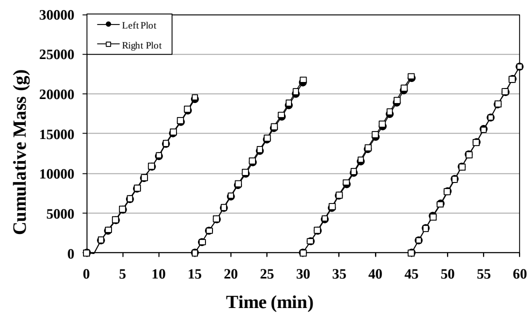
(a) Runoff Volume



(b) Cumulative Runoff Volume

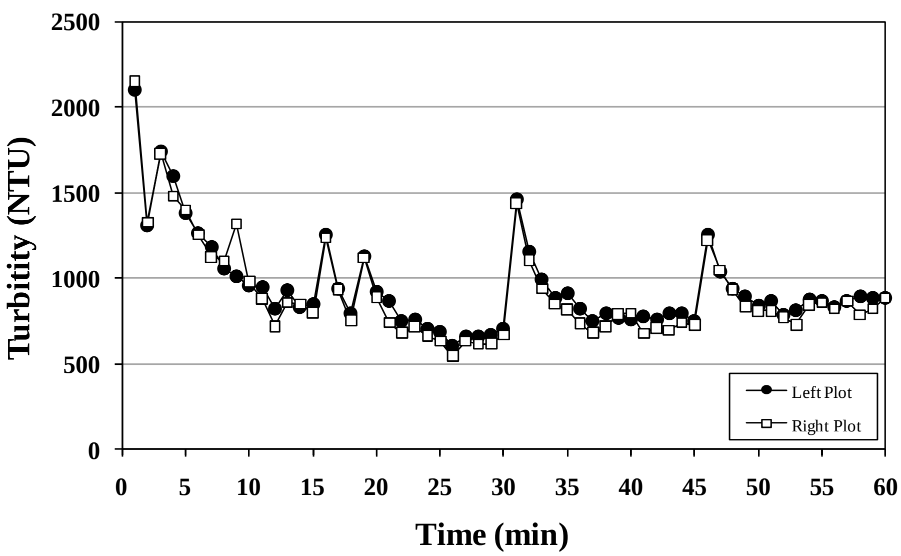


(c) Runoff Mass

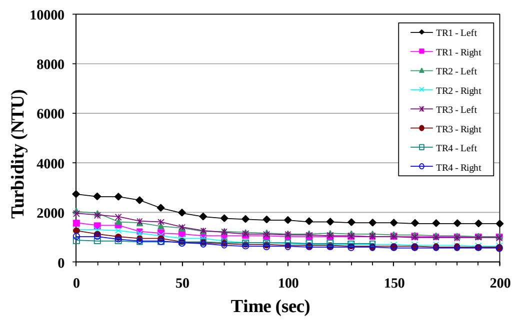


(d) Cumulative Runoff Mass

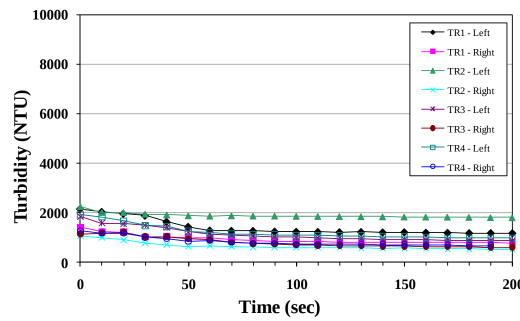
Surface Runoff Measurements vs. Time.



Surface Runoff Initial Turbidity vs. Time.

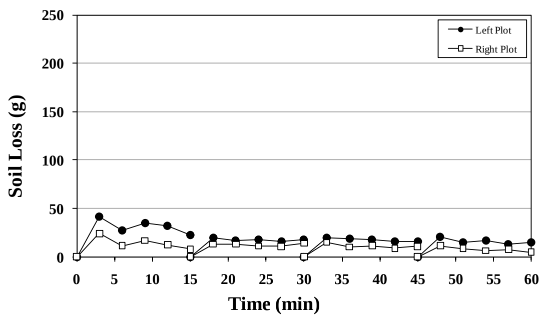


(a) Turbidity vs. Time at 5 Minutes

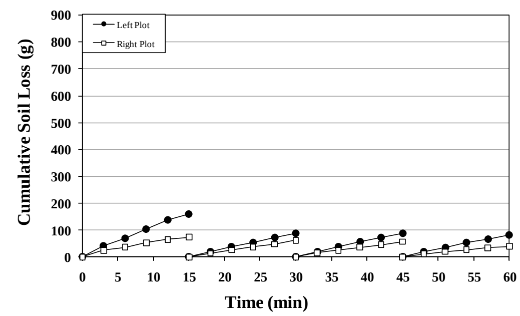


(b) Turbidity vs. Time at 10 Minutes

Turbidity vs. Time for Samples Collected at 5 and 10 Minutes.

