Effectiveness of selected erosion control covers during vegetation establishment under simulated rainfall

by

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ABSTRACT

Soil erosion on unprotected roadside slopes generates significant soil loss during storm events. Proper surface protection to reduce erosion is promoted by water protection agencies including the United States Environmental Protection Agency (USEPA) and the United States Department of Agriculture (USDA). In the present study, selected seeded and non-seeded covers were evaluated on a sandy clay soil transported from an earthen roadside embankment in Russell County, AL. The selected cover treatments were polyacrylamide (BS+P), wheat straw with and without seed (WS+P+S, WS+P), and engineered fiber matrix with and without seed (EFM+S, EFM). Cover treatments were evaluated using 1.2 m x 0.6 m (47 in x 22 in) test plots on a 3:1 slope subjected to 15 minutes (2.9 cm depth) of simulated rainfall. Annual ryegrass (*Lolium multiflorum*) and browntop millet (*Panicum ramosum*) were planted on seeded plots in spring and summer test periods, respectively

The objectives of the study were to quantify reduction of runoff volume (ml), turbidity (NTU), and modified total suspended solids (MTSS) compared to the bare soil control, and to determine the most cost-effective temporary cover treatment for similar soil, rainfall, and slope conditions. The seeded EFM+S and WS+P+S treatments were observed to be the most effective in terms of runoff volume with 68% and 49% reduction, respectively, as compared to the bare soil control. The most effective treatment with respect to turbidity and MTSS was EFM+S, with 98.7% and 99.8% reduction, respectively, as compared to the bare soil control. Water quality response of seeded treatments combined (EFM+S, WS+P+S) were negatively correlated with days after seeding (DAS) (r = -0.48,-0.47, and -0.63 for runoff volume, turbidity, and MTSS, respectively), as compared to a flat correlation of corresponding responses in non- seeded treatments (r = 0.10, 0.01, and 0.02, respectively), indicating important water quality benefits of seeding. The EFM+S treatment resulted in 39% less MTSS delivery per hectare than WS+P+S but the WS+P+S treatment (cost of \$1.03 kg^{-1} sediment reduction) was found to be 84% less expensive per hectare than the EFM+S treatment (cost of \$6.36 kg^{-1} sediment reduction). The WS+P+S treatment can therefore be recommended over EFM+S as a cost effective method for sediment delivery reduction under conditions similar to this study. Results confirm the cost effectiveness of vegetation in conjunction with other temporary covers to reduce erosion and sediment loss, and provide a method to quantify environmental benefits of erosion control in terms of economic cost.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVATIONS

AGC	Alabama General Contractors
ALDOT	Alabama Department of Transportation
ANOVA	Analysis of Variance
ARS	Agricultural Research Station
ASABE	American Society of Agricultural and Biological Engineers
ASTM	American Society for Testing and Materials
ASWCC	Alabama Soil and Water Conservation Committee
BFM	Bonded Fiber Matrix
BMP	Best Management Practice
BS	Bare soil
BS+P	Bare soil with PAM
BS+P+S	Bare soil with PAM and seed
CSES	Crop, Soil and Environmental Sciences
CWA	Clean Water Act
DAS	Days after Seeding

ECTC	Erosion Control Technology Council
EFM	Engineered Fiber Matrix
EFM+S	Engineered Fiber Matrix with seed
ESRI	Environmental Systems and Research Institute
FRM	Fiber Reinforced Matrix
GLM	General Linear Model
HECP	Hydraulically Applied Erosion Control Product
HM	Hydraulic Mulch
MBFM	Mechanically Bonded Fiber Matrix
MDEQ	Mississippi Department of Environmental Quality
MTSS	Modified Total Suspended Solids
NCAT	National Center for Asphalt Technology
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge Elimination System
NPS	Non-point Source
NRCS	Natural Resources Conservation Services
NTU	Nephelometric Turbidity Units
PAM	Polyacrylamide
PEB	Product Evaluation Board

SAS	Statistical Analysis System
SLR	Soil Loss Ratio
SMM	Stabilized Mulch Matrix
TGRU	Turf Grass Research Unit
US	United States
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
VFD	Variable Frequency Drive
WS+P	Wheat straw with PAM
WS+P+S	Wheat straw with PAM and seed
WSDOT	Washington State Department of Transportation

CHAPTER 1 INTRODUCTION

1.1 Background

According to the United States Department of Agriculture (USDA) (2014) "soil erosion involves the breakdown, detachment, transport, and redistribution of soil particles by forces of water, wind, or gravity." A major water quality concern from erosion is non-point source (NPS) pollution. According to the United States Environmental Protection Agency (USEPA) (1994), NPS can be defined as the pollution that comes from a diffuse source and is driven by rainfall or snowmelt moving over or through the land. In the United States (US), NPS pollution from agricultural activities is the leading source of water quality pollution, which directly affects drinking water (USEPA, 2003). However, streams within cities and highway right of ways are impacted by construction activities (Berndtsson, 2010; Chen et al., 2009). According to USEPA (2008), sediment is the most important NPS pollutant in the US.

Over 72 million metric tons (80 million tons) of sediment from construction sites end up in surface water bodies of the US each year. Other detrimental effects of erosion and sedimentation include loss of reservoir storage capacity and increased nutrient loading within streams (Novotny, 2003). The measured erosion rate from construction sites is 45 to 448 metric tons ha^{-1} (20 to 200 tons $acre^{-1}$) per year, which is 3 to 100 times greater than erosion from croplands. Construction sites can generate approximately 8 to 18 times more sediment and phosphorus, respectively, than industrial sites and 25 times more sediment and phosphorus than row crops (Pitt et al., 2007).

1.2 Erosion on roadside slopes

Soil erosion and water quality are the main concerns for land managers in the US. Special attention is needed to reduce NPS pollution including soil erosion and sedimentation on any forest areas. Road erosion can lead to a major failure in road embankments, which resulted in water quality degradation (Xiao et al., 2006). Forest road side slopes (i.e. cut and fill slopes) are one of the major sources of erosion loss from a managed forest systems (Grace, 2000). Road construction creates bare and steep roadside slopes (Cerda, 2007, Bochet and Fayos, 2004) and lack of surface protection generates significant soil loss during storm events (Bochet and Fayos, 2004, Bochet et al., 2010, Jordan-Lopez et al., 2009, Arnaez et al., 2004).

1.3 Best management practices (BMPs) to control erosion

Different best management practices (BMPs) can be used to control and manage erosion as well as sediment loading into water bodies (USEPA, 2005). Vegetation cover has been shown as an effective long term means to reduce roadside slope erosion and is used in many areas worldwide (Megahan et al., 1983, and Cerda, 2007). Vegetation promotes infiltration and resistance to soil scouring by stabilizing soil structure with roots and intercepting runoff and rainfall, thereby playing an important role in soil and water conservation (Li et al., 1992a, 1992b; Pan and Shangguan, 2006). A related technology used to stabilize disturbed roadside slopes is hydroseeding. Hydroseeding is a method in which a mixture of water, seed, fertilizer, and mulches are mixed and sprayed hydraulically.

Harvested agricultural wheat straw or other available straw is also widely used as a temporary erosion control cover until vegetation is established. Straw is typically assumed to be the most cost effective measure, because it is easily applied by hand or mechanically, and is often readily available (Foltz and Dooley, 2003). Burned areas, harvest landings, decommissioned roads, hillslope cut and fill areas, and other disturbed forested areas of the US have often been protected using agricultural straw (Robichaud et al., 2000). Straw provides a high degree of ground cover when applied, reducing the impact of falling raindrops and preventing soil particle mobilization (Foltz and Dooley, 2003). Straw mulch has historically been a preferred material for erosion control on highway construction projects (WSDOT, 1999).

The use of polyacrylamide (PAM) has increased widely as a chemical erosion and sediment control. PAM, a polymer from acrylamide subunits is used to stabilize the soil structure. It has been reported that PAM was able to reduce erosion and increased infiltration while decreasing runoff volume (Babcock and McLaughlin, 2011). The use of PAM has been recognized as a BMP by the USDA-Natural Resources Conservation Service (NRCS) and is included in 2001 edition of the National Handbook of Conservation Practices (NHCP). Shoemaker (2009) applied dry PAM at 40 kg ha^{-1} (35 lbs $acre^{-1}$) and reported 97% and 50% reduction in turbidity and eroded soil mass, respectively, as compared to a bare soil control. Bjorneberg et al. (2000) reported that applying PAM with straw mulch was more effective in reducing erosion and soil loss than either PAM or straw mulch alone. Flanagan and Canady (2006) reported that combining PAM with wheat straw reduced runoff by 66%, as compared to control. Addition of PAM to straw, erosion control blankets or a mechanically bonded fiber matrix resulted in a significant reduction of turbidity compared to those same cover treatments without PAM (McLaughlin and Brown, 2006).

1.4 Research justification

There is a need to reduce erosion on earthen roadside embankments in Russell County near Pittsview, Alabama (AL). Recreational and commercial land owners in the area seek the most cost effective maintenance practices to limit erosion on-site. Small scale field experiments were developed off-site to test different temporary covers on 3:1 slope under simulated rainfall. Tests include plots with and without seeding to quantify the beneficial effect of vegetation in roadside erosion control. Such results should be meaningful for any similarly sloped soil and landscape. Previous studies did not evaluate seeded versus non-seeded treatments to quantify the impact or cost effectiveness of vegetation establishment. Temporary covers including wheat straw and engineered fiber matrix (EFM) were selected to evaluate the most cost effective option to reduce soil erosion and protect water quality on disturbed slopes.

1.5 Objectives of study

The specific objectives of this research are as follows:

1. Evaluate runoff volume, turbidity and modified total suspended solids (MTSS) delivered as affected by selected erosion control covers under simulated rainfall on a 3:1 slope to compare water quality benefits of each.

2. Quantify the beneficial impact of seeded treatments over non-seeded treatments in terms of runoff volume, turbidity, and MTSS delivery.
3. Evaluate the cost effectiveness of temporary covers for sediment reduction, and offer recommendations based on water quality and budget requirements.

The following tasks were performed to satisfy the research objectives:

1. Design and construct small-scale test plots and flumes for runoff collection from each plot to evaluate selected erosion control covers.
2. Collect and examine runoff data to test the effectiveness of different erosion control covers used in the study.
3. Analyse the data to provide a scientific based recommendations for cost effective roadside erosion and sediment control.

1.6 Thesis organization

This thesis is divided into five chapters. Chapter 1 provides an introduction to the process of erosion and selected BMPs used for erosion mitigation followed by the thesis research objectives. Chapter 2 provides a literature review of previous work done in the field of erosion and sedimentation control, and covers a variety of mechanical, chemical and biological covers. Chapter 3 describes the methods used to complete research objectives. Chapter 4 presents the results of simulated rainfall testing in terms of runoff volume, turbidity and MTSS delivery. Chapter 4 also summarizes water quality response as a function of percent vegetation cover and provides a cost comparison of selected cover treatments as a function of sediment reduction performance. Chapter 5 presents summary conclusions and provides recommendations for temporary erosion control on construction sites and road banks similar to the experimental design. Chapter 5 also provides recommendations for future research with temporary and permanent erosion control covers.

CHAPTER 2 LITERATURE REVIEW

2.1 Erosion Process

Soil erosion typically occurs when soil is exposed to water or wind energy (USEPA, 2013). Soil erosion degrades soil productivity and water quality, which makes it a worldwide environmental problem (Ouyang and Bartholic, 2001). Soil erosion results in other serious negative environmental impacts including land degradation, sedimentation, and dust pollution resulting in reduced agricultural production, infrastructure damage, and impaired water quality (Lal, 1998 and Pimentel et al., 1995). As erosion loosens soil, it increases the exposure of soil organic matter to oxidization, which results in atmospheric CO_2 and CH_4 emission, which have a direct impact on the climate change (Lal, 2004).

According to USEPA (2003), "sheet erosion is a process in which detached soil is moved across the soil surface by sheet flow, often in the early stages of runoff." Sheet erosion combines two processes: 1) the detachment of soil particles by raindrop impact and 2) transportation of sediments by overland flow (Lado and Ben-Hur, 2004). Sheet erosion is influenced by rainfall, topography, soil properties, and vegetation cover. Rainfall provides the energy to cause initial detachment of soil particles. Soil properties include particle size distribution, texture, and composition affect the soil particle susceptibility to be moved by flowing water. The soil surface can be protected with a vegetation cover from rainfall impact or the force of moving water (USEPA, 2003).

According to USEPA (2012), “rill erosion is the removal of soil by concentrated water running through little streamlets, or headcuts.” Soil detachment in a rill occurs if the sediment in the flow is less than the amount the runoff can transport while the flow velocity exceeds soil shear stress. As detachment continues or flow increases, rills become wider and deeper. Formation of rills depends upon the hydraulic characteristics of channelized flow such as mean velocity (Slattery and Bryan, 1992), Froude number (Savat and De Ploey, 1982) and bottom shear stress (Torri et al., 1987). Most research dealing with soil erosion by water has focused on these sheet (inter-rill) and resulting rill erosion processes (Morgan and Nearing, 2011).

According to USEPA (2012), “gully erosion occurs when channel development has progressed to the point where the gully is too wide and too deep to be tilled across.” Gully erosion is a more destructive form of rill erosion. Permanent gullies in agricultural land are channels that are too deep to remove with ordinary farm tillage equipment, typically ranging from 0.5 m (1.6 ft) to as much as 25 to 30 m (82-98 ft) depth (Soil Science Society of America, 2010).

2.2 Impact of Runoff on Water Quality

The impact of runoff pollutants on water body quality depends on both the existing water quality and the rate at which pollutants enter the water body. When water borne pollutants such as toxic metals travel a long distance, they may settle down and begin impacting the local environment (Gjessing et al., 1984). Certain chemicals in runoff have specific impacts on water quality. Excessive levels of nutrients from agricultural runoff can cause algae blooms, which blocks the sunlight and absorb oxygen levels in the body of water (Christine, 2014). Total suspended solids (TSS) in water increases turbidity, which directly affects fish survival (Ferrara, 1986). The measurement of water clarity as the material suspended in water decreases the passage of light through the water is known as turbidity (USEPA, 2012). Runoff from agricultural land can carry disease causing organisms from manure into nearby water bodies and can cause damage to a watercourse and adjacent properties leading to the occurrence of (ephemeral) gully erosion (Verstraeten and Poesen, 1999; Boardman, 2001).

Researchers have emphasized the effects of heavy metal accumulation in sediment and in water in terms of risk assessment (Sharma et al., 2004). Due to biogeochemical processes and environmental conditions of rivers, sediment acts as an important sink for heavy metals and other non-point source pollutants affecting water quality (Damian, 1988; Bruces et al., 1996; Balls et al., 1997; Santos et al., 2003). Heavy metals tend to accumulate in the surface sediments and can cause health hazards when concentrations reach minimum threshold (Marchand et al., 2006; Pekey, 2006; Tan et al., 2006; Li et al., 2006).

Surface runoff carries heavy metals, nutrients, and sediment into surface water (He et al. 2001; Davis et al. 2001; Lee and Bang 2000; Barrett et al. 1998), which results in the deterioration of water quality and killing of aquatic species. In the US, 95,770 km (59,509 miles) of rivers and streams were threatened or impaired by storm water runoff (USEPA, 2012).

2.3 History of Federal Regulations

In 1948, the Federal Water Pollution Control Act was the first federal law protecting water pollution. This act was amended in 1972 as a result of growing environmental awareness, and it subsequently becomes the Clean Water Act (CWA). In

1972, the National Pollution Discharge Elimination System (NPDES) was introduced in section 402 of Clean Water Act (CWA) prohibiting the discharge "of pollutants from any point source into the nation's water except as allowed under a NPDES permit" (USEPA, 2010). The CWA was amended by Congress after five years to focus on the control of toxic discharge. In 1987, Congress passed the Water Quality Act to ensure increased monitoring of water bodies and assure water quality standards were maintained by on-site construction contractors (USEPA, 2010).

In 1984, the USEPA submitted a report to the Congress stating that NPS pollution in the US was the leading cause of remaining water quality degradation. Urban storm water runoff in the US was the fourth largest cause of water quality degradation of rivers, and the third vastest source of water quality degradation of lakes (USEPA, 1990; Novotny, 1991; Novotny and Olem, 1994). In 1992, the USEPA ranked urban storm water runoff as the second largest source of pollution in lakes and estuaries, and the third largest source in river pollution (Lee and Jones-Lee, 1994).

2.4 Straw mulch for erosion control

According to USEPA (2014), "mulching is the erosion control practice that uses materials like hay, grass, gravel, wood fibers or straw to stabilize disturbed soil or newly planted surfaces". Alabama Soil and Water Conservation Committee (ASWCC, 2009) states that "surface mulch is the most effective erosion and sediment control measure on an exposed soil prior to vegetation establishment." Table 2.1 shows the typical mulching materials and their recommended application rates used in Alabama (ASWCC, 2009). The table represents different mulch treatments including conventional straw with or without seed, wood chips, bark, pine straw and peanut hulls along with the recommended application rate per ha and appropriate guidelines. This table helps to determine the proper cover on a specified slope for erosion control. Selection of cover should be based upon soil conditions, slope steepness and length, season and type of vegetation (ASWCC, 2009).

Table 2.1: Recommended mulch materials, application rates and guidelines for application, Alabama (ASWCC, 2009)

Mulch	Rate (Metric tons ha^{-1})	Guidelines
Conventional straw with seed	3.4-4.5	Spread by hand or machine to attain 75% groundcover; anchor when subject to blowing.
Conventional straw (No Seed)	5.6-6.7	Spread by hand or machine; anchor when subject to blowing.
Wood chips	11.2-13.5	Treat with 12 lbs. nitrogen/ton.
Bark	26.8 cubic yards	Can apply with mulch blower
Pine straw	2.2-4.5	Spread by hand or machine; will not blow like straw.
Peanut hulls	22-44	Will wash off slopes. treat with 12 lbs. nitrogen/ton.

Agricultural straw is widely used in erosion control as a mulch. Moreover, agricultural straw is inexpensive and easier to spread by hand or machine (Foltz and Dooley, 2003). Typical application of wheat straw by hand is shown in Figure 2.1 for erosion control in Boston, MA. Agricultural straw is used in the forested areas of the US for erosion control on hill slopes, cuts and fills and other disturbed areas (Robichaud et al., 2000). Straw provides a high degree of cover to reduce the impact of raindrops and prevent soil particle detachment (Broz et al. 2003). The long stems of straw act as a mechanism to reduce overland water velocity while capturing sediment already in motion (Foltz and Dooley, 2003). However, straw decomposes over a relatively short time, thus reducing its effectiveness in subsequent rain events (Wishowski et al., 1998).

Figure 2.1: Application of wheat straw by hand over a freshly seeded area to reduce erosion in Boston, MA (Source: http://www.durangoherald.com)

A study conducted by Wilson (2010) tested conventional straw on 0.6 m (2 ft) wide and 1.2 m (4 ft) long test plots having slope 3:1 under a rainfall simulator at National Centre for Asphalt Technology (NCAT) testing facility, Opelika, AL. The simulation ran for an hour with four-15 min rainfall durations leading to rainfall intensity of 11.1 cm h^{-1} (4.4 in h^{-1}). Results showed that straw was able to reduce soil loss by 96% and turbidity by 80% compared to the bare soil control.

Another plot scale study conducted by Benik et al. (2003) tested straw mulch at an application rate of 4,480 kg ha^{-1} (4000 lbs $acre^{-1}$) in 9.8 m x 1.2 m (32 ft x 4 ft) boxes on 35% slope. Rainfall simulation was applied seasonally at an intensity of 60 mm h^{-1} (2.36 in h^{-1}). Turbidity readings were not reported but sediment yield reduction in spring and fall season was approximately 88% and 87%, respectively, as compared to the bare soil control. McLaughlin and Brown (2006) tested straw mulch on 2 m x 1 m x 9 cm (6.6 ft x 3.28 ft x 0.8 in) wooden boxes placed at 10 and 20 percent slope at rainfall intensity of 3.4 cm h^{-1}. The straw reduced turbidity by 78% compared to control.

In 2003, Bjorneberg et al. tested six different treatments in 1.5 m x 1.2 m x 0.2 m (4.9 ft x 3.9 ft x 8 in) steel boxes filled with loam soil on a 2.4% slope. Irrigation water was appplied with a Veejet Nozzle (8070) at 80 mm h^{-1} (3.15 in h^{-1}) for 15 minutes. Straw was applied at two different covers 30% and 70% at a rate of 670 kg ha^{-1} (600 lbs $acre^{-1}$) and 2500 kg ha^{-1} (2230 lbs $acre^{-1}$), respectively. 70% straw cover reduced runoff and sediment loss by more than 80% and 95%, respectively and 30% straw cover reduced runoff and sediment loss by 52% and 51%, respectively.

Kukal and Sarkar (2010) studied the effect of wheat straw and polyvinyl alcohol (PVA) solution on splash erosion and infiltration rate in two different soils under simulated rainfall in semi-arid tropics. They treated the tilled soil surface with chopped wheat straw at the rate of 6 ton ha^{-1} with sprayed 0.1% to 0.5% PVA solution. The average soil loss on the wheat straw treatment was decreased by 56% and 84% with 0.1% PVA and 0.5% PVA, respectively. Results showed that wheat straw and PVA was more effective in decreasing erosion and increasing infiltration in sandy loam than in silt loam. Jiang et al. (2011) investigated the effect of wheat straw mulch on runoff and erosion in the Midwestern United States. Straw in their study reduced runoff and soil erosion by 68% and 95%, respectively, compared to bare soil.

A rainfall simulator study was carried out by Groen and Woods (2008) to compare the erosion and runoff rates from 0.5 m^2 (5.4 ft^2) plots with wheat straw and aerial seeding in July, 2002 in northwest Montana. Wheat straw at an application rate of 2240 kg ha^{-1} (1998 lbs $acre^{-1}$) resulted in 100% ground cover and 87% reduction in erosion compared to the bare soil control. Table 2.2 summarizes the straw mulch literature.

Table 2.2: Summary of straw mulch literature

Study	Test-Scale	Application rate ($kg\ ha^{-1}$)	Reduction (%)	
			Soil loss	Turbidity
Wilson (2010)	Small	4,480	96	80
Benik et al. (2003)	Large	4,480	88	
Mclaughlin and Brown (2006)	Small	2,200	UNK[1]	78
Bjornenerg et al. (2003)	Small	670 2,500	51 95	UNK
Jiang et al. (2011)	Small	6,000	95	UNK
Groen and Woods (2008)	Small	2,240	87	UNK

[1]Unknown

2.5 Hydraulically applied mulch for erosion control

Field practices such as blown straw and straw mulch can be least expensive and reliable form of erosion control whereas the application of hydraulically applied mulch (Figure 2.2) provides to be efficient in terms of performance to provide the highest level of erosion control on disturbed soils (Lipscomb et al., 2006).

Figure 2.2: Hydra CX2® hydromulching operation in the field for erosion reduction (Source: www.fostersupply.com)

Hydraulically applied mulches have shown great improvement over the past 50 years in terms of technological advancement and increased environmental awareness and have become an efficient and widely used tool for erosion control, bank stabilization and vegetation establishment (Wilson, 2010). Erosion control technology council (ECTC) has divided hydraulically applied erosion control products (HECPs) into four different categories based on functional longevity, erosion control effectiveness, and vegetation establishment (Table 2.3). "As a general rule, the more expensive hydromulches, such as bonded fiber matrices (BFM), tend to offer better protection against erosion, but actual results are site specific" (Babcock and McLaughlin, 2008). "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).

Table 2.3: Various types of HECPs (Babcock and McLaughlin, 2008)

Slope Ratio	Material	Rate (kg ha^{-1})	Description
≤2H:1V	Stabilized Mulch Matrix (SMM)	1,680-2,800	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)	3,360-4,480	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)	3,360-5,040	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)	1,680	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.

McLaughlin and Brown (2006) tested straw, straw erosion control blanket and two mechanically bonded fiber matrix (MBFM) hydromulches with PAM in 100 cm (39 in) wide, 200 cm (78 in) long and 9 cm (3.5 in) deep test plots. Two tests were conducted: 1) a 4% slope under natural rainfall, and, 2) 10% to 20% slopes using rainfall simulator intensity of 3.4 cm h^{-1} (1.3 in h^{-1}). A commercial hydroseeder was used to apply MBFM at 3363 kg ha^{-1} (3000 lbs. $acre^{-1}$). Results showed that the application of MBFM without PAM reduced average turbidity by approximately 85% and sediment loss by 86% compared to bare soil control under natural rainfall and 96% turbidity reduction under simulated rainfall. Benik et al. (2003) conducted a study to evaluate the effectiveness of bonded fiber matrix (BFM) treatment. The application rate for BFM was 3363 kg ha^{-1} (3000 lbs. $acre^{-1}$) with a 24 hour drying period, per manufacturer's specifications. Results showed that the Soil Guard® BFM reduced average sediment yield by 94% compared to bare soil.

Plot scale study conducted by Wilson (2010) tested four different hydromulches, (1) Excel® Fibermulch II, (2) GeoSkin®, (3) HydraCX^{2}®, and (4) HydroStraw® BFM and compared their performance with two conventional straw practices, crimped and tackified, with bare soil as a control on a 3:1 slope using a rainfall simulator with a rainfall intensity of 11.1 cm h^{-1} (4.4 in h^{-1}) in 1.2 m x 0.6 m (4 ft x 2 ft) test plots. Cover factor (C factor) was also calculated to determine performance of each cover. Cover factor is the parameter used in revised universal soil loss equation representing a soil loss occurring within the treatments compared to bare soil, unprotect condition (Clopper et al. 2001). Results showed that the Hydro Straw BFM (C factor= 0.04) was the most effective treatment having 99% average turbidity reduction and 100% sediment reduction, as compared to the bare soil control. HydraCX^{2} (C factor = 0.013) was the second best hydromulch treatment with 95%

turbidity reduction and 99% sediment reduction, as compared to the bare soil control followed by GeoSkin (C factor = 0.028) with 92% reduction in turbidity and 97% sediment reduction, as compared to the bare soil control. Excel Fibermulch II (C factor = 0.068) had 85% turbidity reduction and 94% sediment reduction, as compared to the bare soil control.

The stabilization performance of two compost wood mulch blends, a wood based hydromulch and a bare soil to determine the amount of sediment from each treatment was compared by Bradley et al. (2010). Test plots of 12.2 m x 2.4 m (40 ft x 8 ft) were constructed and runoff was evaluated for two years after installation. Results showed that the hydromulch at an application rate of 2242 kg ha^{-1} (2000 lbs $acre^{-1}$) reduced sediment yield by 75% compared to bare soil. Prats et al. (2013) applied hydromulch at3500 kg ha^{-1} (3000 lbs $acre^{-1}$) consisted of a mixture of organic fibers, water, and seed to reduce runoff and erosion from burnt pine planation in central Portugal. Results concluded that hydromulch reduced runoff volume by 70% and soil erosion by 83%, as compared to bare soil.

Holt et al. (2005) performed an experiment on six hydromulch treatments, all tested in 0.6 m (2 ft) wide, 3.05 m (10 ft) long and 0.076 m (3 in) deep trays with a sandy loam soil. Six hydromulch treatments, including wood hydromulch, paper hydromulch, cottonseed hulls hydromulch, cotton by product (COBY) hydromulch produced from stripper waste (COBY Red), COBY produced from ground stripper waste (COBY green) and COBY produced from picker waste (COBY green) were tested on packed and leveled soil at 15.7% slope with a rainfall simulation intensity of 6.35 cm h^{-1} (2.5 in hr^{-1}). Patented cotton hydromulch made from cottonseed hulls is known as COBY (Hold and Laird, 2002). Hydromulches were applied by hand at 1,120 kg ha^{-1} (1,000 lbs $acre^{-1}$) and 2,241 kg ha^{-1}

(2,000 lbs acre^{-1}). Results showed that COBY green, COBY red, COBY yellow, cottonseed hulls , paper and wood hydromulches yielded a cover factor 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 at 1120 kg ha^{-1} and 2241 kg ha^{-1}, respectively. Gabriel (2009) tested the performance of a hydromulch on 2 m x 8 m (6.6 ft x 26 ft) with application rate of 3,900 kg ha^{-1} (3,500 lbs acre $^{-1}$) on 3:1 slope at San Diego State University's Soil Erosion Research Laboratory. The high performance hydromulch produced a C factor of 0.002 with 99.8% effectiveness.

Landloch (2002) tested four different hydromulch treatments including paper hydromulch, flax hydromulch, flax plus paper hydromulch and sugarcane hydromulch, applied at a rate of 1,000 kg ha^{-1} (893 lbs acre^{-1}), 2,500 kg ha^{-1} (2232 lbs acre^{-1}), 3,250 kg ha^{-1} (2,900 lbs acre^{-1}) and 5,000 kg ha^{-1} (4,464 lbs acre^{-1}), respectively. Test plots were 5 m (16.4 ft) long and 1.5 m (4.9 ft) wide at a 25% slope on alluvial black, cracking clay soil. Simulated rainfall was applied at an intensity of 14.4 cm h^{-1} (5.7 in h^{-1}) for 20 minutes to match the 10 year storm event. Cover factors for paper, flax, flax plus paper and sugarcane hydromulches were reported as 0.204, 0.149, 0.044 and 0.037, respectively.

2.5.1 Hydroseeding for erosion control

Hydroseeding is the technique that is often used on steep slopes and areas for vegetation establishment (Enriquez et al., 2004). Hydroseeding consists of mixing seed, fertilizers, water and other substances into an applied slurry, which is applied to prepared seed bed to promote vegetation establishment. Hydroseeding can achieve dense vegetation cover in the short term by stabilizing the soil, thus controlling erosion (Merlin et al., 1999; Robichaud et al., 2000). Hydroseeding had been widely used for vegetation establishment on road fills in Spain but in semi-Mediterranean climate the technique did not produced expected results in establishing a dense vegetative cover (Muzzi et al., 1997; Bochet and Fayos 2004).

Dougherty et al. (2008) tested six cover treatments and one bare soil treatment on 3 m by 7.6 m (10 ft x 25 ft) outdoor plots in Auburn, AL. Seed, lime and fertilizers were mixed as slurry in two of the hydromulch treatments and incorporated in the soil in other two hydromulch treatments. Results proved that incorporation of seed before hydromulching operation was an effective vegetation establishment measure with 30-fold sediment reduction compared to the bare soil plot. The study also reported that the incorporation of lime, fertilizers and seed in the Geoskin™ hydromulch treatment resulted in a 48% reduction in total sediment yield over the corresponding treatment in which seed, lime, and fertilzer was not incorporated.

Montoro et al. (2000) tested the effectiveness of hydroseeding techniques with the application of vegetal mulch, hydroseeding with added humic acid, hydroseeding with vegetal mulch and added humic acid and a control without hydroseeding or soil amendment. They found that all the hydroseeding treatments significantly reduced runoff and soil loss and that vegetal mulch with added humic acid was most effective (98.5% reduction of total soil loss versus 95% for other treatments). Table 2.4 summarizes the hydromulch literature.

Table 2.4: Hydromulch literature summary

Study	Test scale	Type of hydromulch	Application rate (kg ha^{-1})	Reduction (%)		C factor
				Soil loss	Turbidity	
McLaughlin and Brown (2006)	Small and large	MBFM	3,363	86	85	UNK
Benik et al. (2003)	Large	BFM[3]	3,363	94	UNK[2]	UNK
Wilson (2010)	Small	Excel® fibermulch	2,500	94	85	0.064
		Geoskin®	2,000	97	92	0.028
		HydraCX2®	3,500	99	95	0.013
		Hydrostraw® BFM	3,000	100	99	0.004
Bradley et al. (2010)	Large	Wood	2,242	75	UNK	UNK
Prats et al. (2013)	Large	Wood fiber	3,500	83	UNK	UNK
Holt et al. (2005)	Small	Wood	1,120 & 2,241	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
		COBY red		90 and 88	UNK	0.10 and 0.22
		COBY yellow		80 and 88	UNK	0.20 and 0.22
		COBY green		80 and 68	UNK	0.20 and 0.32
Gabriel (2009)	Intermediate	UNK	3,900	100	UNK	0.002
Landloch (2002)	Large	Paper	892	80	UNK	0.204
		Flax	2,232	85	UNK	0.149
		Flax plus paper	2,900	96	UNK	0.044
		Sugar Cane	4,464	96	UNK	0.037

[1]Mechanical Bonded Fiber Matrix [2]Unknown [3]Bonded Fiber Matrix

2.6 PAM for erosion control

In 1950s, a low molecular weight polyacrylamide (PAM) was introduced in agricultural market to control soil erosion, but mixing of PAM with soil was expensive. Therefore, the product disappeared from the market. It was later introduced in the late 1980s with the advancement in polymer chemistry to control erosion in furrow-irrigated agriculture. It generally increases infiltration by preserving a more pervious pore structure (Sojka and Lentz, 1996) but effects varied with soil texture (Sojka et al., 1998). The net increase of infiltration on fine textured soils was higher using PAM and infiltration rates increased by 15% on a Portneuf silt loam soil (Sojka et al., 1998). Polyacrylamide increased and preserved surface aggregate structure, with reduced surface crusting, increased infiltration and decreased runoff volume (Sojka et al. 2007; Green et al., 2000; Vacher et al. 2003; Yu et al. 2010; Flanagan et al. 2002a; 2002b).

Polyacrylamide can be an effective erosion and sediment control technique for reducing soil loss, decreasing runoff volume, increasing infiltration, preventing surface crusting (Akbarzadeh et al., 2009; Babcock and McLaughlin, 2011; Flanagan et al., 2002a, 2002b; Green et al., 2000; Zhang et al., 1998). Polyacrylamide effectiveness varies by application rate and soil conditions. The cost of PAM application on steep slopes (80 kg ha^{-1}) ranged from \$265-550 ha^{-1} less than the cost of other straw mulch products (Flanagan and Chaudhari, 1999). So, PAM can be an effective cost saving measure in controlling erosion and increasing vegetation establishment on construction sites. Figure 2.3 shows the effect of PAM in sediment laden water.

Polyacrylamide has three different forms: emulsive, solutions, and dry granules. Liquid PAM has been shown to increase soil infiltration up to 1.7 to 2.8 times compared with non-PAM controls (Yu et al., 2010). Dry granular PAM spread on the soil surface was more effective in increasing infiltration than mixing dry granular PAM in to the top soil with soil erosion was decreased by 80% compared to the control (Yu et al., 2010). Liquid PAM applied and then dried on the soil surface was the most effective in reducing runoff by 62% to 76% and sediment yield by 93% to 98%, as compared to a non-PAM control (Peterson et al., 2002).

(Without PAM) **(With PAM)**

Figure 2.3: Effect of PAM upstream on sediment laden water

(Source: http: //www. ucanr.edu)

Shoemaker (2009) tested the dry granular PAM product known as Silt Stop 712 (Applied Polymer Systems, Woodstock, GA) with application rates of 16.8, 27.9, and 39.2 kg ha^{-1} (15, 25 and 35 lbs $acre^{-1}$) on untreated, unseeded 1.2 m x 0.6 m (2 ft x 4 ft) laboratory scale test plots. Polyacrylamide treatment applied at recommended application rate of 39.2 kg ha^{-1} (15 lbs $acre^{-1}$) was able to reduce turbidity by 97% and net soil loss by 50%, as compared to bare soil control. Results indicate that dry PAM applied at the recommended application rate kept eroded soil from washing away by reducing detachment.

Some researchers had reported mixed results with PAM. Soupir et al. (2004) reported that PAM applied as a dry powder at 20 kg ha^{-1} (18 lbs $acre^{-1}$) on large scale (28 m x 2 m) plots reduced TSS by 50% compared to control. Zhang et al. (1998) found that application of 20 kg ha^{-1} PAM on a 6% slope reduced runoff volume by 44% and soil loss by 19% over a five month period. Past research suggest that a minimum application rate of 22 kg ha^{-1} is required for any benefit in reducing erosion (McLaughlin, 2006) but application rate below 22 kg ha^{-1} can be effective in erosion control and requires further research.

A study conducted in Iran by Sepaskhah and Bazrafshan-Jahromi (2006) used 1.4 m x 1.4 m (4.5 ft x 4.5 ft) steel boxes with a depth of 0.09 m (3.5 in) with 2.5%, 5%, and 7.5% slopes. A flume was constructed downslope to divert runoff to a collection point. A PAM treatment was applied at 1, 2, 4, and 6 kg ha^{-1} and was subjected to sprinkler irrigation. Researchers concluded that treatment with a steeper slope required a higher application rate of PAM to reduce erosion. The study also concluded that PAM treatments were more effective in reducing sediment erosion, rather than reducing runoff volume.

Polyacrylamide was effective in reducing soil loss, with the higher rate of PAM (40 kg ha^{-1}) having less soil loss than that from a lower rate of PAM (20 kg ha^{-1}) at slopes of 20% and 40%. (Lee et al., 2011). Partington and Mehuys (2005) found that PAM applied at 10 kg ha^{-1} and 20 kg ha^{-1} (9 lbs $acre^{-1}$ and 18 lbs $acre^{-1}$) was inadequate to control erosion after natural rainfall on a loam soil. They conducted a similar experiment under simulated rainfall conditions and found that PAM applied at 10 kg ha^{-1} and 20 kg ha^{-1} (9 lbs $acre^{-1}$ and 18 lbs $acre^{-1}$) on silt loam soil reduced soil erosion by 84% and 76%, respectively, and turbidity of runoff water by 99%.

Zhang et al. (1998) found that 20 kg ha^{-1} (18 lbs $acre^{-1}$) of PAM applied in conjunction with gypsum on a very low slope reduced runoff by 44% compared to a non-PAM control. Application of PAM reduced runoff continuously compared to the control for up to 160 days after application by 35%. Polyacrylamide application reduced the runoff volume significantly by 94% and 90% in the first and second storms, respectively, but resulted in only 17% reduction in soil loss compared to a non-PAM bare soil in the fourth month of the experiment.

Flanagan et al. (2002a) tested PAM, PAM plus gypsum and untreated control on nine 9.14 m x 2.96 m (30 ft x 9.7 ft) long erosion plots in West Lafayette, Indiana under simulated rainfall. The application of PAM (80 kg ha^{-1}) and 5 Mg ha^{-1} (4461 lbs $acre^{-1}$) gypsum significantly reduced runoff and sediment yield by 52% and 91%, respectively, compared to control on a 32% slope. Total soil loss was reduced in the range of 40% to 54% compared to control when applied at the same application rate on 35% and 45% slope under natural rainfall. They found that application of PAM and PAM with gypsum protected the soil during the period of vegetation growth for disturbed soils on steep slopes more than non-PAM control. Table 2.5 is the summary of PAM literature.