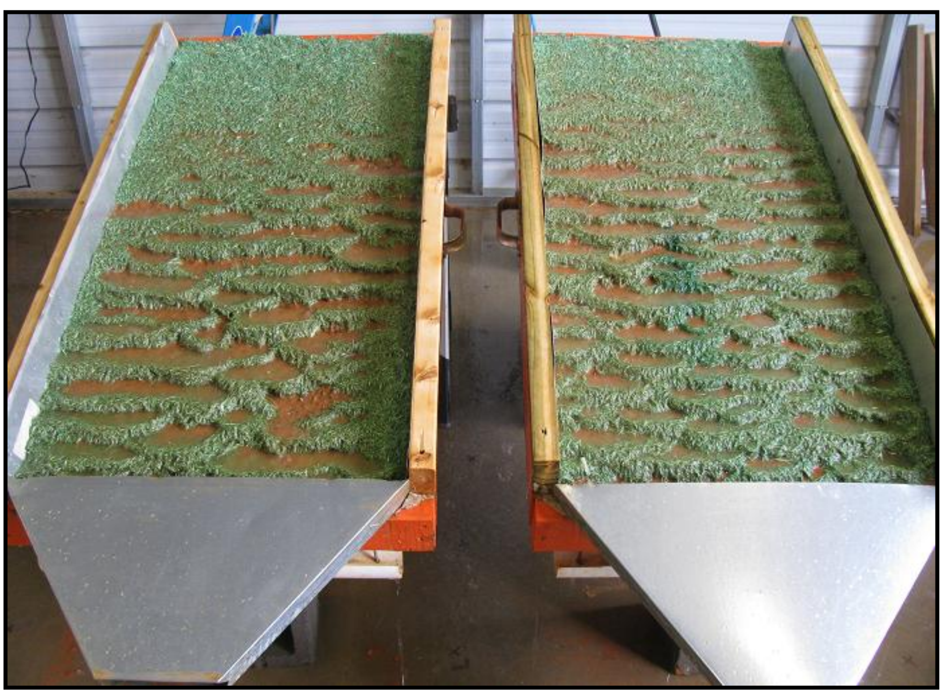


(a) Soil Loss vs. Time



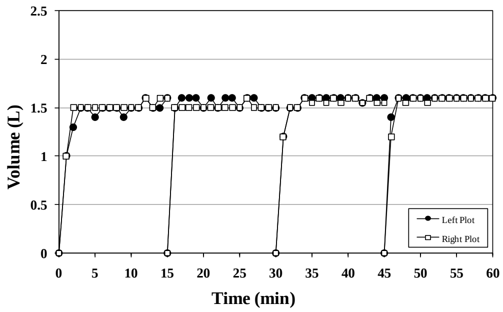
(b) Cumulative Soil Loss vs. Time

Soil Loss and Cumulative Soil Loss vs. Time.

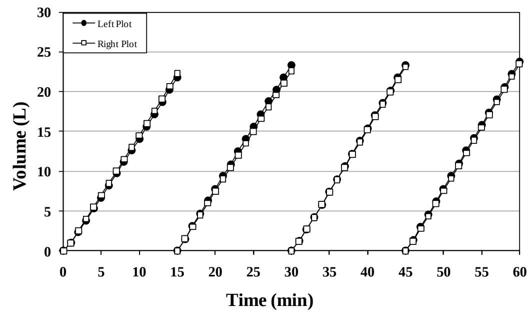


Excel® Fibermulch II, Post-Experimentation.

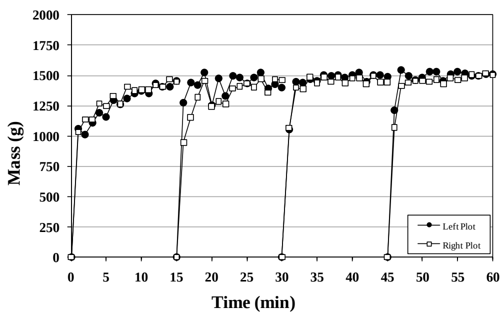
GEOSKIN®
(AVERAGE DATA FROM EXPERIMENT 9 & 10)



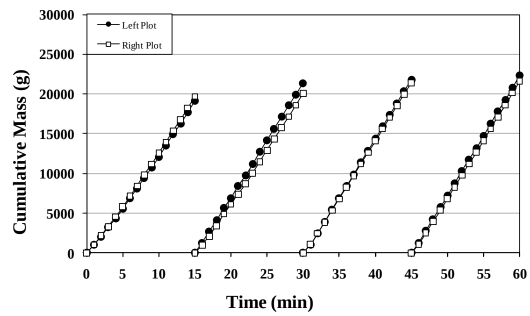
(a) Runoff Volume



(b) Cumulative Runoff Volume

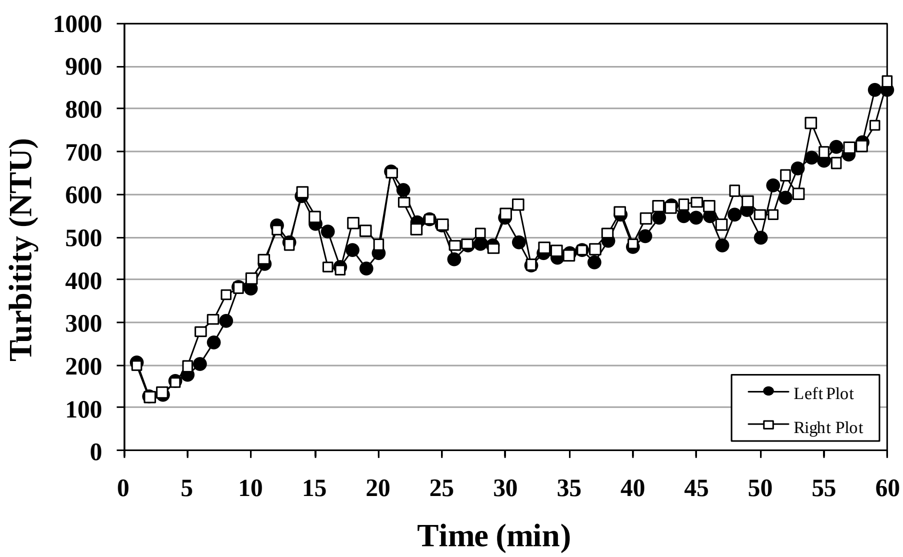


(c) Runoff Mass

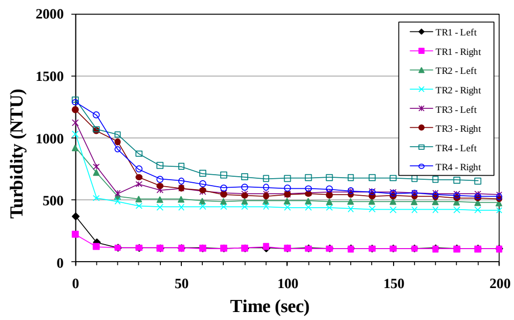


(d) Cumulative Runoff Mass

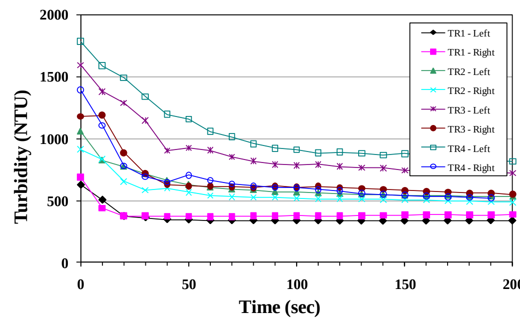
Surface Runoff Measurements vs. Time.