Table 2.5: PAM literature summary

Study	Test Scale	Application rate (kg ha^{-1})	Reduction (%)	
			Soil loss	Turbidity
Shoemaker (2009)	Small	39	50	97
Soupir et al. (2004)	Large	20	50	UNK[1]
Zhang et al. (1998)	UNK	20	19	UNK
Partington and Mehuys (2005)	UNK	20	76	99
Flanagan et al. (2002a)	Large	80*	91**	UNK

[1]Unknown *Gypsum was added (5 Mg ha^{-1}) **32% slope

2.6.1 PAM with wheat straw for erosion control

Several Studies were tested using PAM in combination of wheat straw. Bjorneberg et al. (2000) tested PAM and PAM with wheat straw in steel boxes of 1.5 x 1.2 m x 0.2 m (5 ft x 4 ft x 0.6 ft) irrigated at 80 mm h^{-1} (3.4 in h^{-1}) for 15 minutes. Wheat straw was applied at 2500 kg ha^{-1} (2230 lbs $acre^{-1}$) by visually estimating a 70% and 670 kg ha^{-1} (600 lbs $acre^{-1}$) for 30% straw cover with PAM applied at 2 and 4 kg ha^{-1} (1.8 and 3.6 lbs $acre^{-1}$) in both the straw treatments. Results showed that 70% wheat straw cover with PAM (2 kg ha^{-1}) reduced runoff and sediment loss by 98% and 99%, respectively compared to bare soil. 30% straw cover with PAM (2 kg ha^{-1}) reduced runoff and sediment yield by 53% and 82%, respectively compared to bare soil. 70% straw cover with PAM (4 kg ha^{-1}) significantly reduced soil loss by almost 100% compared to bare soil than 70% straw with 2 kg ha^{-1} PAM.

Lentz and Bjorneberg (2003) tested wheat straw treatment with PAM in conventially irrigated furrows. Five irrigations were performed on a 1.5% slope silt loam soil. Polyacrylamide and straw reduced sediment loss by 64% to 100% in all the irrigations. Adding PAM to low (485 kg ha^{-1}) and high (1490 kg ha^{-1}) application rates of straw treatment increased sediment loss reduction from 80% to 100% in the first two irrigations and from 94% to 99.8% in subsequent irrigations.

PAM used with seed and mulch had been effective in reducing runoff and turbidity. An experiment conducted by Hayes et al. (2005) showed that PAM used in conjunction with seed and mulch significantly decreased turbidity and sediment loss from plots compared with PAM alone. Seed/mulch with PAM reduced 83% erosion when compared to 42 ton ha^{-1} rate of bare soil from a single storm event. Roa-Espinosa et al. (1999) tested

PAM with straw and PAM alone in 1 m x 1m (3.28 ft x 3.28 ft) plots on 10% slope. Simulated rainfall with an intensity of 6.32 cm h^{-1} (2.5 in h^{-1}) was applied over each treatment. Results reported that a treatment of 22.5 kg ha^{-1} (20 lbs $acre^{-1}$) PAM and mulch applied to dry soil reduced sediment loss by 93% compared to control. Dry PAM reduced the sediment yield by 83% compared to control.

Flanagan and Canady (2006) tested the effectiveness of PAM on 4% and 8% slopes with two wheat straw cover levels of 0% and 30% under a rainfall simulator. The experiment was conducted in aluminum boxes measuring 31 cm (12 in) wide, 45 cm (18 in) long, and 30 cm (12 in) deep. Two different storms were simulated, with the first storm using a duration of 1 hour with a constant intensity of 64 mm h^{-1} (2.5 in h^{-1}). A second storm had varying intensities of 64, 94 and 25 mm h^{-1} (2.5, 3.7 and 0.98 in h^{-1}) in sequential 20 min increments. Results showed that PAM in conjunction with wheat straw reduced runoff up to 66% compared to bare soil control.

2.7 Vegetation for erosion control

The presence of vegetation has shown to be effective tool in reducing runoff and sediment loss (Marques et al. 2007). Vegetation reduces water induced erosion by intercepting rainfall, increasing the infiltration rate of the soil, intercepting runoff at the soil surface and stabilizing the soil with roots (Gyssels et al., 2005), resulting in lower soil detachment energy (Bochet and Fayos, 2004). The cover factor value of Universal soil loss equation for fallow land is 1 and for a permanent cover, C factor value is 0.001. This indicates that the same soil under a permanent grass cover is 1000 times less erosive than bare soil (Troeh and Thompson, 2005).

Cover crops were grown to provide cover in winter and fallow conditions during annual cropping systems (Meerkerk, 2008). Several studies reported on the use of cover crops as erosion control measures (Kaspar et al., 2001; Malik et al., 2000). Four species of cover crop including ryegrass (*Lolium*), crimson clover (*Trifolium incarnatum*), Sericea lespedeza (*Lespedeza cuneata*) and tall fescue (*Festuca arundinacea*) reduced soil erosion by about 64%, 61%, 51% and 37%, respectively, compared to bare soil in the early development of a short rotation woody crop plantation (Malik, et al., 2000).

Plots seeded with annual ryegrass (*Lolium Multiflorum.*) had 31% less sediment loss as compared with non-seeded plots (Gautier, 1983). Zhou and Shangguan (2007) conducted four rainfall simulator experiments with rainfall intensity of 1.5 mm min^{-1} (0.59 in min^{-1}) to investigate the effect of ryegrass (*Lolium*) on runoff and soil loss and found that runoff decreased 25% and 70%, respectively, after the 12^{th} and 27^{th} week of planting in ten ryegrass pans, 2.0 m (6.6 ft) long, 0.28 m (0.9 ft) wide, and 0.35 m (1.15 ft) deep. Sediment reduction compared to bare soil amounted to 95% in the 27^{th} week. Mitchell et al. (2003) reported that perennial ryegrass (*Lolium perenne)* reduced erosion by 46% compared to the bare soil.

Pan and Shangguan (2006) conducted an experiment on different percent of grass cover (35%, 45%, 65% and 90%) of Perennial black ryegrass (*Lolium perenne L.*) and found runoff reduction of 14%, 25%, 16%, and 21% and sediment loss reduction of 81%, 85%, 87% and 94% at 35%, 45%, 65% and 90% cover, respectively, compared to bare soil. Liu et al. (2010) performed a similar experiment to reduce erosion on loess plateau in China. They constructed artificial road sections packed with the soil from the plateau and planted differing grass covers (0%, 30%, 40%, 50%, 60% and 70%) of Kentucky bluegrass (*Poa*

Pratensis) with simulated rainfall at 120 mm hr^{-1} (4.7 in h^{-1}) for 1 hour. Increasing grass cover inhibited overland flow, increased friction and surface roughness and reduced mean flow velocities. Runoff and sediment from grass covered plots were reduced from 12.4% to 27.9% and 39% to 76%, respectively with increase in percent vegetation cover, compared to bare soil.

Gross et al. (1991) tested different seeding rates at 98, 244, 390, and 488 kg ha^{-1} (87, 218, 348 and 435 lbs $acre^{-1}$) of tall fescue (*Festuca arundinacea*) with different rainfall intensities of 76, 94 and 120 mm h^{-1} (3, 3.7 and 4.7 in h^{-1}). Results reported that at high rainfall intensity (120 mm h^{-1}), the sediment loss was reduced six times at 98 kg ha^{-1} seeding rate compared with control. There were no significant differences in sediment loss across all seeding rates at medium and low rainfall intensity. Fox et al. (2010) conducted plot scale field trails consisting of Japanese millet (*Echinochloa esculenta*) and buffel grass (*Cenchrus Ciliaris*) to control erosion on slopes of railway embankment and found that after 63 days of seeding, millet alone reduced soil erosion by 50% as compared to buffel grass alone. Soil loss was reduced by 90% compared to the bare soil control as a result of over 60% grass cover from all the seeded treatments established after 11 months of planting.

Grace (2002) tested the effectiveness of wood excelsior, native vegetation and exotic vegetation in erosion control for forest road side slopes in the Talladega National Forest in Alabama over a 4-year period in 12 plots of 1.5 m x 3.1 m (5 ft x 10 ft). The native species mixture included big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), and Alamo switch grass (*Panicum virgatum*). The exotic species mixture consisted of Kentucky 31 tall fescue (*Festuca arundinecea*), Pensacola bahiagrass

(*Paspalum notatum*), Annual lespedeza (*Lespedeza cuneata*), and white clover (*Trifolium repens*). Sediment and runoff yield was significantly reduced by vegetation compared with the bare soil control. Mean sediment yield from native species, exotic species and erosion mats was 1.1, 0.45 and 0.80 g m^{-2} mm^{-1}, (251, 100 and 178 lbs $acre^{-1}$ in^{-1}) respectively.

2.7.1 Vegetation with temporary erosion control covers

Temporary vegetation with erosion control covers proved to be a cost effective temporary stabilization and erosion control method (Idaho BMP manual, 2014). Lemly (1982) tested five different treatments including asphalt-tacked straw, jute netting, mulch blanket, wood chips and Curlex® Excelsior blanket seeded with 2 kg ha^{-1} (1.8 lbs $acre^{-1}$)of tall fescue. All the treatments reduced erosion by approximately 75%, as compared to the bare soil control. Grass coverage was significantly increased by the introduction of all the treatments and results showed that all treatments obtained grass coverage of approximately 75% within three months after seeding. Bare soil plots had only 40% cover in same period.

Megahan et al. (2006) studied different erosion control practices on granitic road fills for forest roads in Idaho. They used different plots 1-8 m (3-26 ft) wide and 4-6 m (13-20 ft) long to calculate runoff. They found that combining mulch with vegetation was a more effective erosion control measures than mulch alone or vegetation alone. Xin-Hu et al. (2011) conducted an experiment to determine runoff and soil loss from a 5 m x 15 m (16 ft x 49 ft) plot for a duration of five years (2001-2005) using cover (Bahiagrass), mulch and bare soil. They found that Bahiagrass (*Paspalum notatum*) and mulch plots had less erosion and runoff compared to bare soil and suggested that Bahia grass cover was excellent as it is easier to use and therefore a feasible practice for soils in Southern China.

Dougherty et al. (2008) found out that 75% establishment of Bermudagrass cover took approximately 90 days from seeding. Three general stages of vegetation growth including: 1) 0% to 50% cover providing the highest sediment yield (0-45 days after seeding) 2) 50% to 75% with moderate sediment yield (50-60 DAS) 3) 75% to 100% were reported with lowest sediment yield (> 80 DAS). Dougherty et al (2010) found that adding PAM hydromulch did not significantly improve seeding grass establishment when compared to a non-PAM hydromulch treatment. Hydromulch was more effective than erosion control blanket or loose straw treatments in terms of grass establishment.

Baharanyi (2010) tested the differences in Bermudagrass establishment with temporary covers like wheat straw, erosion control blankets, and hydromulch with and without PAM. He found that after the first 90 days of planting, PAM application had no effect on Bermudagrass establishment and Bermudagrass was established quicker with hydromulch, compared with loose straw or erosion control blankets.

2.7.2 Line point intercept method for vegetation cover determination

There are several methods to determine the extent of vegetation cover, including point based sampling and line intercept sampling method. The standard alternative to the point based sampling method is the line intersect sampling method (Jennings et al., 1999, Williams et al., 2003). The points on the line where the canopy cover begins and ends are recorded using tape measure and percentage cover is calculated by number of points hitting the canopy projecting from the top to the total number of points in a transect. The lines should be placed in either systematic or random way covering the entire plot (Jennings et al., 1999, Williams et al., 2003).

Godinez-Alvarez et al. (2009) used the line point intercept method along a 70 m (230 ft) baseline with four 70 m (230 ft) transects spaced equally 10 m (33 ft) apart to analyze foliar cover in the Chihuahuan Desert in Mexico. Cover was recorded after every 1 m, with 70 points per transect. Percent cover as measured from the line transect method was significantly higher than subjective visual estimates. Weltz et al. (1994) used the line intercept point transect method in a 20 pin vertical point frequency frame on 0.5 m x 1 m (1.6 x 3.2 ft) quadrats located along line intercept transects. Three 20 point pin frames were evaluated, resulting in a total of 60 points. Plant height, canopy cover and canopy diameter were estimated using this method.

Ruthven et al. (1993) used the line intersect method to estimate woody plant canopy cover with twenty five transects ranging from 72 to 351 m (236 to 1152 ft) long with four 20 m (66 ft) lines placed along and perpendicular to the transect, leading to a total of 100 points per site. Booth et al. (2006) used a sighting device or pin to read points along the transect. Readings were recorded observing the color at every 10 cm (0.33 ft) increment on a tape stretched along the transect.

Etchberger and Krausman (1997) studied five different methods, including the line intercept method, to sample desert vegetation Tumamoc Hill, Pima County, Arizona. Four 30 m (98 ft) transects were randomly placed at 12 points, a total of 40 transects. The total vegetation cover was calculated not by measuring the length of vegetation canopy intercept, but by dividing the total number of hits for a plant species by the total number of hits for all species.

2.8 Rainfall simulator use in erosion control experiments

The use of rainfall simulators in erosion studies is not new (Young and Burwell, 1972). As researchers require erosion and sediment control experiments suitable for repetitive testing, use of simulated rainfall to generate runoff has increased (Benik et al., 2003; Bjorneberg et al., 2000; Flanagan et al., 1997; Flanagan et al., 2002a; McLaughlin and Brown, 2006; Peterson et al., 2002; Roa-Espinosa et al., 1999; Sepaskhah and Bazrafshan Jahromi 2006; Shoemaker, 2009; Wilson, 2010).

Cerda et al. (1997) used a nozzle, a structure in which the nozzle was installed and connections with water supply and pumping systems. A wind protector to avoid interference during the experiment was highly recommended. The nozzle was connected directly to the pump by a single pipe. The height of the nozzle was 2 m (6.6 ft) above the soil surface. The pumping system was operated mechanically or by hand. They found that the most homogenous rainfall distribution was found at water pressure of 1.55 kg cm^{-2} (22 psi) and the rain intensity at this pressure was 54.6 mm h^{-1} (2.15 in h^{-1}).

Esteves et al. (2000) designed and field tested a rainfall simulator for 5 m x 10 m (16 ft x 32 ft) plots. The rainfall simulator was 6.58 m (22 ft) high with a 25.4 mm (1 in) galvanized vertical standpipe. A nozzle was mounted at the end of the stand pipe which sprayed a square area of 7 m x 7 m (23 ft x 23 ft). The spraying system nozzle was mounted at a height of 6.53 m (21 ft) at the top of the pipe and the water was jetted to the height of approximately 8 m (26 ft). An oil-immersed pressure gauge and cut off valve was installed at the bottom of the pipe to achieve pressure control. Six rainfall simulators were combined along two lines to spray the 50 m^2 (538 ft^2) plot. Guy ropes attached to stand pipes were used to stabilize the system. The system was supplied by a pump from a storage tank near the plots. Rainfall intensity was changed by adjusting water pressure. The rainfall intensity produced by the rainfall simulator was 75 mm h^{-1} (3 in h^{-1}) at a constant water pressure of 47.8 kPa (7 psi). Faucette et al. (2004) used eight V-jet nozzles in a rainfall simulator obtained from the USDA National Soil Erosion Research Laboratory. The spray area of the uniform rainfall with simulator was 6 m x 2 m (20 ft x 7 ft).

Miller (1987) used a portable, variable-intensity and low cost rainfall simulator in runoff erosion studies that could be adapted for large plot studies for field use. Intensity was varied from 0.0004 mm s^{-1} (0.056 in h^{-1}) to 0.024 mm s^{-1} (0.34 in h^{-1}) at 29 kPa (4.2 psi) water pressure by closing and opening electrically operated solenoid valve into which wide square spray nozzles were fitted and controlled via switches operated by a rotating cam or microcomputer. The coefficient of uniformity was 90% to 95% under a single nozzle in a 1 m^2 (10.76 ft^2) field plot and 85% to 90% under a three nozzle system in a 1 x 3 m field plot. Similarly, Munn (1974) built a highly portable rainfall simulator to study the erosion potential of different soil types in the Lake Tahoe Basin. Water was supplied by a 20 L (5.3 gallon) jug attached to the top of the simulator. Rainfall occurred over 0.71 x 0.71 m (2.3 ft x 2.3 ft) square area and runoff was collected into collection jars from 0.61 x 0.61 m 9 2 ft x 2 ft) plots during 15 min long storms.

Grierson and Oades (1977) used a rainfall simulator mounted on a 1.8 x 1.2 m (6 ft x 4 ft) steel trailer for a field study of erosion and runoff. A frame of steel tubing was used to support the roof canopy and two side doors. Water was stored in two 200 L (53 gallon) reservoirs mounted over the trailer. The nozzle was 2 m (6.6 ft) above the ground and rested over a hole cut in the roof over the center of the plot with simulated rainfall intensity ranges from 0.6 cm h^{-1} to 15 cm h^{-1}. Freebairn and Gupta (1990) used a drop-former simulator on

0.91 m (3 ft) wide and 1.52 m (5 ft) long plots to study the role of cover, micro-topography and antecedent rainfall on infiltration in fields subject to different tillage regimes in Minnesota where corn had been continuously cropped for 3 years prior to the study. The rainfall simulator was 2.5 m (8.2 ft) above the plots with simulation intesntiy of 100 mm h^{-1} (4 in h^{-1}) and runoff was measured by a tipping bucket mechanism. They found that increased surface roughness decreased runoff when a surface cover was present.

Navas (1993) used a nozzle type simulator on 1.3 m x 1.3 m (4.1 ft x 4.1 ft) plots to examine soil loss affected by different slopes, soil types and cover. Surface was wetted in the first test with cover, and then the cover was removed during the second test, leaving bare soil. Runoff was collected regularly at three-minute intervals. The study found that runoff decreased with cover and increased with slope. Greene et al. (1994) used a trailer mounted, nozzle type simulator over 1 m^2 (10.76 ft^2) plots to study the effect of plant cover on runoff and erosion in Australia. Uniform runoff occurred for rainfall duration between 30 and 60 minutes. Runoff was collected with the help of a channel at the downslope end by using a steel plot frame. They found that increased cover reduced runoff, but had no effect on sediment concentration.

Roth et al. (1985) developed a simple and easily operated rainfall simulator for infiltration research in Brazil. The water delivery structure was mounted at a height of 3 m above the ground containing four water reservoirs. Drop size depended upon the different tube diameters and rainfall intensity was verified between 0-185 mm h^{-1} (0-7.3 in h^{-1}) by adjusting water head in the reservoir. Rainfall intensify was 60% to 80% of the kinetic energy of natural rainfall, calculated by an equation 2-1 developed by Foster et al. (1981).

$$e = 0.119 + 0.0873\ \log(i) \qquad (2.1)$$

Where, i = intensity of rainfall (mm h^{-1})

e = rainfall energy (MJ ha^{-1} mm^{-1})

Martinez et al. (2001) constructed a rainfall simulator consisting of a square frame with 2.5 m (8.2 ft) sides and supported by four pillars of 3.6 m (11.8 ft) to study change in physical properties of the soil on 2 m x 2 m (6.6 ft x 6.6 ft) plots. They used two different nozzles under pressures of 100 kPa (14.5 psi) and 90 kPa (13.05 psi) to produce rainfall intensities of 33 mm h^{-1} (1.3 in h^{-1}) and 60 mm h^{-1} (2.4 in h^{-1}) , respectively.