Surface Runoff Initial Turbidity vs. Time.

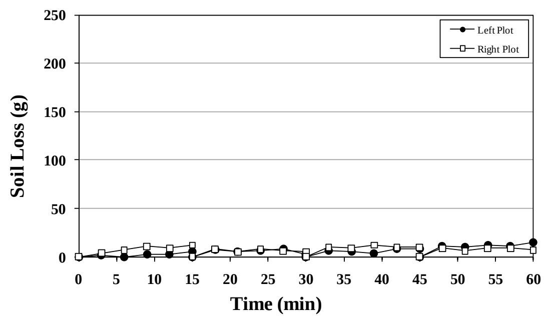


(a) Turbidity vs. Time at 5 Minutes

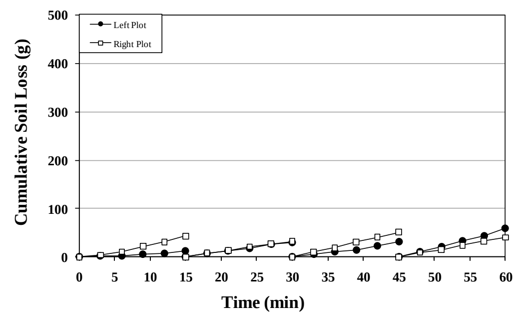


(b) Turbidity vs. Time at 10 Minutes

Turbidity vs. Time for Samples Collected at 5 and 10 Minutes.



(a) Soil Loss vs. Time

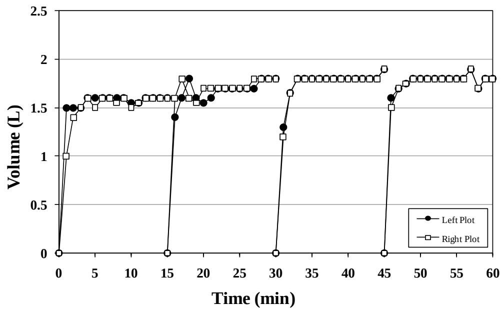


(b) Cumulative Soil Loss vs. Time

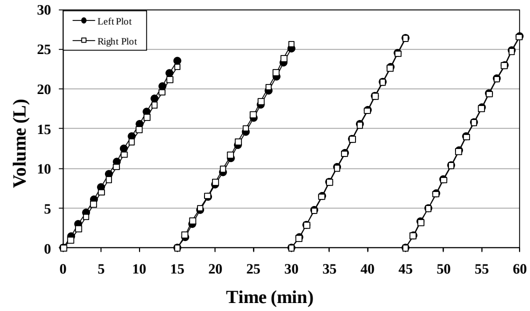
Soil Loss and Cumulative Soil Loss vs. Time.

GeoSkin®, Post-Experimentation.

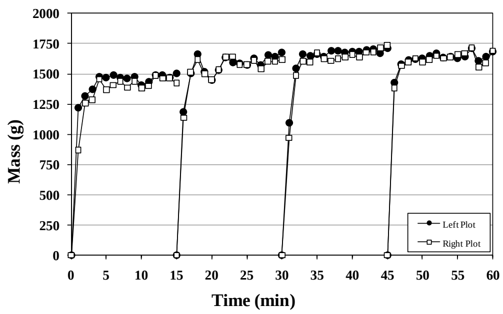
HYDRACX^2®
(AVERAGE DATA FROM EXPERIMENT 11 & 12)