Cornelis et al. (2004) studied the effect of wind and rainfall on soil erosion with the help of a rainfall simulator and wind tunnel. The simulator was constructed with three pipes attached to the sprinkler delivering pressurized water covering a 1.2 x 1.2 m (4 ft x 4 ft) section. Arnaez et al. (2007) constructed a rainfall simulator with a sprinkler mounted at a height of 2.5 m (8.2 ft) with pressurized water for 30 min simulations to compare runoff and sediment production under different rainfall intensities in a vineyard plantation in Spain. Three different rainfall intensities i.e. < 40, between 40 and 70 and >70 mm h^{-1} were used with low intensity, intermediate intensity and high intensity nozzles, respectively.

Sheridan et al. (2008) used a rainfall simulator on 1.5 m x 2 m (5 ft x 6.6 ft) plots to predict modified erodibility indices to estimate annual erosion rates for forest roads. The rainfall intensity was fixed at 100 mm h^{-1} (3.9 in h^{-1}) with a 30 min simulation and estimated rainfall energy of 0.295 MJ ha^{-1} mm^{-1} as calculated by an equation 2.1 developed by Fosters et al. (1981), was found to be similar to the energy of a high intensity rainfall. Table 2.6 summarizes the important literature of rainfall simulator.

Table 2.6: Important rainfall simulator literature summary

Study	Test plots	Nozzle height (m)	Rainfall Intensity (cm h^{-1})
Cerda et al. (1997)	UNK[1]	2	5.5
Esteves et al. (2000)	Large	6.5	7.5
Grierson and Oades (1977)	Small	2	0.6-15
Freebairn and Gupta (1990)	Small	2.5	10
Roth et al. (1985)	UNK	3	0-19
Martinez et al. (2001)	Small	2.5	3.3-6
Arnaez et al. (2007)	UNK	2.5	<4, 4-7, and >7

[1]Unknown

2.9 Cost of erosion control BMPs in previous studies

Jin and Englande (2008) tested five erosion control measures againsta bare soil as control in Louisiana, US. The cost of temporary seeding used in the study was \$0.20 per 92 m^2 (990 ft^2) and cost of straw bedding was \$5 per 92 m^2 (990 ft^2). The most cost effective treatment was temporary seeding using perennial ryegrass, with 10.9 metric tons (12 tons) of soil loss per acre per year per unit price. Wear et al. (2013) tested three erosion and sedimentation control BMPs for skidder stream crossing. The cost of straw mulch and seed was \$280 per stream crossing. Babcock and McLaughlin (2013) found that adding PAM to straw ground cover was cost effective, and produced results similar to hydromulch. Bahranyi (2010) reported the cost of loose straw as \$0.60 m^{-2} (\$ 0.056 ft^2) and hydromulch as \$0.30 m^{-2} (\$0.028 ft^2). Grace (2000) found that use of exotic species cost about \$ 2400 ha^{-1} (\$971 $acre^{-1}$) and native species as \$2400 ha^{-1} (\$ 971 $acre^{-1}$), four times cheaper than an erosion mat treatment. The cost of PAM ranged from \$4.5 to \$12 when applied at an application rate of 1 to 5 kg ha^{-1} (0.89 to 4.5 lbs $acre^{-1}$) (Sojka et al., 1998). Faucette et al. (2009) reported that the installation cost of straw as \$2.87 per 30 cm, compared to the cost of sediment control devices as \$1 to \$2.87 per 30 cm. Ageyi (2004) tested erosion control blankets and mulch to aid grass establishment on steep slopes and found that seeding can be the most cost effective treatment to reduce soil erosion. The total cost of hand applied straw could exceed \$12500 ha^{-1} (\$5058 $acre^{-1}$) and found that mulching can be effective and expensive to reduce sediment yield, but requires detailed economic assessment (Wohlgemuth et al. 2006). A hydromulch with bonded fiber matrix and tackifier delivered as a slurry at a cost of \$5000 ha^{-1} (\$2023 $acre^{-1}$) (Hubbert, 2004). Kay (1980) proved that a rough seedbed or covering the seed may be the cheapest erosion control measure for establishing vegetation. The study also concluded that straw plus tackifier is more useful than any other expensive treatments in terms of erosion control and plant establishment.

2.10 Literature review summary

Runoff and its attributed sediment has been recorded as the largest contributor of non-point source pollution in the US. Several BMPs are used to control runoff, and to prevent sediment loading to water bodies. In this chapter, the impact of runoff on water quality with other toxic metals attached with the sediments entering the water body and applicable USEPA regulations have been discussed. Due to its relatively inexpensive cost and ease of application, PAM has been widely used to increase infiltration and reduce sediment delivery and turbidity. Vegetation can be an effective erosion control measure compared with other mechanical and chemical covers, but requires further research. Literature emphasizes the use of seeding with straw and hydromulch, and it has been found that combining straw or hydromulch with seeding can be more effective for erosion control than seeding alone.

Straw mulching can be the cheapest and effective method of erosion control. Literature suggests that wheat straw with and without seed can reduce a significant amount of sediment loss and turbidity. Hydromulch is a newer practice in the industry, being tested as more effective than other erosion control covers. Rainfall simulators can be an effective alternative to natural rainfall as one can set the intensity of repetitive rainfall events according to the natural rainfall of that area or whatever intensity is desired. The literature summarizes the use of PAM with wheat straw, hydromulching on seeded plots, and combining straw or hydromulch with vegetation all of which can be an effective erosion control measure.

CHAPTER 3 MATERIALS AND METHODS

3.1 Introduction to the study

This section describes the methods used to test the effectiveness of selected erosion control covers with and without vegetation to reduce erosion and improve runoff water quality. This study was carried out to determine the effects on water quality during plant establishment when temporary covers supplement growing vegetation. Previous studies in the department of Biosystems engineering by Baharanyi (2010) and Messer (2011) were conducted on a large plot scale 3 m x 7.6 m (10 ft x 25 ft). This study was conducted on test plots having dimensions of 1.2 m x 0.6 m (3.9 ft x 1.8 ft) designed to compare selected treatments under simulated rainfall during vegetation establishment. The test plots were placed on a 3:1 slope using cinder block and lumber to create a slope. A 15 minute rainfall was applied to treatments using a fabricated portable rainfall simulator. The test plot design was similar to test plots used by Shoemaker (2009). Data collection consisted of runoff volume, turbidity, MTSS, and percent vegetation cover. The percent vegetation cover was monitored to quantify the performance of the seeded treatments during the establishment period. Parametric and non-parametric tests to determine the significance between the treatments were performed on normal and non-normal data, respectively. Installed costs of each treatment were used to evaluate cost effectiveness of each treatment in terms of sediment delivery reduction compared to an untreated bare soil.

3.2 Study site description and experimental set-up

The study site is located at Auburn University's Department of Crop, Soil and Environmental Sciences (CSES) Turfgrass Research Unit (TGRU) at 105 Shug Jordan Parkway, Auburn, AL. A galvanized steel frame hoop house 11 m x 7.5 m (35 ft x 24 ft) with tarps installed was used to cover the test plots, providing shelter from natural rain, and eliminating cross winds during simulated rainfall testing. Five meters of house length was covered with clear plastic tarps under which the seeded treatments were placed to expose them to sunlight. The remaining 5.5 m of roofline was covered with heavy duty tarps secured at the top and sides (Figure 3.1 and 3.2). Annual ryegrass (*Lolium multiflorum)* and Browntop millet (*Panicum ramosum*) were used as the temporary vegetation in this study. Pressurized water supply used for simulating rainfall was provided by a hose bib adjacent to the plots.

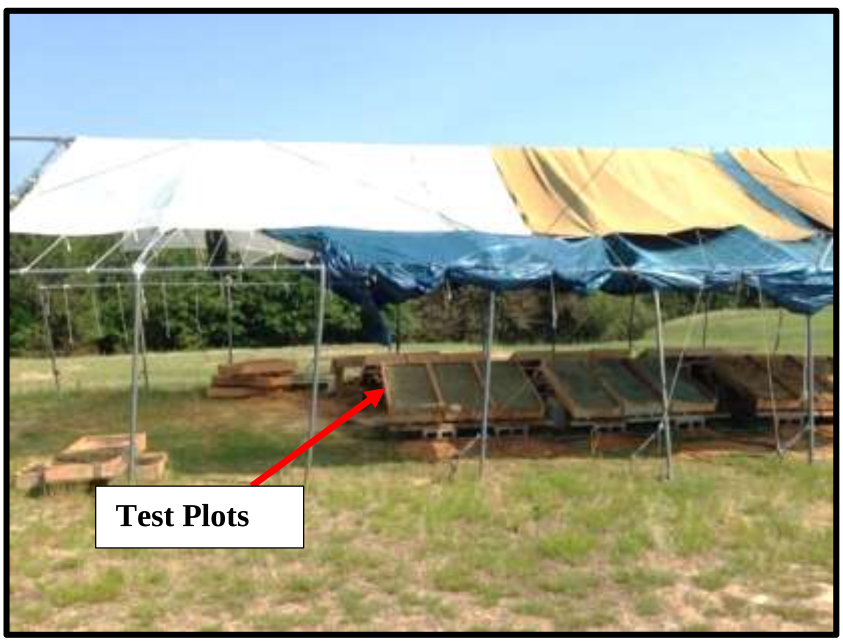


Figure 3.1: Experimental installation in Auburn, AL showing placement of test plots at 3:1 slope and placement of tarps for rain and wind protection

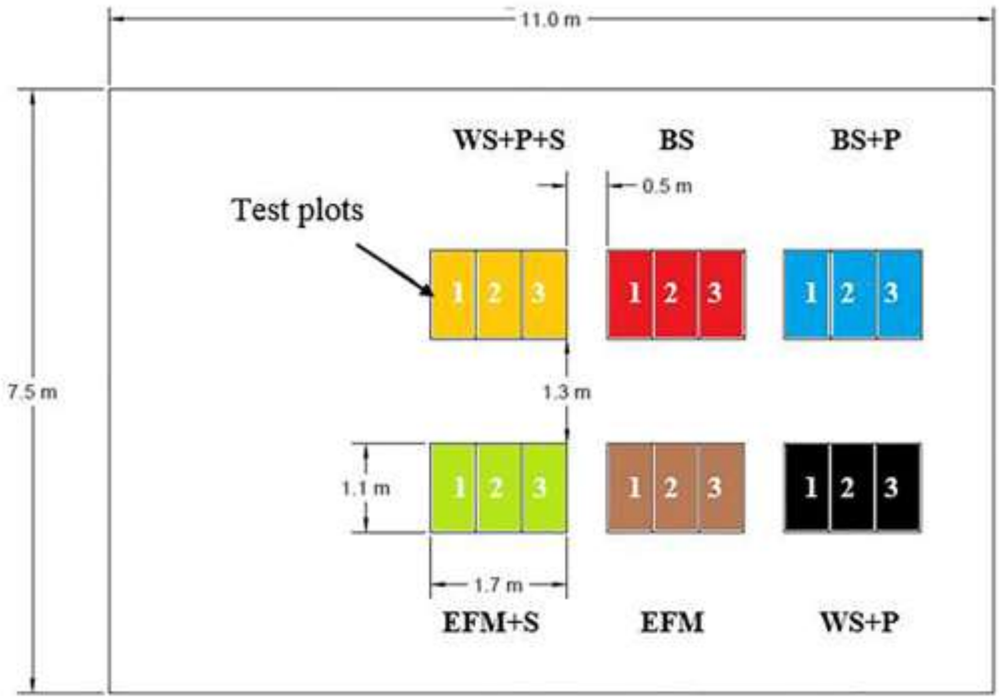


Figure 3.2: Experimental layout of test plots and treatments under hoop house structure, TGRU, Auburn, AL

Note: BS (Bare soil), BS+P (Bare soil with PAM),

EFM (Engineered fiber matrix), EFM+S (EFM with seed),

WS+P (Wheat straw with PAM), WS+P+S (WS+P with seed)

Table 3.1 provides information about the test periods, along with planting and sample dates and also the different plant species used along with their scientific names.

Table 3.1: Study period dates with plant species and planting dates

Growth Period	Plant species	Planting date	Sample Dates
Preliminary[1]	Annual ryegrass (*Lolium multiflorum.)*	1 Oct. 2013	21 Oct. -19 Nov. 2013
I	Annual ryegrass (*Lolium multiflorum*)	13 Mar. 2014	21 Mar. - 5 May 2014
II	Browntop millet (*Panicum ramosum*)	22 May 2014	27 May - 14 July 2014

[1] Data treated as preliminary to set up monitoring and sampling protocols

3.3 Test soil analysis and composition

The soil used in the study was taken from the road banks of the forested site located at Pittsview in Russell County, AL (32º 9’29.30”N, and 85º 10’ 8.09”W) and owned by Alabama General Contractors Association (AGC) (Figure 3.3). Nearly 3.4 m^3 (120 ft^3) of soil was excavated and transported by dump truck to the TGRU on 30 July, 2013. Transported soil was stored under tarps until use.

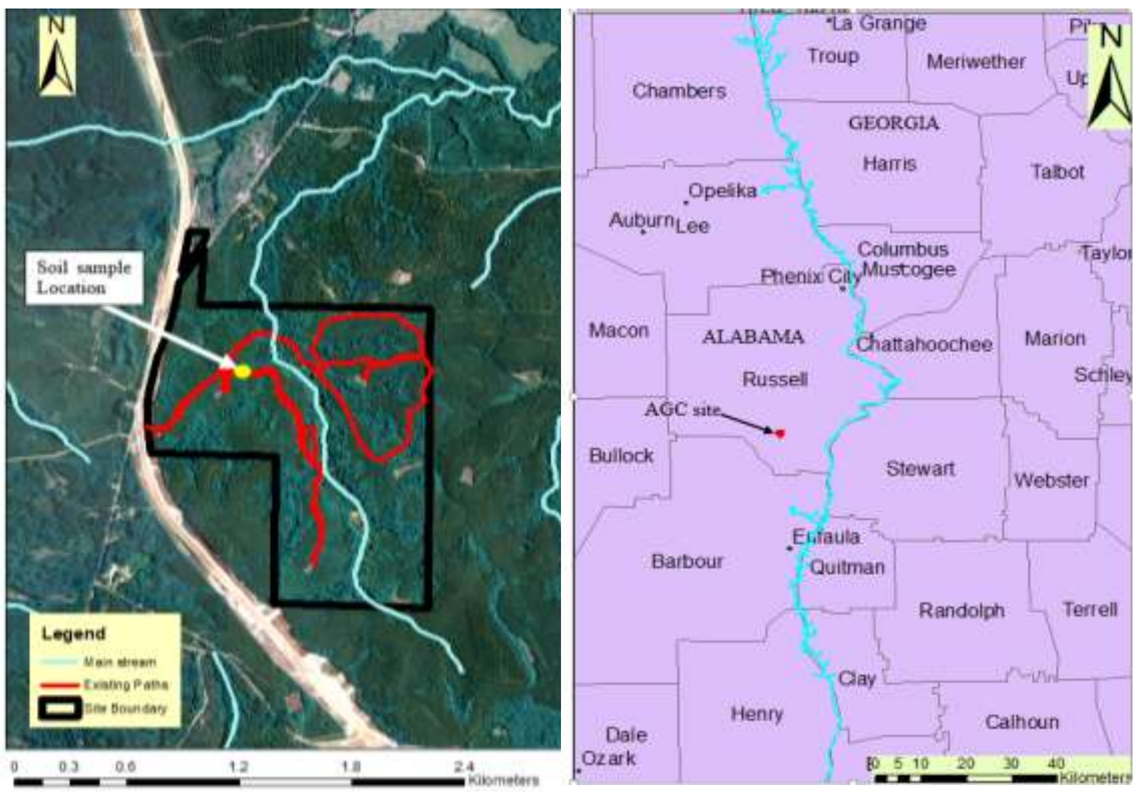


Figure 3.3: Alabama General Contractors (AGC) site soil sample location maps, Russell Co, AL

The road bank location from where soil was taken is shown in Figure 3.4. Composite samples were taken from the soil (Figure 3.5) and soil analyses were conducted by Auburn University Soil Testing Laboratory (AUSTL) to determine soil texture and fertilizer recommendations for grass cover.

Figure 3.4: Source for study soil: eroded road bank, Russell County,

Figure 3.5: Taking composite samples of soil for fertility and textural analysis

Soil fertility testing was performed twice, one before preliminary test period (17 August, 2013) and other before test period II (16 May, 2014). Soil textural analysis (Table 3.2) yielded very high sand and clay content with smaller amounts of silt. The resulting textural class was sandy clay. The textural analysis performed before test period II yielded the same soil texture. Soil reports recommended lime of 7.8 metric tons ha^{-1} (3.5 tons $acre^{-1}$) and 6.7 metric tons ha^{-1} (3 tons $acre^{-1}$) in a soil test report before preliminary tests and before test period II, respectively. Annual ryegrass (*Lolium multiflorum*) was chosen as the seeded treatment for test period I. Annual ryegrass is a cool season annual and so that it can be grown in early winter and spring. Browntop Millet (*Panicum ramosum)* was grown in test period II in summer 2014 as warm season annual.

Table 3.2: Percent composition and textural class of experimental soil

Soil test report date	% Sand	% Silt	% Clay	Textural Class
17 Aug., 2013	46.3	15.6	38.1	Sandy Clay
16 May, 2014	45.6	16.3	38.1	Sandy Clay

3.4 Design and preparation of test plots

Test plots were constructed similar to Shoemaker's (2009) test plots with pressure treated lumber of 0.6 m (1.8 ft) width, 1.2 m (3.9 ft) length, and 0.1 m (0.46 ft) depth (Figure 3.6) placed on a 3:1 slope using cinder blocks (Figure 3.7). Each of the test plot bottoms were constructed from 1.3 cm (0.5 in) thick exterior grade plywood. Additional lumber was fixed to the bottoms of selected plywood boxes for reinforcement. Drain holes of 3.2 cm (1.3 in) diameter, were drilled at the bottom of the boxes for drainage during simulated rainfall events. A permeable fabric was placed over the drill holes prior to soil placement to prevent soil loss. A weir of 0.3 m (12 in) was cut into the front face of each plot to direct water flow into fabricated flumes. Metal flumes were fabricated of sheet metal to divert surface runoff from each test plot into collection buckets (Figure 3.8). Flumes were fixed at the front face of each plot into the soil.