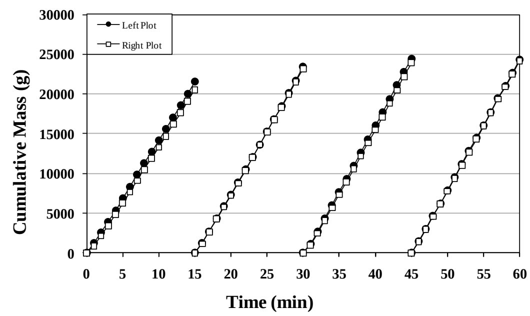
(a) Runoff Volume



(b) Cumulative Runoff Volume

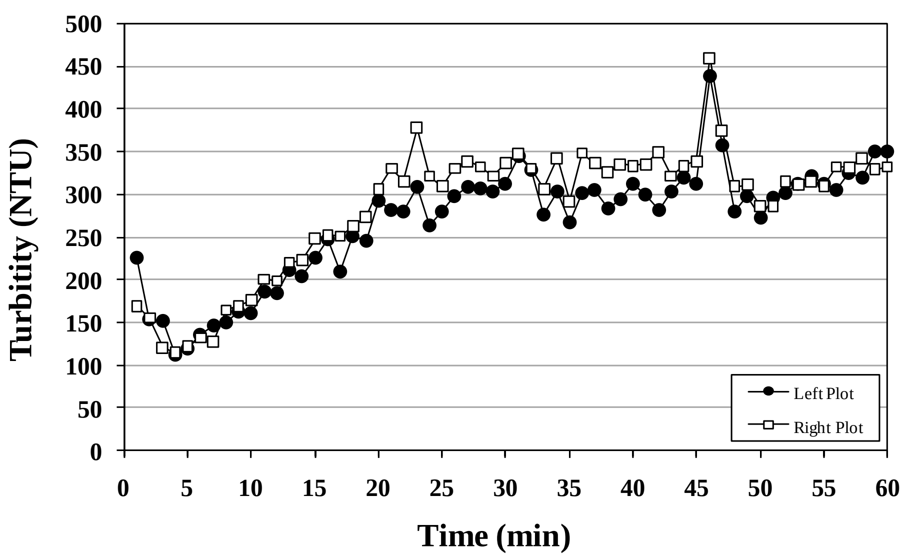


(c) Runoff Mass

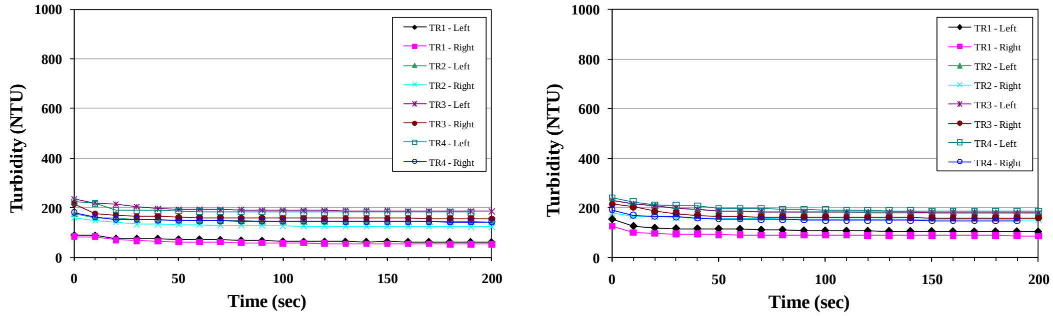


(d) Cumulative Runoff Mass

Surface Runoff Measurements vs. Time.

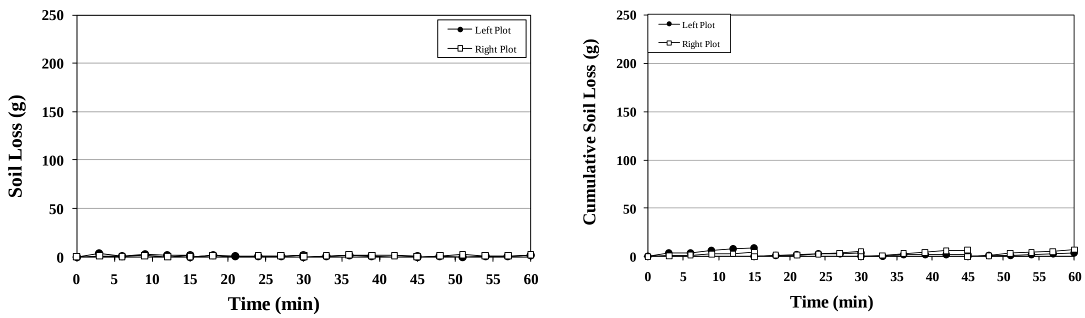


Surface Runoff Initial Turbidity vs. Time.



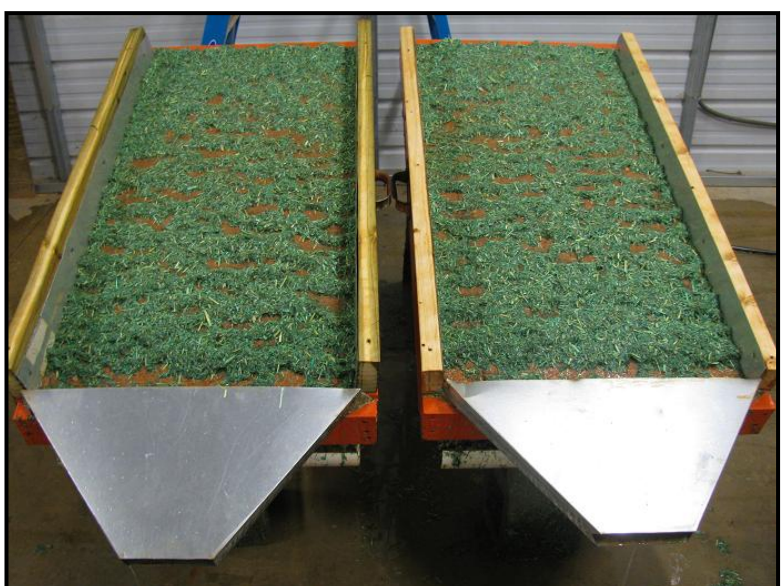
(a) Turbidity vs. Time at 5 Minutes **(b) Turbidity vs. Time at 10 Minutes**

Turbidity vs. Time for Samples Collected at 5 and 10 Minutes.



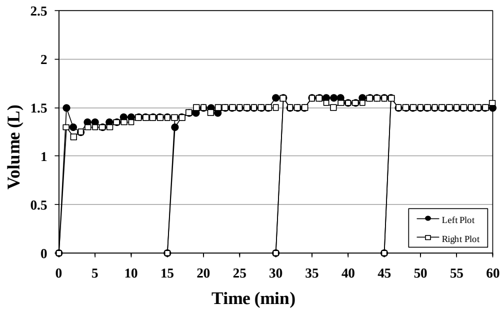
(a) Soil Loss vs. Time **(b) Cumulative Soil Loss vs. Time**

Soil Loss and Cumulative Soil Loss vs. Time.

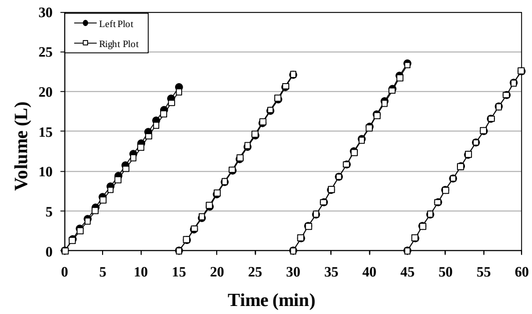


HydraCX^2®, Post-Experimentation.