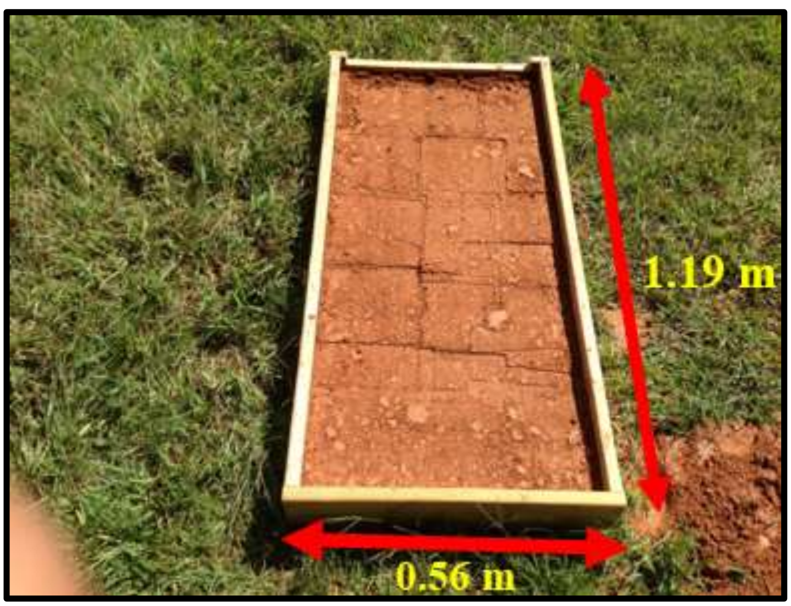


Figure 3.6: Soil filled and compacted small scale test plots

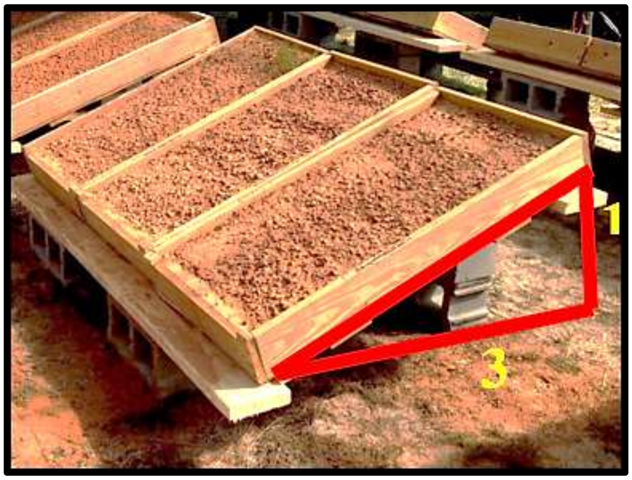


Figure 3.7: Test plots placed on 3:1 slope using concrete blocks and lumber

Figure 3.8: Flumes to direct runoff from test plots into collection buckets

Shoemaker (2009) achieved a target 95% maximum soil density using ASTM D 698 standard proctor density. McLaughlin and Brown, (2006) provided typical seedbed preparation along a roadside to provide loose soil and match the bulk density of the soil. In the present study, compaction was done to approximate the dry bulk density of the native soil as a suitable seed bed. The sum of an equal number of hand tamps was used to simulate the native seedbed and subsoil system for the vegetation establishment experiments, as follows.

A core sample was taken from the soil site in Russell County, AL. Dry bulk density of the soil was determined by *in-situ* core sampling and found out to be 0.9 g cm^{-3}. A mold box 25.4 cm x 25.4 cm (10 in x 10 in) was constructed and filled with native soil from the site (Figure 3.9). Soil in the mold box was tamped several times to achieve similar dry bulk density as the original soil. The number of hand tamps required to achieve a dry bulk density of 0.9 g cm^{-3} was 60. This number of hand tamps was subsequently used to prepare each test plot. Testing and tamping of the soil was done with air dry soil. No water was added to the soil while packing into the test plots.

Figure 3.9: Mold box (25.4 cm x 25.4 cm) used to determine required tamps to achieve a field bulk density of 0.9 g cm^{-3}

Test boxes were filled using four 19 L (5 gallon) buckets to spread soil evenly to 15 cm (6 in). The soil was then compacted to 5 cm (2 in) from the top resulting in total of 10 cm (4 in) of soil in each box. The soil in each test plot was hand tamped 60 times uniformly along the test plot (Figure 3.10) and then raked to approximately 5 cm (2 in) of loose surface depth after compaction. Refilling of boxes before test period I and II was done by removing the top soil, treatments and any grass grown. Two additional 19 L (5 gallon) buckets of native soil were added, then again compacted 60 times and raked to approximately 5 cm (2 in) of depth before the start of the new test period.

Figure 3.10: Compaction of soil boxes (119 cm x 56 cm) by hand tamping

3.5 Portable rainfall simulator

The rainfall simulator (Figure 3.11) consisted of 1.9 cm (0.75 in) galvanized steel pipe, sprinkler nozzle, water filter, pressure regulator, pressure gauge, garden hose, and ball valve. The sprinkler nozzle was installed 3.05 m (10 ft) above the ground to provide a rectangular spray area of 2.4 m x 2.4 m (7.9 ft x 7.9 ft). A Single FullJet™ ½ HH – 30WSQ spray nozzle manufactured by Spraying Systems, Co. (Wheaton, IL) was used for the rainfall simulator. Shoemaker (2009) used the same nozzle for his study. A Senninger® PMR-10 MF pressure regulator manufactured by Senninger Irrigation Inc., Clermont, FL with an operating pressure of 0.69 bar (10 psi) was attached to provide a flow rate of 11.37 L min^{-1} (3 gpm). An Arkal® water filter with connection diameter of 1.9 cm (0.75 in) manufactured by Arkal Filtration Systems, (Israel) was attached to the water inlet to prevent nozzle clogging. A pressure gauge was placed after the water filter to monitor operating pressure and a brass ball valve was used to start and end testing. A heavy duty hose conveyed water from a pressurized water source at the site. Three test plots of each treatment were tested simultaneously. To mitigate the effects of wind during testing, the rainfall simulator was fully enclosed in a temporary chamber made of tarps.

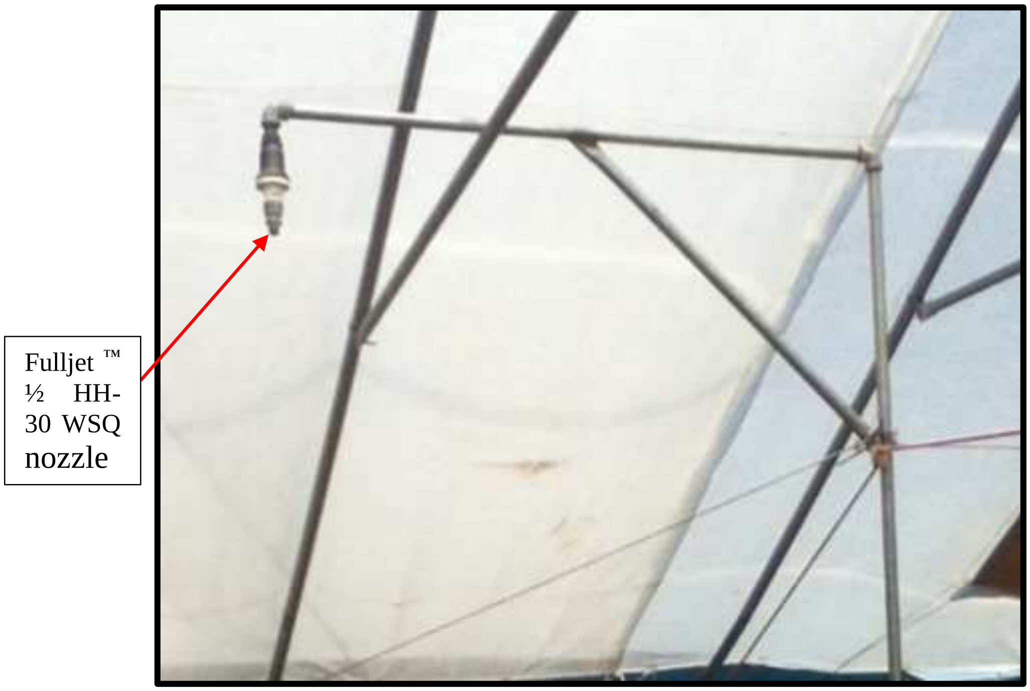


Figure 3.11: Portable galvanized steel rainfall simulator with sprinkler nozzle

3.5.1 Uniformity of simulated rainfall

A uniform distribution is desirable for simulated rainfall on test plots (Hudson, 1993). Lowest distribution uniformity testing developed by USDA, NRCS was performed to assure a uniform distribution of rainfall during testing. Both the distribution uniformity and precipitation rate for the rainfall simulator was calculated. Twenty catch cans 30 cm (12 in) apart were placed in five lines with each line 28 cm (11 in) apart (Figure 3.12 and 3.13). Run time for the uniformity testing was six minutes. The volume in each catch can was recorded and the average catch of the five lowest catches (ml) was calculated.

Figure 3.12: Placement of catch cans over test plots during uniformity testing, TGRU, Auburn, AL

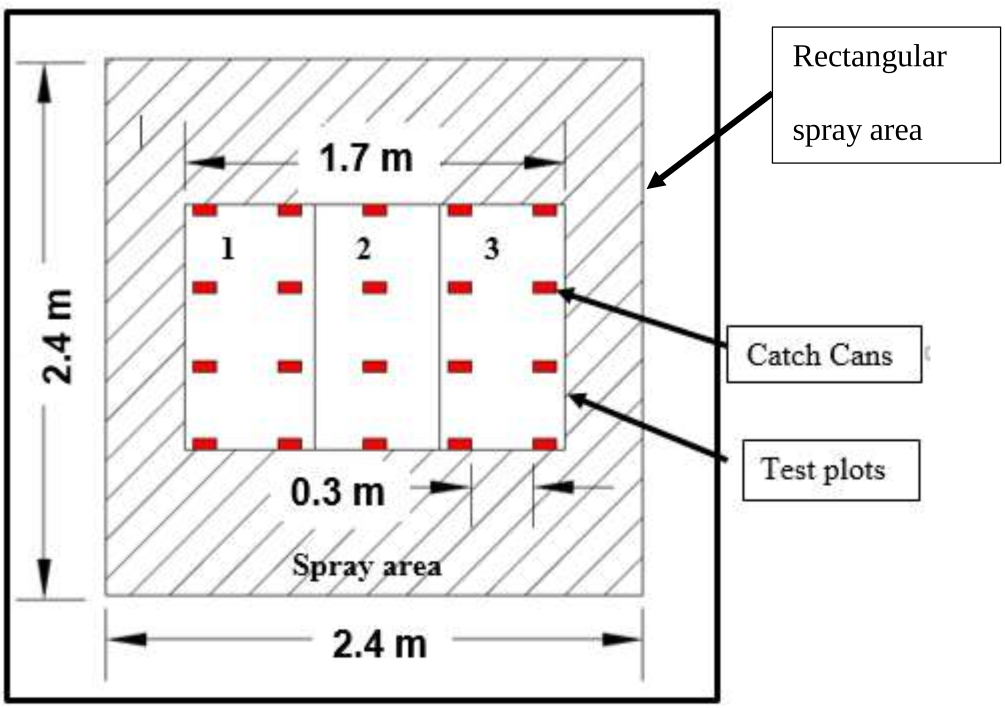


Figure 3.13: Layout of catch cans on test plots to determine the lowest distribution uniformity

Lowest distribution uniformity was calculated using Equation 3.1 (Duke and Perry, 2006) and determined to be 73.5% (Table 3.3), which is good for sprinkler system (The Irrigation Association, 2002).

$$Du = \left(\frac{Q_l}{Q_t}\right) \times 100 \qquad (3.1)$$

Where D_U = Lowest distribution uniformity Q_l= Avg. Catch in lowest quarter

Q_t= Average catch

Table 3.3: Uniformity at six test plot locations

Test plot	Uniformity
1	67.1%
2	79.1%
3	69.4%
4	75.3%
5	72.1%
6	78.3%
Average	73.5%

3.5.2 Rainfall regime

A 2-year 24-hour design depth is often used by researchers in testing of erosion control BMPs (ASWCC, 2009) but was not feasible in this study due to the number of test plots and resulting collection limitations. According to the manufacturer specifications, the nozzle can produce a flow rate of 11.37 L min^{-1} (3 gpm) at 70 kPa (10 psi) pressure which was verified in the field by placing 5 gallon bucket under the nozzle. As per Figure 3.13, the spray nozzle provided a rectangular spray area 2.4 m x 2.4 m (7.9 ft x 7.9 ft). The intensity of simulated rainfall can be calculated by using equation 3.2 (Jain Irrigation System Ltd., India):

$$I = \frac{60 \times F}{A} \tag{3.2}$$

Where, I = Intensity of rainfall (mm hr^{-1})

F = Flow rate (L min^{-1}) = 11.37 L min^{-1}

A = Spray Area (m^2) = 2.4 m x 2.4 m

Resulting intensity was 11.84 cm h^{-1} and the precipitation depth based on the 15 minute rainfall runtime was 2.96 cm (1.16 in.) of rainfall. Based on City of Auburn precipitation data for the past 36 years, the 90^{th} percentile storm depth for 2 year-15 min and 2 year-30 min ranges between 2.3 cm (0.9 in) to 3.3 cm (1.3 in) (NOAA, 2014). Simulated rainfall was designed to match the rainfall depth between a 2-year 15-minute and 2-year-30 minute storm event for the area.

3.6 Treatments

Initially, six erosion and sediment control treatments were tested in this study including the bare soil control and bare soil with PAM and seed (BS+P+S) treatment. However after preliminary testing, the vegetation stand failed in BS+P+S. Previous literature indicates that PAM application is not correlated with vegetation establishment (McLaughlin and Brown, 2006; Baharanyi, 2010). Consequently, a bare soil with PAM and seed treatment was not included in this study. Table 3.4 summarizes the six treatments tested with labels, trade name, manufactures, and content.

Table 3.4: Treatments with their trade names, manufacturers and content used in the study

Treatment with labels	Trade name	Manufacturer	Content
Bare soil (BS)			
Bare soil with Polyacrylamide (PAM) (BS+P)	EnviroPAM®	Innovative Turf Solutions, Cincinnati, OH	Sodium Acrylamide Copolymer
Engineered Fiber Matrix (EFM)	Promatrix™ EFM	Profile Products, Buffalo Groove, IL	Wood Fiber
Engineered Fiber Matrix with seed (EFM+S)	Promatrix™ EFM	Profile Products, Buffalo Groove, IL	Wood Fiber
Wheat straw with PAM (WS+P)	EnviroPAM®	Innovative Turf Solutions, Cincinnati, OH	Wheat straw
Wheat straw with PAM and seed (WS+P+S)	EnviroPAM®	Innovative Turf Solutions, Cincinnati, OH	Wheat straw

3.6.1 PAM application (Treatments: BS+P, WS+P, and WS+P+S)

EnviroPAM distributed by Innovative Turf Solutions, (Cincinnati, OH) was used in this study. Jar testing of PAM was performed in accordance with Mississippi Department of Environmental Quality (MDEQ, 2007) recommendations to confirm that the product was an effective flocculant for the tested soil. A 473 ml bottle was filled with water and a pinch of PAM was added with a teaspoon of soil. The solution was shaken for 20 seconds and allowed to sit. The addition of PAM resulted in soil particle settlement in the jar indicating suitability for the study soil. PAM was consequently applied uniformly to appropriate test plots (BS+P, WS+P, WS+P+S) using a salt shaker at the manufacturer recommended application rate of 10 kg ha^{-1} (9 lbs $acre^{-1}$), equivalent to 0.70 g per plot.

3.6.2 Wheat straw application (Treatments: WS+P, WS+P+S)

Wheat straw is the most commonly used straw and can be applied by mechanical mulch blower or by hand (ASWCC, 2009). Typical application of wheat straw is accomplished by chopping and blowing straw onto the land surface to achieve approximately 75% coverage (Pitt et al. 2007) (Figure 3.14). The ASWCC (2009) recommended application rate of wheat straw was 4,480 kg ha^{-1} (4,000 lbs $acre^{-1}$), which is equivalent to 333 g per plot. Wheat straw was weighed and applied by hand and Figure 3.15 shows the thickness of applied wheat straw when applied at the ASWCC recommended application rate. Based on experience with previous test plots, the ASWCC application rate was halved to 167 g (0.37 lbs) per plot to prevent smothering of seed and ensure proper germination.

Figure 3.14: Wheat straw application by straw blower as performed in a commercial application

Figure 3.15: Wheat straw application by hand at the ASWCC recommended rate of 4480 kg ha^{-1}, TGRU, Auburn, AL

3.6.3 Hydraulic mulch application (EFM, EFM+S)

The hydraulic applied product tested as a temporary cover in this study was Promatrix® EFM manufactured by Profile Products, Buffalo Grove, IL. This Product has been approved by the Alabama Department of Transportation (ALDOT)-Product Evaluation Board (PEB) for rolled and hydraulic erosion control products (ALDOT, 2014). The EFM was applied using a hydromulcher system and a precision applicator, as described below. The manufacturer's recommended EFM application rate was 3,362 kg ha^{-1} (3,000 lbs $acre^{-1}$).

3.6.4 Hydromulcher/Precision applicator system

The hydromulcher used to apply the Promatrix® EFM treatment was the Turf Maker® 380 manufactured by Turf Maker (Rowlett,TX) and shown in the Figure 3.16. The capacity of the hydroseeder is 1,438 L (380 gallons) of hydromulch and water mixture. In additon to a storage tank, the main components of the hydromulcher are a gasoline powered engine, belt driven pump, and mechanical agitator.

Figure 3.16: Hydromulcher Turf Maker® 380, TGRU, Auburn, AL

The pressurized hyromulcher outlet was connected to a hyrdomulcher precision applicator system developed by the Agricultural Research Station (ARS) in Lubbock, TX. The main components of the hydromulcher system are a steel gantry, a variable frequency drive (VFD) controller, pump/agitator, and main power disconnect (Figure 3.17). The gantry has overall dimensions of 6.37 m x 2.43 m x 2.51 m (21 ft x 8 ft x 8.2 ft) including electrical connections, quick connects, and spray nozzle. The VFD controller has dimensions of 1.25 m x 0.72 m x 0.53 m (4 ft x 2.4 ft x 1.7 ft) with electric connections as its main components. Main power to the gantry is supplied through the VFD electrical controller. During testing, hydroseeder discharge was connected to a hose using a 3.8 cm (1.5 in) banjo quick-connect. The hydroseeder hose and pump was connected to the gantry hose and nozzle with a 5 cm (2 in) banjo quick-connect. A garden hose was connected to fill the hydroseeder level above the agitator shaft to 758 L (200 gallons) along with two 23 kg (50 lbs) bags each of EFM. With the engine running, the agitator clutch was engaged to mix the EFM and water slurry. Before each test period, the calibration was completed using the VFD controller to set the frequency and application rate of the EFM product to be sprayed. Calibration was based on the time the nozzle takes to cross the gantry, the inside length and width of the box to be sprayed, and the spray height from tip of the spray nozzle to the top of the soil inside the test box. The hydromulcher provided EFM product at sufficient operating pressure of 1.03 bar (15 psi) to accurately apply product to test plots.