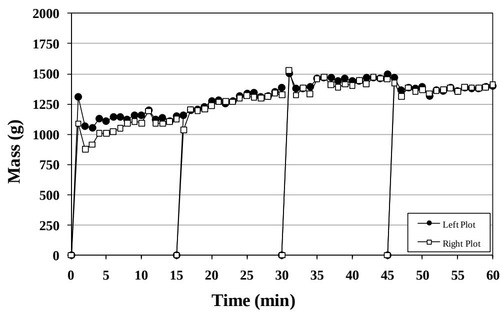
HydroStraw® BFM
(AVERAGE DATA FROM EXPERIMENT 13 & 14)



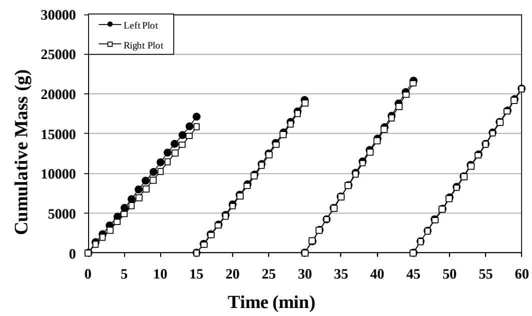
(a) Runoff Volume



(b) Cumulative Runoff Volume

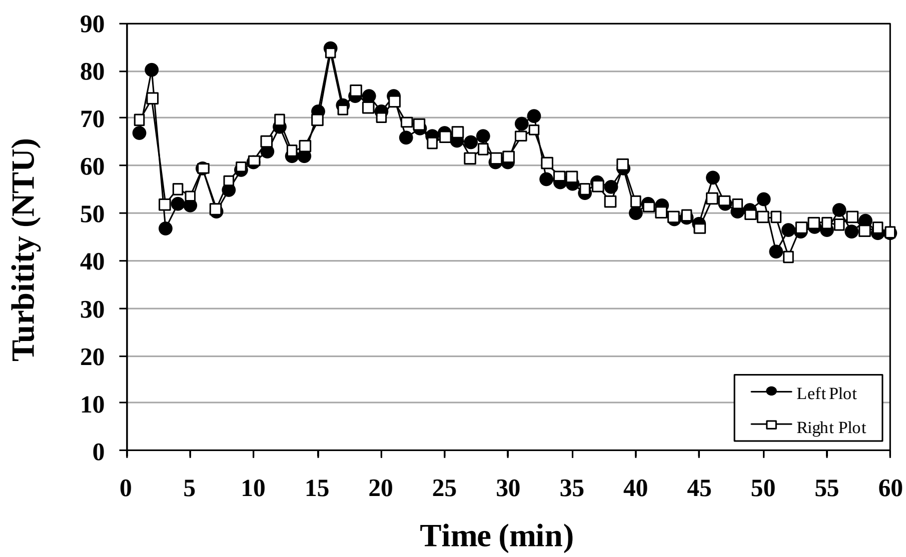


(c) Runoff Mass

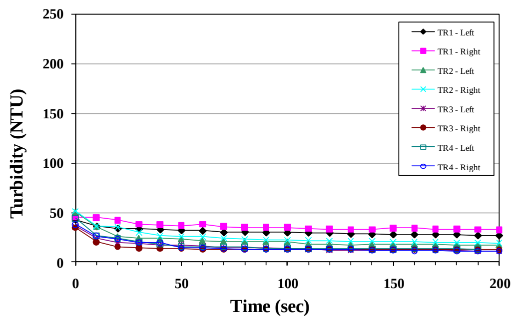


(d) Cumulative Runoff Mass

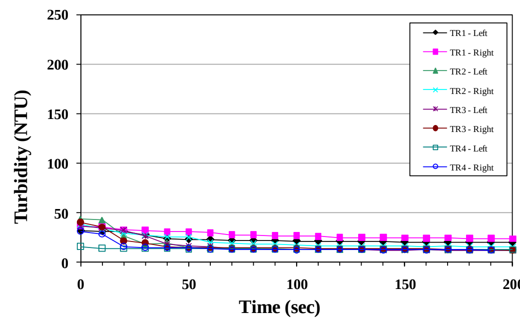
Surface Runoff Measurements vs. Time.



Surface Runoff Initial Turbidity vs. Time.

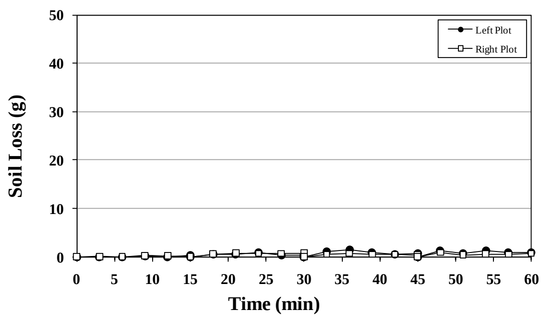


(a) Turbidity vs. Time at 5 Minutes

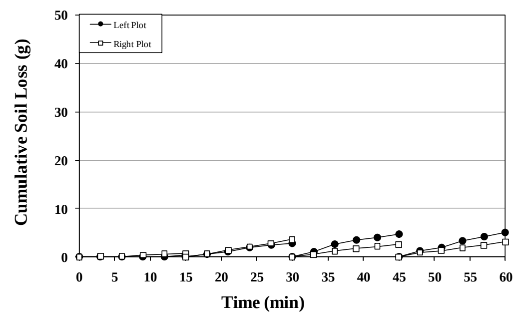


(b) Turbidity vs. Time at 10 Minutes

Turbidity vs. Time for Samples Collected at 5 and 10 Minutes.



(a) Soil Loss vs. Time



(b) Cumulative Soil Loss vs. Time

Soil Loss and Cumulative Soil Loss vs. Time.

HydroStraw® BFM, Post-Experimentation.

Appendix 7 Statistical Analysis

Tukey-Kramer Multiple Comparisons on Average Initial Turbidity [*Test 1*]

Comparison	$\mu_i - \mu_j$	CI [LB]	CI [UB]	Significantly Different
Control vs. GeoSkin	6640	6351	6929	Yes
Control vs. Straw, Crimped	5155	4866	5444	Yes
Control vs.HydraCX^2	6806	6518	7095	Yes
Control vs. Excel Fibermulch II	5777	5489	6066	Yes
Control vs. HydroStraw BFM	6914	6625	7203	Yes
Control vs. Straw, Tackified	6873	6584	7162	Yes
GeoSkin vs. Straw, Crimped	1485	1197	1774	Yes
GeoSkin vs. HydraCX^2	166	-123	455	No
GeoSkin vs. Excel Fibermulch II	863	574	1152	Yes
GeoSkin vs. HydroStraw BFM	274	-15	563	No
GeoSkin vs. Straw, Tackified	232	-56	521	No
Straw, Crimped vs. HydraCX^2	1652	1363	1940	Yes
Straw, Crimped vs. Excel Fibermulch II	623	334	911	Yes
Straw, Crimped vs. HydroStraw BFM	1759	1470	2048	Yes
Straw, Crimped vs. Straw, Tackified	1718	1429	2007	Yes
HydraCX^2 vs. Excel Fibermulch II	1029	740	1318	Yes
HydraCX^2 vs. HydroStraw BFM	108	-181	397	No
HydraCX^2 vs. Straw, Tackified	66	-222	355	No
Excel Fibermulch II vs. HydroStraw BFM	1137	848	1426	Yes
Excel Fibermulch II vs. Straw, Tackified	1095	807	1384	Yes
HydroStraw BFM vs. Straw, Tackified	41	-247	330	No

Notes: [LB] signifies lower bound of confidence interval
[UB] signifies upper bound of confidence interval
$q_{crit} = 4.28$

Tukey-Kramer Multiple Comparisons on Average Initial Turbidity [*Test 2*]

Comparison	$\mu_i - \mu_j$	CI [LB]	CI [UB]	Significantly Different
Control vs. GeoSkin	5541	5391	5691	Yes
Control vs. Straw, Crimped	4795	4645	4945	Yes
Control vs.HydraCX^2	5757	5607	5907	Yes
Control vs. Excel Fibermulch II	5267	5117	5416	Yes
Control vs. HydroStraw BFM	5983	5833	6133	Yes
Control vs. Straw, Tackified	5916	5766	6065	Yes
GeoSkin vs. Straw, Crimped	746	596	896	Yes
GeoSkin vs. HydraCX^2	216	66	365	Yes
GeoSkin vs. Excel Fibermulch II	275	125	424	Yes
GeoSkin vs. HydroStraw BFM	441	292	591	Yes
GeoSkin vs. Straw, Tackified	374	224	524	Yes
Straw, Crimped vs. HydraCX^2	962	812	1112	Yes
Straw, Crimped vs. Excel Fibermulch II	471	322	621	Yes
Straw, Crimped vs. HydroStraw BFM	1188	1038	1337	Yes
Straw, Crimped vs. Straw, Tackified	1120	971	1270	Yes
HydraCX^2 vs. Excel Fibermulch II	490	340	640	Yes
HydraCX^2 vs. HydroStraw BFM	226	76	376	Yes
HydraCX^2 vs. Straw, Tackified	159	9	309	Yes
Excel Fibermulch II vs. HydroStraw BFM	716	566	866	Yes
Excel Fibermulch II vs. Straw, Tackified	649	499	799	Yes
HydroStraw BFM vs. Straw, Tackified	67	-83	217	No

Notes: [LB] signifies lower bound of confidence interval
[UB] signifies upper bound of confidence interval
$q_{crit} = 4.28$

Tukey-Kramer Multiple Comparisons on Average Initial Turbidity [*Test 3*]

Comparison	$\mu_i - \mu_j$	CI [LB]	CI [UB]	Significantly Different
Control vs. GeoSkin	5427	5301	5554	Yes
Control vs. Straw, Crimped	4880	4753	5007	Yes
Control vs.HydraCX^2	5616	5490	5743	Yes
Control vs. Excel Fibermulch II	5081	4954	5207	Yes
Control vs. HydroStraw BFM	5878	5751	6004	Yes
Control vs. Straw, Tackified	5764	5637	5890	Yes
GeoSkin vs. Straw, Crimped	547	421	674	Yes
GeoSkin vs. HydraCX^2	189	63	316	Yes
GeoSkin vs. Excel Fibermulch II	347	220	473	Yes
GeoSkin vs. HydroStraw BFM	450	324	577	Yes
GeoSkin vs. Straw, Tackified	336	210	463	Yes
Straw, Crimped vs. HydraCX^2	736	610	863	Yes
Straw, Crimped vs. Excel Fibermulch II	200	74	327	Yes
Straw, Crimped vs. HydroStraw BFM	998	871	1124	Yes
Straw, Crimped vs. Straw, Tackified	884	757	1010	Yes
HydraCX^2 vs. Excel Fibermulch II	536	409	663	Yes
HydraCX^2 vs. HydroStraw BFM	261	135	388	Yes
HydraCX^2 vs. Straw, Tackified	147	21	274	Yes
Excel Fibermulch II vs. HydroStraw BFM	797	671	924	Yes
Excel Fibermulch II vs. Straw, Tackified	683	557	810	Yes
HydroStraw BFM vs. Straw, Tackified	114	-13	241	No

Notes: [LB] signifies lower bound of confidence interval
[UB] signifies upper bound of confidence interval
q_{crit} = 4.28

Tukey-Kramer Multiple Comparisons on Average Initial Turbidity [*Test 4*]