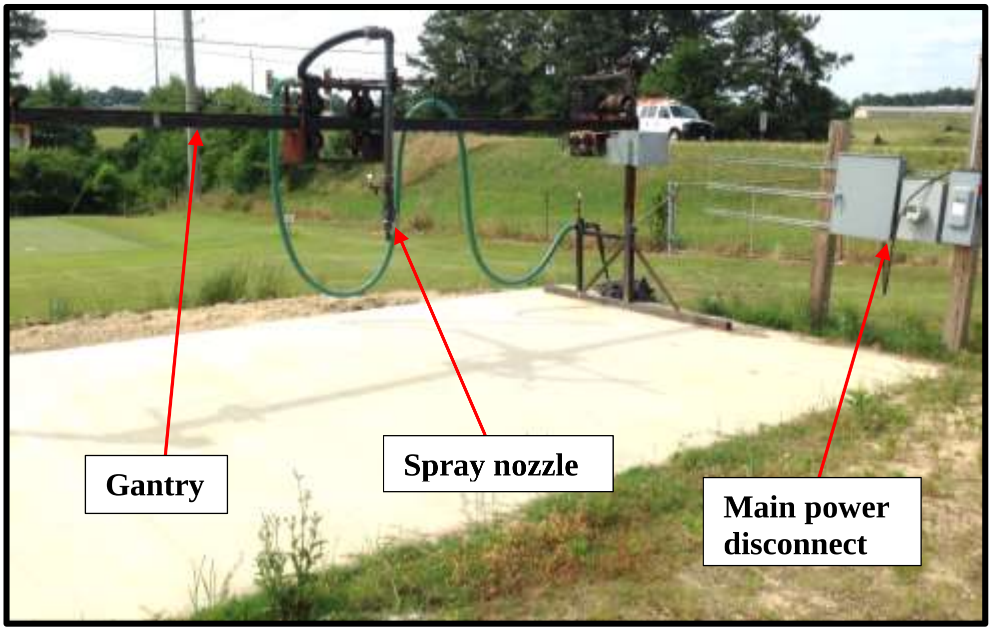


Figure 3.17: Components of hydromulcher precision applicator system, TGRU, Auburn, AL (VFD controller not shown)

3.6.5 Seeded treatments (WS+P+S, EFM+S)

Soil test fertilizer recommendations for roadside turf from the Auburn University soil testing lab were 135-179-90 kg ha^{-1} (120-160-80 lb. acre^{-1}) of N, P_2O_5 and K_2O, respectively. Fertilizer application was calculated using available fertilizers (30-0-0 N, 0-46-0 P and 0-0-60 K).The recommended lime application from the initial soil report was 7,845 kg ha^{-1} (7,000 lbs acre^{-1}), which is equivalent to 0.58 kg (1.3 lbs.) per plot. The soil test report before test period II indicated only that K_2O was reduced by half due to high potassium. Table 3.5 shows the fertilizer and lime recommendations for both soil test reports.

Table 3.5: Fertilizer and lime recommendation modification for test plots

Date	Fertilizer recommendations (kg ha^{-1})	Fertilizer application rate for test plots(g)	Lime Recommendation (kg ha^{-1})	Lime application rate (kg)
17 Aug. 2013	135-179-80	33-29-11	7845	0.58
16 May 2014	135-179-40	33-29-5.5	6725	0.50

Annual ryegrass and browntop millet were planted in six plots (2 treatments x 3 test plots). In this study, grass seed was mixed with sand for uniform distribution and incorporated into the soil by hand prior to the application of all cover treatments (WS+P and EFM) (Figure 3.18). The recommended application rate of annual ryegrass and browntop millet was 67 kg ha^{-1} (5 g per plot) and 45 kg ha^{-1} (3.4 g per plot), respectively. As mentioned, soil in test plots was raked to approximately 5 cm (2 in) deep. Fertilizers and lime were also mixed with sand in a container and applied uniformly by hand on to the treatment surface. Hand watering was provided at a rate of 1 cm (0.39 in) every two days after the incorporation of seed, fertilizers and lime. To ensure that seed did not runoff the surface during hand watering, hose pressure was reduced. The data collection was started after 7 days and 4 days of seeding in test period I and II, respectively.

Figure 3.18: Application of seed by hand, TGRU, Auburn, AL

3.7 Data collection and analysis

Data collected for this research included (1) runoff volume (ml), (2) turbidity (NTU), (3) MTSS (g), and (4) Percent vegetation cover. Runoff and sediment generated from each plot during simulated rainfall was recorded as a function of time and vegetated cover throughout the establishment period. Nineteen liter (5 gallon) buckets were fitted under collection flumes to collect runoff from test plots. Collection buckets were covered to ensure that no water from the simulator fell directly into the bucket (Figure 3.19).

Figure 3.19: Collection of runoff from the test plots, TGRU, Auburn, AL

Selected conclusions for the treatment and cost effectiveness from the data was done according to the test period II as it has more complete set of data points than test period I. Test periods I and II were used as a combined data set to test different grass species in comparing seeded and non-seeded treatments. So, test period II was used in concluding objective 1 and 3 but test periods I and II combined were used for objective 2 conclusions (Table 3.6).

Table 3.6: Test periods used for different objective conclusions

Objectives	Objective statement	Conclusion basis
Objective 1	Treatment effectiveness in water quality responses	Test period II
Objective 2	Comparison of seeded vs. non-seeded treatment	Test period I and II combined
Objective 3	Cost Effectiveness	Test period II

3.7.1 Turbidity measurement (NTU)

Runoff was collected in each bucket until it stopped flowing from the plots. Each runoff sample was stirred completely and an unfiltered grab sample was taken in a 150 ml (5 oz) bottle from each test plot and brought back to the laboratory for turbidity measurement. Turbidity was measured using a Hach 2100 P turbidimeter (Loveland, CO) (USEPA, 2012). At the laboratory, unfiltered samples were shaken to resuspend sediments and then poured into a 15 ml (0.5 oz) turbidimeter vial for analysis. After each sample was analyzed, the container was rinsed with water to prevent contamination between samples. The turbidity of bare soil plots (BS) and bare soil with PAM (BS+P) treatments routinely exceeded the maximum reading on the turbiditimeter. As a result, samples were diluted as needed according to manufacturing recommendations to provide in-range turbidity results by dilution.

3.7.2 MTSS (g) & runoff volume (ml) measurement

A modified standard method for total suspended solids method (TSS 2540 D) (USEPA 160.2) was used to determine MTSS. Modifications from the standard method included use of filter bags in the field, rather than a filter of similar mesh with vacuum filtration in the laboratory. After each rainfall simulation test, 1 µm filter bags (36 cm long) manufactured by Hayward Flow Control (Clemmons, NC) were used to filter sediments from collected runoff to determine modified TSS. A total of 18 bags were used per sample date (6 treatments x 3 test plots) with each runoff sample filtered through one filter bag. To filter runoff, filter bags were inserted into a 20 cm (8 in) PVC pipe column and the PVC pipe was placed in a 19 L bucket (5 gallon). All collected plot runoff was poured through the filter (Figure 3.20). Filtered runoff from each test plot was subsequently poured into a graduated cylinder to determine the volume of runoff (Figure 3.21). Filter bags were brought back to the laboratory and dried in a conventional forced-air oven manufactured by VWR (Radnor, PA) at a temperature of 105^{o} C (221^{o} F) for a minimum of 24 hours. The dried filter bag and soil weight was compared with oven dry weight of the bag prior to filtration. Before and after difference of the filter bags was the dry weight of suspended solids from each test plot, providing an estimate of sediment yield as modified TSS in each plot.

Figure 3.20: Pouring the sediment water into the filter bags, TGRU, Auburn, AL

Figure 3.21: Pouring the filtered water into graduated cylinder to measure runoff volume, TGRU, Auburn, AL

3.7.3 Vegetation cover measurement

Percent vegetation cover was measured on each day of rainfall simulation and runoff testing using the line transect method, also known as line point intercept method (Godinez-Alvarez et al., 2009). The line transect method was performed by stretching two string having 25 equal marks diagonally from one side of the test plot to the other (Figure 3.22). Each point represents a sample point to be tallied when viewed from directly above. Each plot was analyzed to determine the number of times a point hit the target grass species. The percentage vegetation cover was determined dividing the number of hits of target grass species (Annual ryegrass and browntop millet) by the total number of points. The two string diagonals represent a total of 50 points per plot. Therefore, number of hits were doubled to obtain an estimate of percent vegetation cover of the target grass.

Figure 3.22: Strings tied to test plots for vegetation cover measurement, TGRU, Auburn, AL

3.8 Cost analysis

Overall performance, maintenance and required labor can affect the overall cost of erosion control BMPs (Donald, 2013). BMP cost comparison was performed to determine which treatment was the most cost effective per unit of sediment loss reduced. The ALDOT maintains a cost database known as the ALDOT item bid summary, which is representative of construction industry costs in the southeast US. Erosion control bid items listed in the summary were classified on a cost per unit area basis (dollar per hectare). Mulching as defined in the ALDOT bid summary includes wheat and other straws blown as a dry mulch. The EFM treatment used in this study corresponds to type S3 ALDOT product per their approved list II-11 dated August 5, 2013. The ALDOT bid data was divided into counties within the state and was averaged to obtain the mean cost of erosion and sediment control BMPs for the state of Alabama. The most current ALDOT bid summary of March 6, 2014 was used as a reference for this analysis except for PAM cost which was available only from the ALDOT bid summary of October 1, 2012. Table 3.7 summarizes the average cost per square meter and cost per hectare for Alabama.

Table 3.7: Average cost for selected erosion control BMPs for Alabama

Treatment	Average cost per sq. m.	Average cost per ha
PAM[1]	$0.03	$307
Straw mulching[2,3]	$0.21	$2,062
Straw mulching with PAM[2,3]	$0.24	$2,369
Temporary seeding[2]	$0.13	$1,288
Straw mulching + PAM + seeding	$0.37	$3,657
Engineered fiber matrix(EFM)[2]	$2.13	$21,306
EFM with seeding[2]	$2.26	$22,594

[1]Source: ALDOT bid summary, 2012. Unit cost based on application rate of 10 kg ha^{-1}
[2] Source: ALDOT bid summary, 2014
[3]Straw mulching includes wheat and other straws

3.9 Statistical analysis

Turbidity, MTSS, runoff volume, and percent vegetation cover data recorded by date and treatment were organized using an Excel spreadsheet. A JMP 11 software developed by Statistical Analysis Systems (SAS) (Cary, NC) was used to determine significant differences between the means of treatments for test periods I and II. All three response means (runoff volume, turbidity, and MTSS) were tested separately for each test period. Tests of normality including QQ plots were used to verify the normality of data. Consequently, one way analysis of variance (ANOVA) was performed using general linear model (GLM) to determine significant differences between the runoff volume means for test periods I and II, separately. Significant differences between runoff volume means of different treatment pairs were compared using the Tukey Kramer procedure. Significance was reported using an alpha value (p-value) of 0.05. The typical null and alternate hypothesis used for this research is illustrated in equations (3.3) and (3.4):

$$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6 \qquad (3.3)$$

$$\text{Ha: Not all means are equal} \qquad (3.4)$$

Where,

H_o = Null Hypothesis

H_a = alternate hypothesis

μ_i = Mean value of each data set ‘i’

i= independent groups (i.e. bare soil, WS + P etc.)

Turbidity and MTSS data were found to be non-normal and subsequently analyzed using Kruskal Wallis Rank Sum test as an alternative non-parametric procedures. Kruskal Wallis Rank Sum Test was used to test for the statistical differences between the means. Kruskal Wallis test is used to test more than two groups and is an extended form of the Mann-Whitney U test (Easton and McColl, 1997). The Kruskal Wallis uses data as ranks instead of original values, providing p-value approximation of difference. If the K statistic is not significant, there is no evidence of difference between the means. However, if the test statistic is significant at least one treatments dominate at least one other treatment. When differences were indicated, multiple comparison tests were performed to determine the significant difference between specific pairs of all treatments means. For this series of tests, Wilcoxon non-parametric multiple comparison tests were performed. These tests of significant difference between pairs of treatment means were performed for turbidity and MTSS for test periods I and II, separately. Graphical and statistical analysis of seeded versus non-seeded treatments was analyzed using combined data from test periods I and II. The significance between the correlated slopes of seeded and non-seeded treatments for test periods I and II combined was determined at significance level of 0.05 using StatGraphics software developed by Statpoint technologies, Warrenton, VA.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Introduction

This chapter records observed response of five erosion control covers (1) BS+P, (2) WS, (3) WS+P, (4) EFM, and (5) EFM + S compared to the bare soil control (BS) for two test periods. Treatment means were analyzed and results discussed in terms of benefit of vegetated cover over time to reduce important construction runoff parameters such as volume, turbidity and sediment. Performance ranking of the different treatments tested were according to test period II. Graphical and statistical analysis of seeded versus non seeded treatments was completed using combined data from test periods I and II normalized as a function of days after seeding (DAS).

4.2 Experimental results

4.2.1 Runoff volume (ml)

Figure 4.1 illustrates runoff volume for all treatments as a function of DAS during test period I. Bare soil has the highest mean runoff volume, as expected. In test period I, EFM+S, EFM and WS+P+S performed similarly with an average runoff volume of 2694 ml, 2886 ml, and 4531 ml, respectively. Bare soil with PAM had the runoff volume of 9092 ml followed by WS+P with an average runoff volume of 6270 ml.

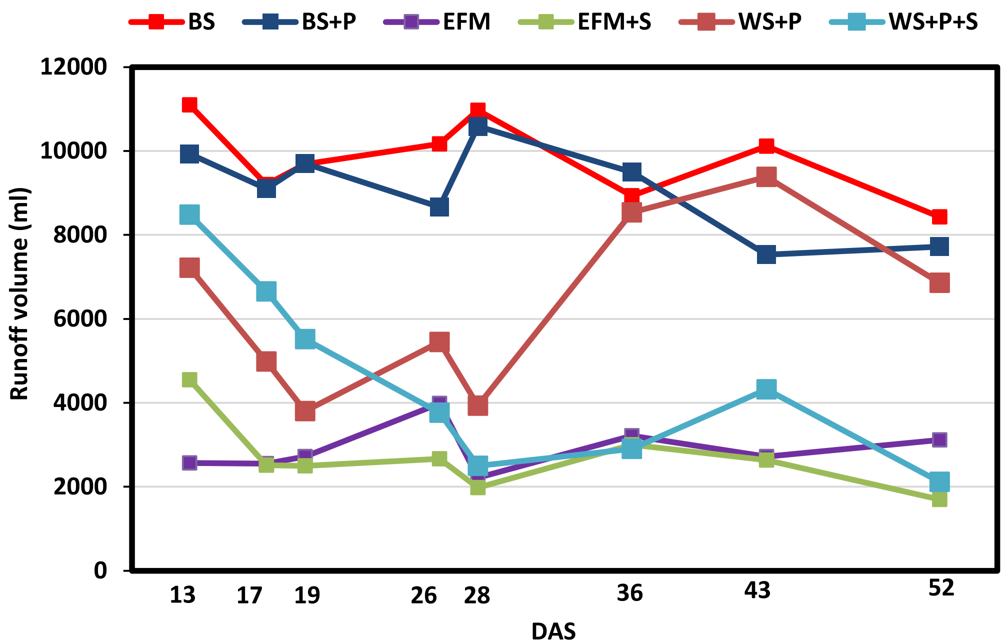


Figure 4.1: Runoff volume for cover treatments with DAS for test period I, Auburn, AL

Figure 4.2 illustrates the runoff volume for all the cover treatments during test period II. During test period II, EFM had the more runoff volume than during test period I due to apparent early sealing of the soil surface by the EFM. The treatment with the most effective volume reduction in test period II was EFM+S with an average volume of 2873 ml, statistically similar to WS+P+S (4595 ml). EFM and WS+P were not statistically similarly with average runoff volumes of 6265 ml and 4873 ml, respectively. All cover treatments except BS+P reduced average runoff volumes from 30% to 68%, as compared to control (Table 4.1).

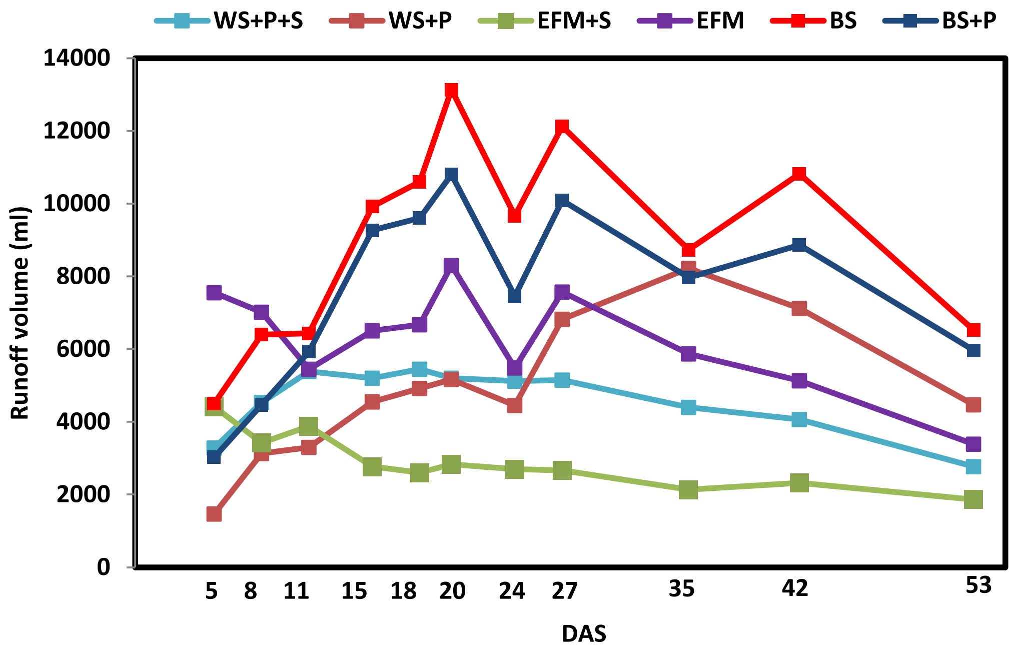


Figure 4.2: Runoff volume for cover treatments with DAS for test period II, Auburn, AL

Table 4.1 presents the mean treatment runoff volumes with standard deviation and percent reduction, as compared to the bare soil control for both test periods. Mean runoff ratios across test period II for the treatments are shown in the right column. The percent runoff reduction, as compared to control in test period II was: (1) EFM+S (68%), (2) WS+P+S (49%), (3) WS+P (46%), (4) EFM (30%), and BS+P (16%). Bare soil with PAM used alone did not perform well in this study compared to the other covers likely due to a) the degradation of chemical after several simulated rainfall events, b) relatively low application rate, and c) the lack of surface roughness compared to other cover treatments.

One way ANOVA indicated significant differences between treatments in both test periods (p-value < 0.0001). Tukey Kramer procedure indicated that neither of the EFM treatments were significantly different in test period I, but were significantly different in test period II due to apparent sealing in the EFM treatment, not identified in test period I. The EFM treatment runoff volume was significantly lower than WS+P in test period I. No statistical significance was observed between wheat straw treatments in both test periods indicating that vegetation seeding in wheat straw treatments did not have much effect on average mean runoff volume. Runoff means from bare soil and bare soil with PAM treatments were not significantly different from each other in either test period apparently due to the low application rate of PAM. Seeded treatments (WS+P+S, EFM+S) were not significantly different from each other in either test periods in terms of runoff volume. Runoff volume for the EFM+S treatment was statistically lower than the EFM and WS+P treatments indicating vegetation had a significant impact on runoff volume reduction at least in the EFM+S treatment.