Comparison	$\mu_i - \mu_j$	CI [LB]	CI [UB]	Significantly Different
Control vs. GeoSkin	4628	4516	4741	Yes
Control vs. Straw, Crimped	4450	4338	4562	Yes
Control vs.HydraCX^2	4953	4840	5065	Yes
Control vs. Excel Fibermulch II	4393	4280	4505	Yes
Control vs. HydroStraw BFM	5230	5118	5343	Yes
Control vs. Straw, Tackified	5096	4983	5208	Yes
GeoSkin vs. Straw, Crimped	178	66	291	Yes
GeoSkin vs. HydraCX^2	325	212	437	Yes
GeoSkin vs. Excel Fibermulch II	236	123	348	Yes
GeoSkin vs. HydroStraw BFM	602	490	715	Yes
GeoSkin vs. Straw, Tackified	468	355	580	Yes
Straw, Crimped vs. HydraCX^2	503	390	615	Yes
Straw, Crimped vs. Excel Fibermulch II	57	-55	170	No
Straw, Crimped vs. HydroStraw BFM	780	668	893	Yes
Straw, Crimped vs. Straw, Tackified	646	533	758	Yes
HydraCX^2 vs. Excel Fibermulch II	560	448	673	Yes
HydraCX^2 vs. HydroStraw BFM	278	165	390	Yes
HydraCX^2 vs. Straw, Tackified	143	31	255	Yes
Excel Fibermulch II vs. HydroStraw BFM	838	725	950	Yes
Excel Fibermulch II vs. Straw, Tackified	703	591	816	Yes
HydroStraw BFM vs. Straw, Tackified	135	22	247	Yes

Notes: [LB] signifies lower bound of confidence interval
[UB] signifies upper bound of confidence interval
q_{crit} = 4.28

Tukey-Kramer Multiple Comparisons on Average Soil Loss [*Test 1*]

Comparison	$\mu_i - \mu_j$	CI [LB]	CI [UB]	Significantly Different
Control vs. GeoSkin	17158	15582	18733	Yes
Control vs. Straw, Crimped	16656	15080	18231	Yes
Control vs.HydraCX^2	17256	15680	18832	Yes
Control vs. Excel Fibermulch II	16461	14886	18037	Yes
Control vs. HydroStraw BFM	17332	15756	18908	Yes
Control vs. Straw, Tackified	17158	15582	18734	Yes
GeoSkin vs. Straw, Crimped	502	-1074	2078	No
GeoSkin vs. HydraCX^2	98	-1477	1674	No
GeoSkin vs. Excel Fibermulch II	696	-880	2272	No
GeoSkin vs. HydroStraw BFM	174	-1401	1750	No
GeoSkin vs. Straw, Tackified	0	-1575	1576	No
Straw, Crimped vs. HydraCX^2	601	-975	2176	No
Straw, Crimped vs. Excel Fibermulch II	194	-1382	1770	No
Straw, Crimped vs. HydroStraw BFM	676	-899	2252	No
Straw, Crimped vs. Straw, Tackified	502	-1073	2078	No
HydraCX^2 vs. Excel Fibermulch II	795	-781	2370	No
HydraCX^2 vs. HydroStraw BFM	76	-1500	1652	No
HydraCX^2 vs. Straw, Tackified	98	-1478	1674	No
Excel Fibermulch II vs. HydroStraw BFM	871	-705	2446	No
Excel Fibermulch II vs. Straw, Tackified	697	-879	2272	No
HydroStraw BFM vs. Straw, Tackified	174	-1402	1750	No

Notes: [LB] signifies lower bound of confidence interval
[UB] signifies upper bound of confidence interval
$q_{crit} = 4.49$

Tukey-Kramer Multiple Comparisons on Average Soil Loss [*Test 2*]

Comparison	$\mu_i - \mu_j$	CI [LB]	CI [UB]	Significantly Different
Control vs. GeoSkin	7347	7252	7442	Yes
Control vs. Straw, Crimped	7211	7115	7306	Yes
Control vs.HydraCX^2	7450	7355	7545	Yes
Control vs. Excel Fibermulch II	6989	6894	7084	Yes
Control vs. HydroStraw BFM	7506	7411	7602	Yes
Control vs. Straw, Tackified	7385	7290	7481	Yes
GeoSkin vs. Straw, Crimped	137	42	232	Yes
GeoSkin vs. HydraCX^2	103	8	198	Yes
GeoSkin vs. Excel Fibermulch II	358	263	453	Yes
GeoSkin vs. HydroStraw BFM	159	64	254	Yes
GeoSkin vs. Straw, Tackified	38	-57	133	No
Straw, Crimped vs. HydraCX^2	240	145	335	Yes
Straw, Crimped vs. Excel Fibermulch II	221	126	316	Yes
Straw, Crimped vs. HydroStraw BFM	296	201	391	Yes
Straw, Crimped vs. Straw, Tackified	175	80	270	Yes
HydraCX^2 vs. Excel Fibermulch II	461	366	556	Yes
HydraCX^2 vs. HydroStraw BFM	56	-39	151	No
HydraCX^2 vs. Straw, Tackified	65	-30	160	No
Excel Fibermulch II vs. HydroStraw BFM	517	422	612	Yes
Excel Fibermulch II vs. Straw, Tackified	396	301	491	Yes
HydroStraw BFM vs. Straw, Tackified	121	26	216	Yes

Notes: [LB] signifies lower bound of confidence interval
[UB] signifies upper bound of confidence interval
$q_{crit} = 4.49$

Tukey-Kramer Multiple Comparisons on Average Soil Loss [*Test 3*]