Table 4.1: Runoff volume results of all the treatments for both the test periods

Treatment[2]	Test Period I		Test Period II		Avg. runoff ratio[3]
	Average vol. (ml)	Reduction[1]	Average vol. (ml)	Reduction[1]	
BS	9825±2094 [a]	-	8985±566 [a]	-	0.42
BS+P	9092±1472 [a]	8%	7584±1346 [a,b]	16%	0.35
EFM	2886±434 [c]	71%	6265±2319 [b,c]	30%	0.29
EFM+S	2694±294 [c]	73%	2873±690 [d]	68%	0.13
WS+P	6270±2452 [b]	36%	4873±1400 [c]	46%	0.23
WS+P+S	4531±661 [b,c]	54%	4595±631 [c,d]	49%	0.21

Note: Treatments with same letters are not significantly different at α=0.05

[1]Percent reduction in runoff volume compared to control

[2]EFM (Engineered Fiber Matrix), EFM+S (EFM with seed), WS+P (Wheat Straw with PAM), WS+P+S (WS+P with PAM and seed), BS+P (Bare soil with PAM), BS (Bare Soil)

[3]Average Runoff ratio calculated as ratio of runoff volume (ml) to precipitation applied (ml) for test period II

Figure 4.3 shows the comparison of runoff volume of seeded and non-seeded EFM treatments versus DAS for combined test period I and II. The graph provides information about the effect of cover on runoff volume over time from the seeded treatments. Both the EFM+S and EFM treatments showed a declining trend in runoff volume (r = -0.73 and -0.42, respectively). The declining regression slopes of both treatments were not statistically different (p value = 0.55), indicating that although test period II runoff volume mean was significantly lower for EFM+S treatment, the relationship of rate of runoff reduction over time was not significantly different with or without seeding.

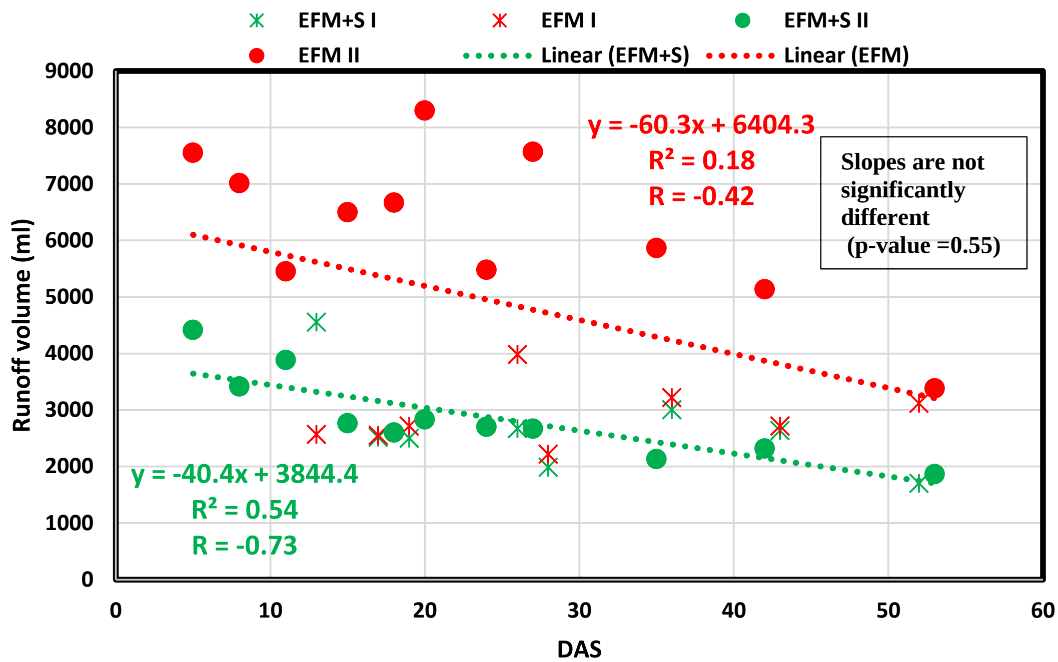


Figure 4.3: Comparison of EFM seeded and non-seeded treatments with DAS (Combined test periods I and II)

Figure 4.4 plots runoff volume for seeded and non-seeded treatments for wheat straw with PAM for combined test periods I and II. Seeded treatments had negative runoff volume correlation with increased vegetation cover (r = - 0.57). Non- seeded treatment means had rising slope and positive correlation (r = 0.62), indicating the degradation of the non-seeded wheat straw treatment after frequent rain events similar to Wishowski et al. (1998). Wheat straw sub sample test plots had more variable results, as compared to EFM treatments due to varied surface contact of wheat straw. The regression slopes of both treatments were significantly different from each other (p value < 0.0001).

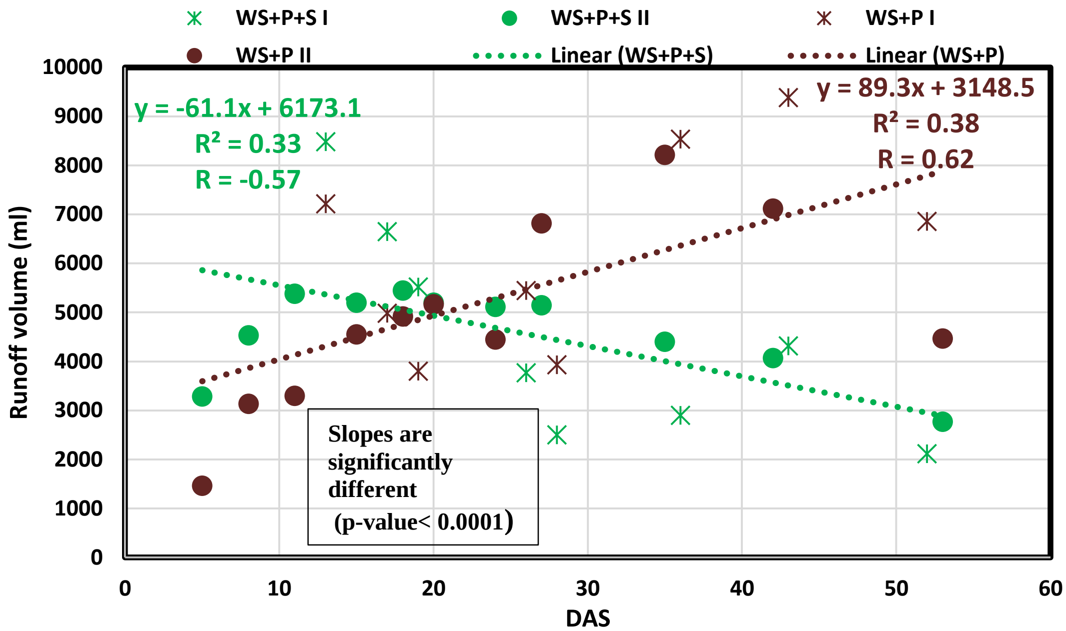
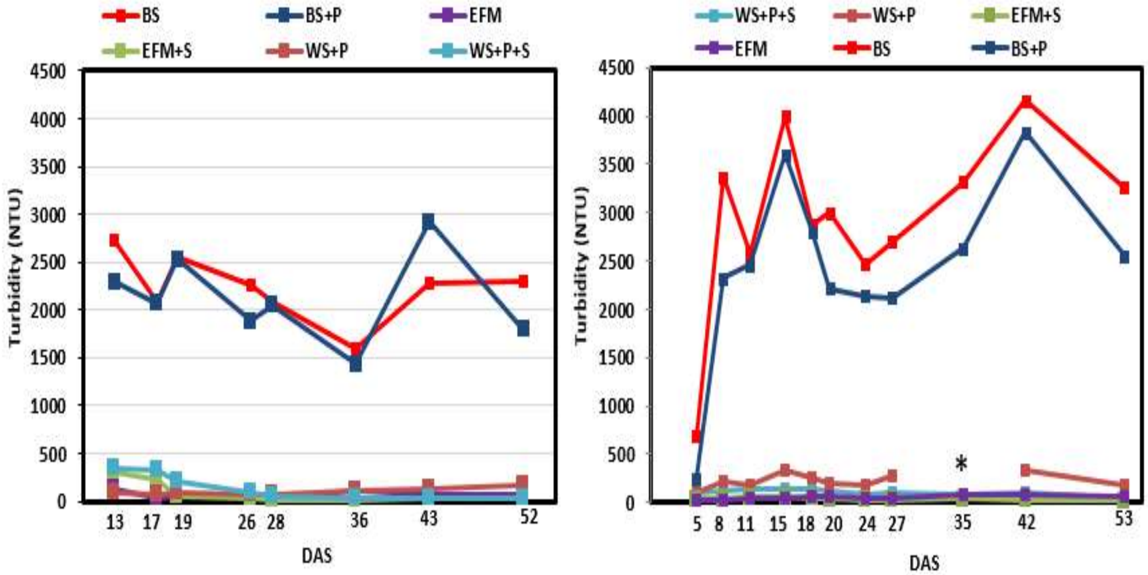


Figure 4.4: Comparison of runoff volume of WS+P and WS+P+S treatments with DAS (Combined test periods I and II)

4.2.2 Turbidity (NTU)

Turbidity samples grabbed from thoroughly stirred plot runoff in the catchment buckets from each test plot were averaged by treatment. Figures 4.5(a) and (b) illustrates the turbidity of all treatments for test period I and II versus DAS. As expected, turbidity of the bare soil treatment (BS) was higher than any other treatment similar to the findings reported by McLaughlin and Brown, (2006) and Wilson, (2010). In test period II, all cover treatments except WS+P reduced turbidity below 150 NTU. EFM+S was the significantly effective cover treatment evaluated, with an average test period II turbidity of 38 NTU (Table 4.2). The lower value in bare soil and bare soil with PAM in test period II initially was due to hardness and dryness of the soil but it starts rising due to the rill formation after certain simulated rainfall events.



(a) Test period I **(b) Test period II**

Figure 4.5: Turbidity of all the cover treatments vs. DAS, Auburn, AL

***-Data Missing in WS+P treatment**

Figure 4.6 illustrate turbidity of cover treatments not including bare soil and bare soil with PAM to more closely investigate treatment effect for test period I. In test period I, WS+P performed well until 28 days after seeding when straw degradation becomes prevalent. EFM, EFM+S, and WS+P+S treatments performed similarly with average turbidity's of 66 NTU, 84 NTU, and 134 NTU, respectively (Table 4.2). The initial turbidity of seeded treatments in test period I was higher than non-seeded treatments likely due to the insufficient raking of the surface in the non-seeded treatments. The EFM treatment included a bonding agent to bond the mulch particles to soil surface. When the bonding agent washed away after frequent storm events, the EFM treatment also starts to lose its effectiveness as shown in both the test periods similar to the findings reported by Wilson (2010).

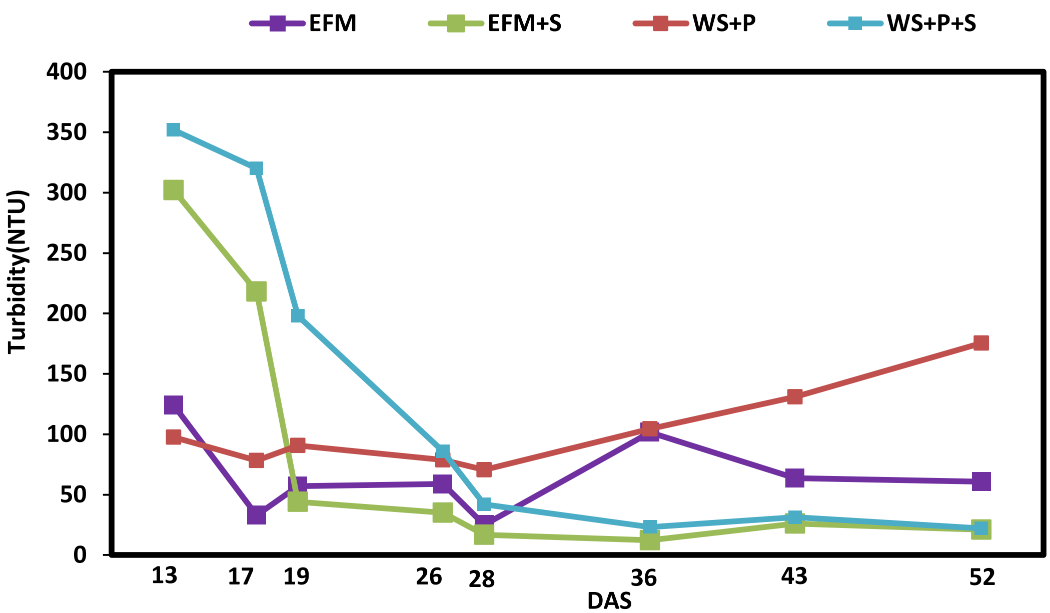


Figure 4.6: Turbidity of cover treatments without BS and BS+P for test period I

Figure 4.7 plots test period II mean turbidity of cover treatments without BS and BS+P. In test period II, the EFM treatment with and without seed was observed to consistently reduce average turbidity levels to below 100 NTU. The WS+P treatment had higher mean NTU values than any other cover treatment except BS+P treatment. EFM was a more effective turbidity reduction treatment than wheat straw which is similar to results reported by Babcock and McLaughlin (2013). The experimental method in test period II was indicated by similar day 5 mean turbidity values for corresponding seeded and non-seeded treatments. So, test period II was used for overall results due to less variability in results, as compared to test period I.

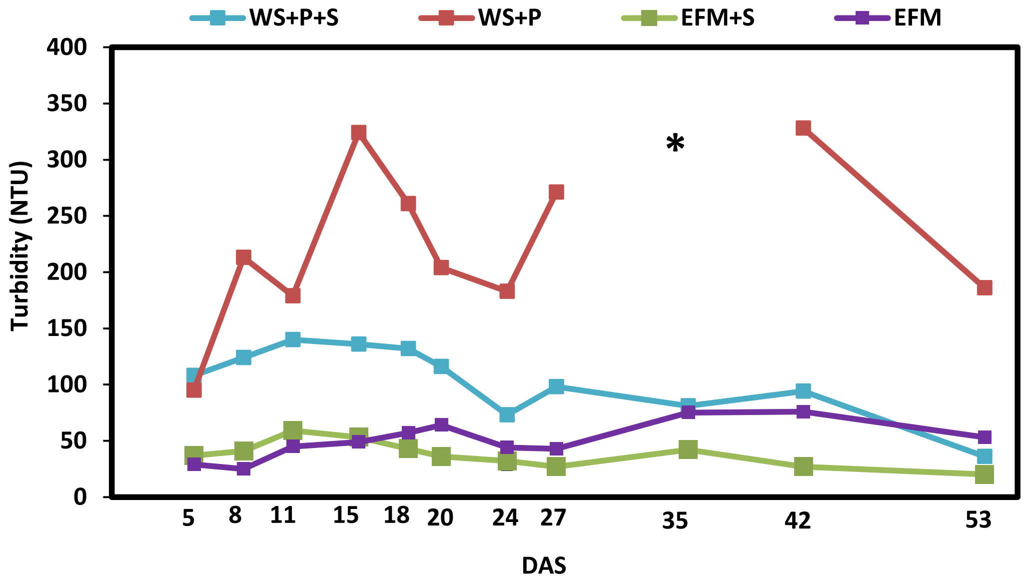


Figure 4.7: Turbidity of cover treatments without BS and BS+P for test period II
***- Data Missing in WS+P treatment**

Table 4.2 presents average turbidity values with standard deviation and percent reduction, compared to a control for both test periods. Results were ranked from most to least effective turbidity reduction treatments compared to the bare soil control in test period II as: (1) EFM+S (98.7%) (2) EFM (98.3%), (3) WS+P+S (96.5%), (4) WS+P (92.4%), and (5) BS+P (16.9%). All cover treatments except BS+P in both the test periods were able to reduce the turbidity by over 90%, as compared to bare soil. Mean turbidity of the WS+P treatment was higher than turbidity measured in any EFM treatment in both test periods due to more soil exposed. No statistical significance was found between EFM, EFM+S, and WS+P+S. The application of PAM (BS+P) were not significantly different from bare soil (BS) in terms of turbidity reduction. However, all other test period II treatment pairs had significantly different means from each other. The EFM+S treatment was significantly lower than all other treatments and was the most effective treatment in terms of turbidity reduction.

Table 4.2: Turbidity results of all the treatments for both the test periods

Treatment[2]	Test period I		Test period II	
	Average turbidity (NTU)	Percent reduction[1]	Average turbidity (NTU)	Percent reduction[1]
BS	2234±431 [a]	-	2946±461 [a]	-
BS+P	2120±325 [a]	5.1%	2449±156 [a]	16.9%
EFM	66±25 [c]	97.1%	51±9 [d]	98.3%
EFM+S	84±26 [c]	96.2%	38±5 [e]	98.7%
WS+P	103±46 [b]	95.4%	224±75 [b]	92.4%
WS+P+S	134±34 [b,c]	94.0%	103±13 [c]	96.5%

Note: Treatments with same letters are not significantly different at $\alpha = 0.05$

[1]Percent reduction compared to control

[2]EFM (Engineered Fiber Matrix), EFM+S (EFM with seed), WS+P (Wheat Straw with PAM), WS+P+S (WS+P with seed), BS+P (Bare soil with PAM), BS (Bare Soil)

Figure 4.8 compares turbidity means of EFM and EFM+S treatments for combined test periods I and II. The seeded treatment (EFM+S) was observed to have declining trend with time (r = - 0.37), as expected while the non- seeded treatment (EFM) has a flatten response with time (r = 0.26). The slopes of both the treatments were not significantly different from each other (p value = 0.056). Consequently, although turbidity means were lower for EFM+S than EFM treatment, vegetation cover in EFM treatment did not have a significant effect in turbidity reduction over time.

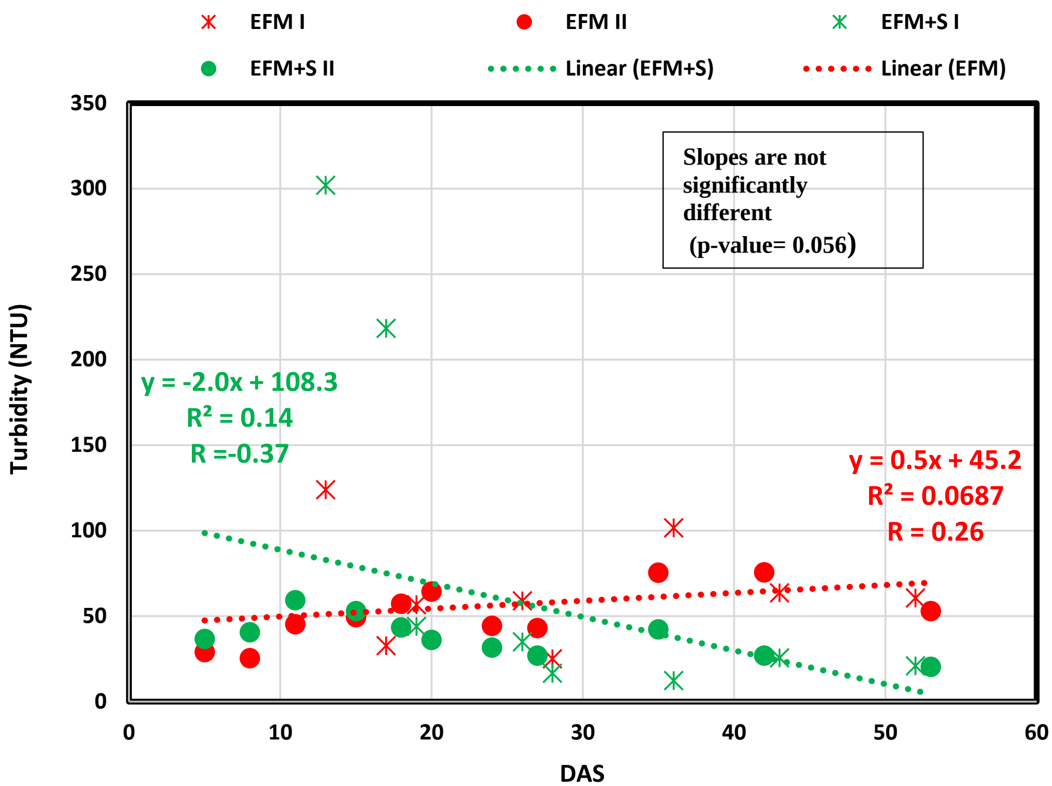


Figure 4.8: Comparison of turbidity of EFM and EFM+S treatments with DAS (Combined test periods I and II)

Figure 4.9 illustrates turbidity means over time for WS+P and WS+P+S treatments for combined test periods I and II. The WS+P+S treatment shows a declining trend with time, as expected (r = -0.60), while the WS+P treatment does not correlate with time (r = 0.1). The WS+P treatment loses effectiveness after approximately 25- 30 days but seeded treatment (WS+P+S) show continued and improved effectiveness over time. The regression slopes of both treatments were significant from each other (p value = 0.027) indicating the significant effect of seeded vegetation with respect to turbidity reduction in wheat straw covers.