Comparison	$\mu_i - \mu_j$	CI [LB]	CI [UB]	Significantly Different
Control vs. GeoSkin	6859	6764	6953	Yes
Control vs. Straw, Crimped	6869	6774	6964	Yes
Control vs.HydraCX^2	7013	6918	7108	Yes
Control vs. Excel Fibermulch II	6604	6509	6699	Yes
Control vs. HydroStraw BFM	7098	7003	7193	Yes
Control vs. Straw, Tackified	7011	6916	7106	Yes
GeoSkin vs. Straw, Crimped	10	-85	105	No
GeoSkin vs. HydraCX^2	155	60	249	Yes
GeoSkin vs. Excel Fibermulch II	254	160	349	Yes
GeoSkin vs. HydroStraw BFM	240	145	335	Yes
GeoSkin vs. Straw, Tackified	152	57	247	Yes
Straw, Crimped vs. HydraCX^2	144	50	239	Yes
Straw, Crimped vs. Excel Fibermulch II	265	170	360	Yes
Straw, Crimped vs. HydroStraw BFM	230	135	324	Yes
Straw, Crimped vs. Straw, Tackified	142	47	237	Yes
HydraCX^2 vs. Excel Fibermulch II	409	314	504	Yes
HydraCX^2 vs. HydroStraw BFM	85	-10	180	No
HydraCX^2 vs. Straw, Tackified	2	-92	97	No
Excel Fibermulch II vs. HydroStraw BFM	494	399	589	Yes
Excel Fibermulch II vs. Straw, Tackified	407	312	501	Yes
HydroStraw BFM vs. Straw, Tackified	88	-7	182	No

Notes: [LB] signifies lower bound of confidence interval
[UB] signifies upper bound of confidence interval
q_{crit} = 4.49

Tukey-Kramer Multiple Comparisons on Average Soil Loss [*Test 4*]

Comparison	$\mu_i - \mu_j$	CI [LB]	CI [UB]	Significantly Different
Control vs. GeoSkin	5767	5692	5842	Yes
Control vs. Straw, Crimped	5947	5872	6022	Yes
Control vs.HydraCX^2	5980	5905	6055	Yes
Control vs. Excel Fibermulch II	5689	5614	5765	Yes
Control vs. HydroStraw BFM	6097	6022	6172	Yes
Control vs. Straw, Tackified	6001	5926	6077	Yes
GeoSkin vs. Straw, Crimped	180	104	255	Yes
GeoSkin vs. HydraCX^2	213	137	288	Yes
GeoSkin vs. Excel Fibermulch II	78	2	153	Yes
GeoSkin vs. HydroStraw BFM	330	255	405	Yes
GeoSkin vs. Straw, Tackified	234	159	310	Yes
Straw, Crimped vs. HydraCX^2	33	-42	108	No
Straw, Crimped vs. Excel Fibermulch II	257	182	333	Yes
Straw, Crimped vs. HydroStraw BFM	150	75	226	Yes
Straw, Crimped vs. Straw, Tackified	55	-21	130	No
HydraCX^2 vs. Excel Fibermulch II	290	215	366	Yes
HydraCX^2 vs. HydroStraw BFM	117	42	193	Yes
HydraCX^2 vs. Straw, Tackified	22	-54	97	No
Excel Fibermulch II vs. HydroStraw BFM	408	333	483	Yes
Excel Fibermulch II vs. Straw, Tackified	312	237	387	Yes
HydroStraw BFM vs. Straw, Tackified	96	20	171	Yes

Notes: [LB] signifies lower bound of confidence interval
[UB] signifies upper bound of confidence interval
q_{crit} = 4.49

Analysis of Variance (ANOVA) Tables for Initial Turbidity

Hypothesis:

H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6 = \mu_7$

H_a: All μ_i are *not* equal

Source of Variation	SS	df	MS	F	P-value	F_{crit}	Hypothesis
			Test 1				
Between Groups	559833439	6	93305573	**1366**	4.51E-92	**2.193**	**H_a**
Within Groups	6696406	98	68331				
Total	566529845	104					
			Test 2				
Between Groups	410234409	6	68372402	**3718**	3.17E-113	**2.19**	**H_a**
Within Groups	1801984	98	18388				
Total	412036393	104					
			Test 3				
Between Groups	392177502	6	65362917	**4980**	2.05E-119	**2.19**	**H_a**
Within Groups	1286343	98	13126				
Total	393463846	104					
			Test 4				
Between Groups	304399403	6	50733234	**4903**	4.38E-119	**2.19**	**H_a**
Within Groups	1014120	98	10348				
Total	305413523	104					

Where,

μ_i = Mean for i^{th} group [e.i. (1) Control, (2) Conventional Straw, Crimped, … ,(7) HydroStraw® BFM]
SS = Sum of Squares,
df = Degrees of Freedom,
MS = Mean Square, and
F = F-value
Accept Null Hypothesis: $F_{crit} > F$
Reject Null Hypothesis: $F_{crit} < F$

Analysis of Variance (ANOVA) Tables for Soil Loss

Hypothesis:

H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6 = \mu_7$

H_a: All μ_i are *not* equal

Source of Variation	SS	df	MS	F	P-value	F_{crit}	Hypothesis
			Test 1				
Between Groups	49690005	6	8281667	**13.45**	3.93E-07	**2.45**	$\mathbf{H_a}$
Within Groups	17242822	28	615815				
Total	66932826	34					
			Test 2				
Between Groups	9208386	6	1534731	**684.4**	5.06E-29	**2.45**	$\mathbf{H_a}$
Within Groups	62786	28	2242				
Total	9271171	34					
			Test 3				
Between Groups	8213569	6	1368928	**613.7**	2.30E-28	**2.45**	$\mathbf{H_a}$
Within Groups	62462	28	2231				
Total	8276031	34					
			Test 4				
Between Groups	6018693	6	1003116	**713.6**	2.83E-29	**2.45**	$\mathbf{H_a}$
Within Groups	39361	28	1406				
Total	6058054	34					

Where,

μ_i = Mean for i^{th} group [e.i. (1) Control, (2) Conventional Straw, Crimped, … ,(7) HydroStraw® BFM]
SS = Sum of Squares,
df = Degrees of Freedom,
MS = Mean Square, and
F = F-value
Accept Null Hypothesis: $F_{crit} > F$
Reject Null Hypothesis: $F_{crit} < F$