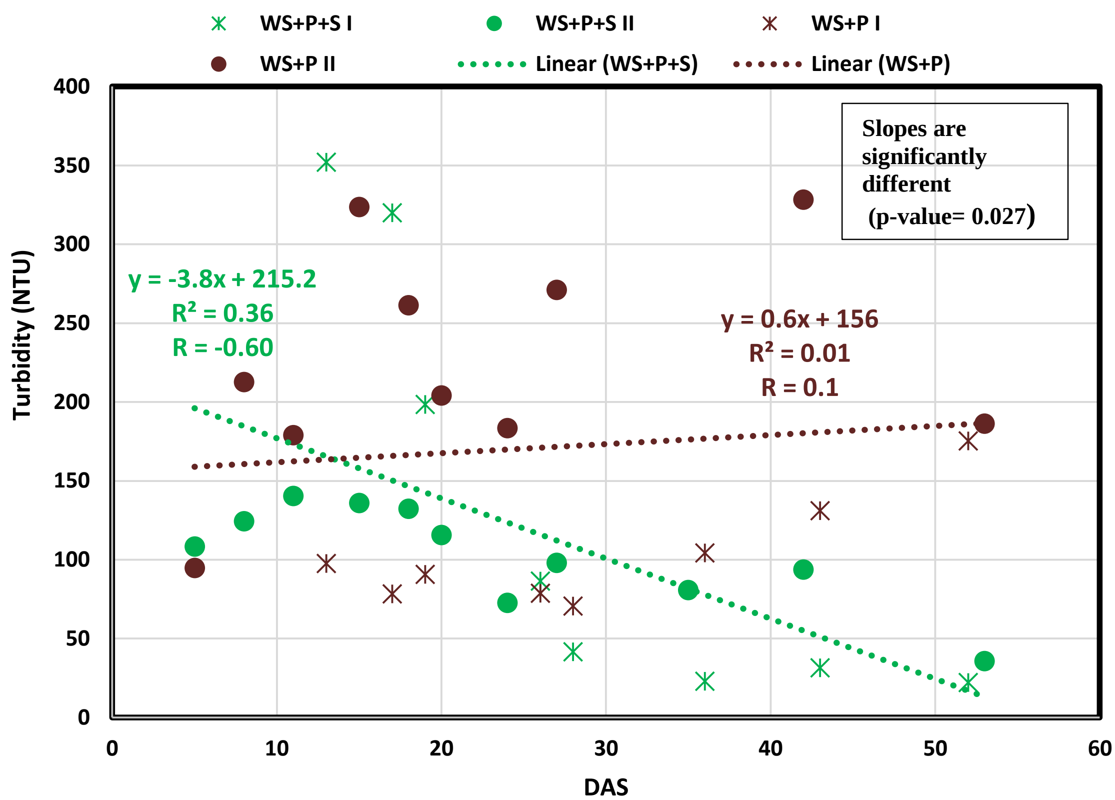
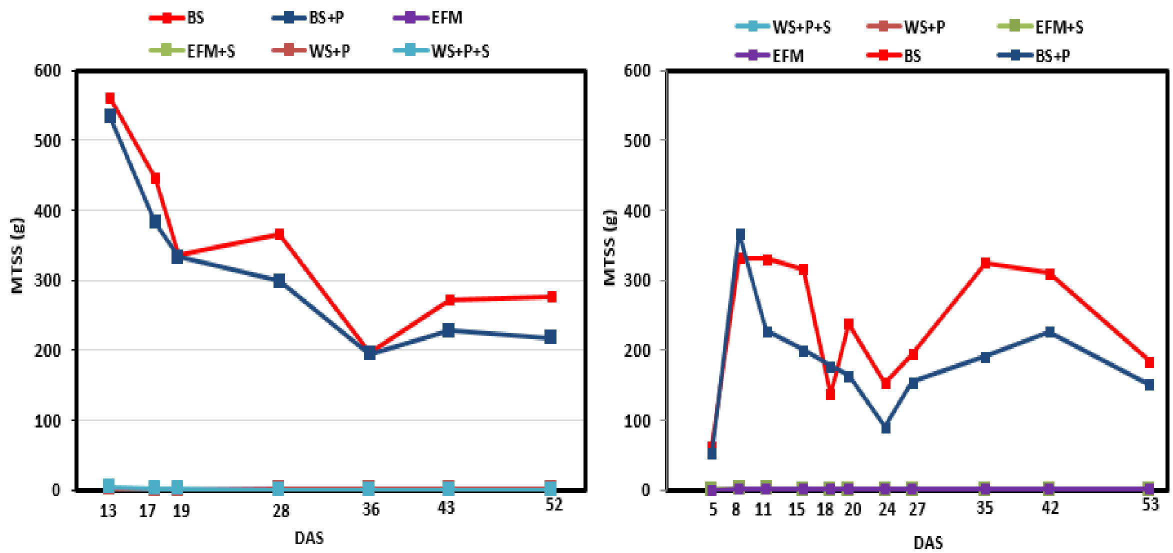


Figure 4.9: Comparison of turbidity of WS+P and WS+P+S treatments with DAS (Combined test periods I and II)

4.2.3 MTSS for all treatments

Figures 4.10 (a) and (b) illustrate the MTSS delivered from all treatments including the two bare soil treatments, BS and BS+P. Results indicate nearly 100 percent reduction of sediment delivery by all cover treatments except BS+P for test period I and II. In test period I, application of EFM+S was the most effective treatment with an average MTSS of 0.53 g similar to WS+P+S and EFM. The EFM+S with an average MTSS of 0.59 g was significantly effective sediment reduction treatment in test period II. MTSS values on 8 April, 2014 (26 DAS) of all treatments were not reported due to data error during weighing of the bags.



(a) Test period I **(b) Test Period II**

Figure 4.10: MTSS of all the treatments with DAS

Figure 4.11 illustrates MTSS excluding BS and BS+P to more closely investigate the effects of the cover treatments for test period I. The EFM, EFM+S, and WS+P+S treatments performed similarly with an average MTSS of 0.85 g, 0.53 g, and 1.01 g, respectively (Table 4.3). The WS+P treatment with an average MTSS of 1.25 g performed similar to EFM and WS+P+S treatments. High initial differences in MTSS deliveries for wheat straw treatments was a result of unequal raking (lack of equal disturbance) in non-seeded WS+P versus WS+P+S treatment.

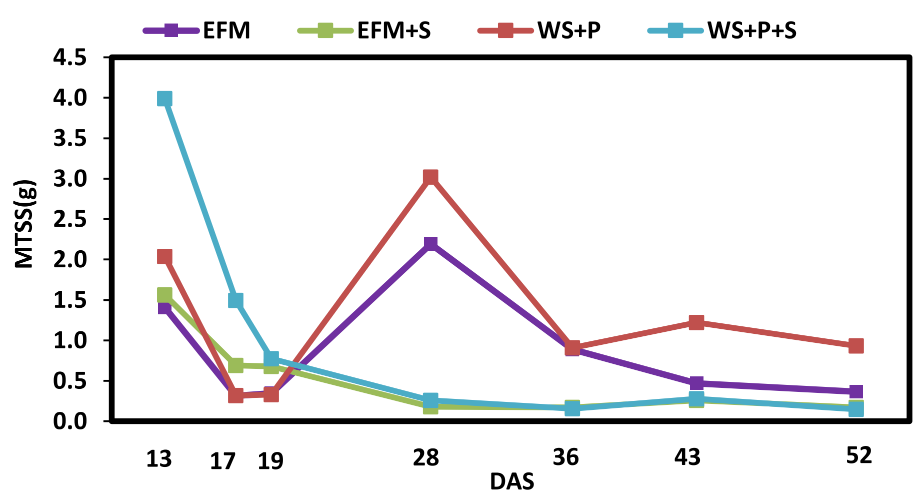


Figure 4.11: MTSS of cover treatments versus DAS without BS and BS+P (Test period I)

Figure 4.12 plots mean MTSS delivered for cover treatments without BS and BS+P versus DAS for test period II. The EFM and WS+P+S treatments performed similarly with an average MTSS of 0.68 g and 0.97 g, respectively (Table 4.3). The WS+P treatment with an average MTSS of 1.48 g performed equally well as the WS+P+S treatment with respect to MTSS delivered.

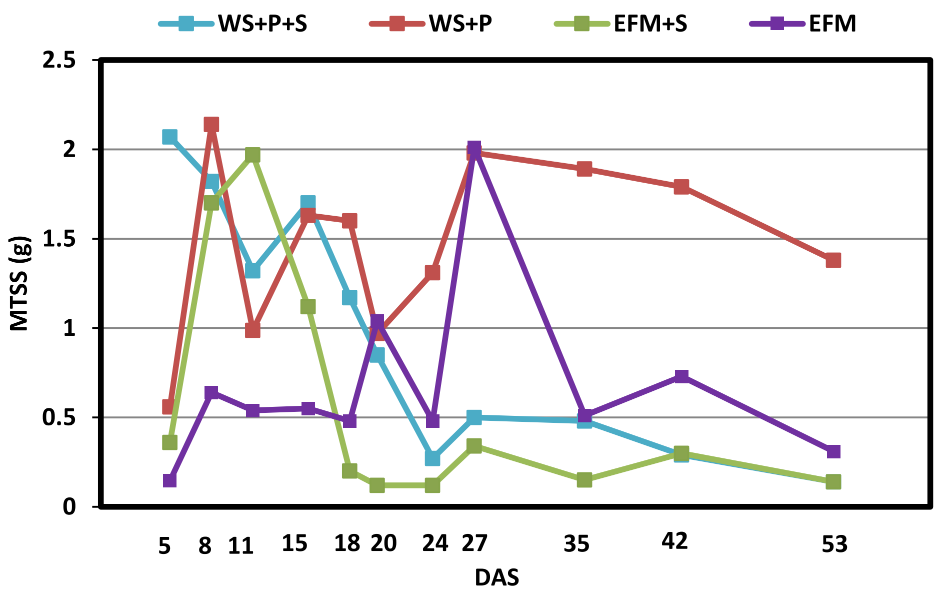


Figure 4.12: MTSS delivery of cover treatments versus DAS without BS and BS+P (Test period II)

Table 4.3 presents the average MTSS delivered for all treatments with standard deviations and percent reduction compared to the bare soil control. In test period II, the effectiveness of treatments were ranked from the most effective to least effective as: (1) EFM+S (99.8%) (2) EFM (99.7%) (3) WS+P+S (99.6%) (4) WS+P (99.4%) (5) BS+P (22.6%). Doolette and Smyle (1990), in a review of 200 studies, reported that mulch reduced soil erosion between 78 to 98 percent. In test period I, EFM+S had significantly lower MTSS delivery than WS+P, but it was not significantly different from EFM and WS+P+S. The sediment delivery of WS+P treatment was not significantly different from

EFM (Babcock, 2008; Lee, 2012) and WS+P+S in test period I. In test period II, the MTSS of the EFM+S treatment was significantly lower than all other cover treatments indicating the overall effect of vegetation in EFM treatments for sediment reduction. EFM sediment delivery was also observed to be significantly lower than WS+P likely due to the variable surface contact of wheat straw. Wheat straw treatment means were not significantly different from each other in both test periods indicating that seeded vegetation in wheat straw doesn't provide a significant effect on average MTSS delivered. The sediment delivery of BS and BS+P treatment were not significantly different from each other in both test periods due to relatively low application rate of PAM used in the study.

Table 4.3: Results of MTSS (g) of all the treatments for both the test periods

Treatments[2]	Test Period I		Test Period II	
	Average MTSS (g)	Percent reduction[1]	Average MTSS (g)	Percent reduction[1]
BS	351±73 [a]	-	235±27 [a]	-
BS+P	313±126 [a]	10.8%	182±21 [a]	22.6%
EFM	0.85±0.33 [c,b]	99.8%	0.68±0.36 [c]	99.7%
EFM+S	0.53±0.19 [c]	99.9%	0.59±0.30 [d]	99.8%
WS+P	1.25±0.30 [b]	99.6%	1.48±0.90 [b]	99.4%
WS+P+S	1.01±0.26 [c,b]	99.7%	0.97±0.28 [c,b]	99.6%

Note: Treatments with same letters are not significantly different at α=0.05
[1]Percent reduction compared to control
[2]EFM (Engineered Fiber Matrix), EFM+S (EFM with seed), WS+P (Wheat Straw with PAM) WS+P+S (WS with PAM and seed), BS+P (Bare soil with PAM), BS (Bare Soil)

Figure 4.13 compares average MTSS delivery of EFM and EFM+S treatments for combined test periods I and II. The observed declining trend in seeded treatment (EFM+S) MTSS with time (r = -0.61) was expected, while non- seeded treatments had a flat response with time (r = 0.03), as expected. The non-seeded EFM treatment (EFM) performed consistently over the time period, as expected. The slopes of both the treatments were not significantly different from each other (p value = 0.07). So, while vegetation has a significant impact on the magnitude of sediment reduction during the establishment period, the impact of seeding over time was not verified statistically at the alpha value tested (α = 0.05).

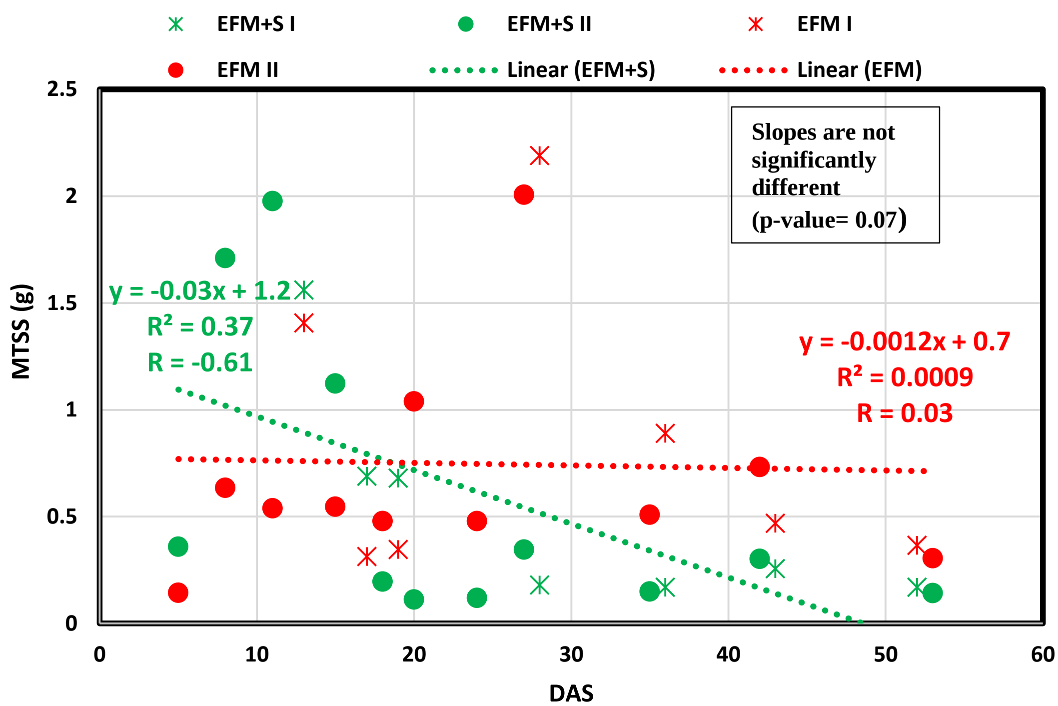


Figure 4.13: Comparison of MTSS of EFM and EFM+S treatments with DAS (Combined test periods I and II)

Figure 4.14 represents the MTSS delivery means of WS+P and WS+P+S treatments with DAS for combined test periods I and II. WS+P+S performed better in terms of MTSS reduction than in runoff volume and turbidity reduction. The declining trend in the seeded wheat straw treatment (r = -0.71) as compared to a flat response in the non-seeded wheat straw treatment (r = 0.2) indicates the importance of vegetation for sediment delivery reduction in a wheat straw treatment. After approximately 30 days, The MTSS of the WS+P treatment began to increase due to loss of treatment effectiveness. The slopes of seeded versus non-seeded treatment were significantly different from each other (p value = 0.045). Therefore, vegetation was observed to have a significant impact in MTSS reduction in wheat straw treatment over time. So, a seeded wheat straw treatment (WS+P+S) would be a better option, as compared to a non-seeded treatments for long term (> 30 days) sediment delivery reduction.

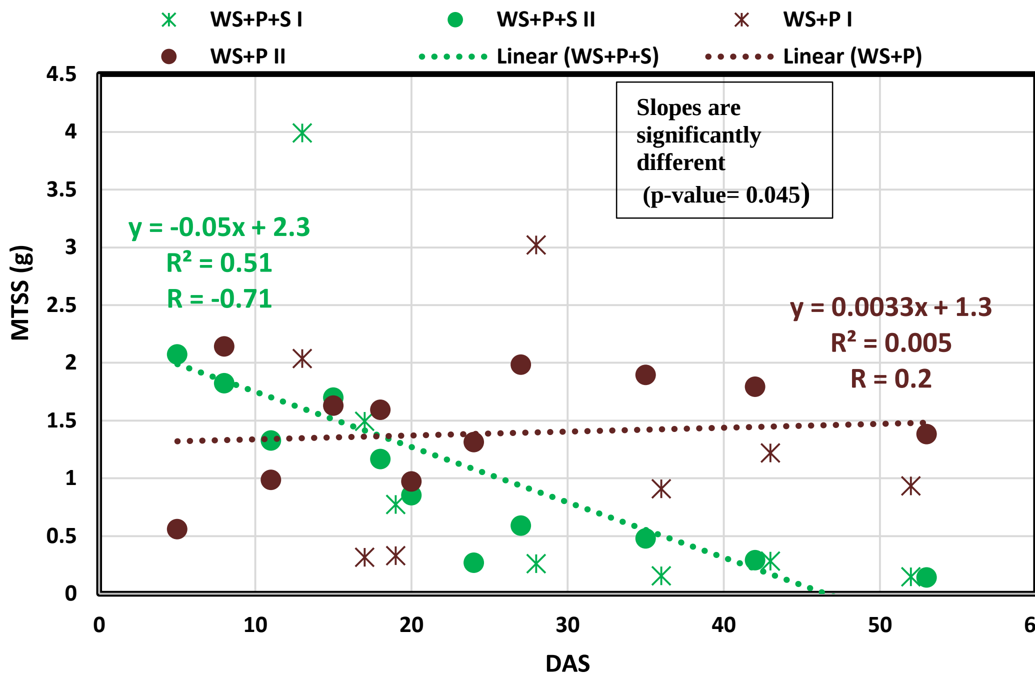
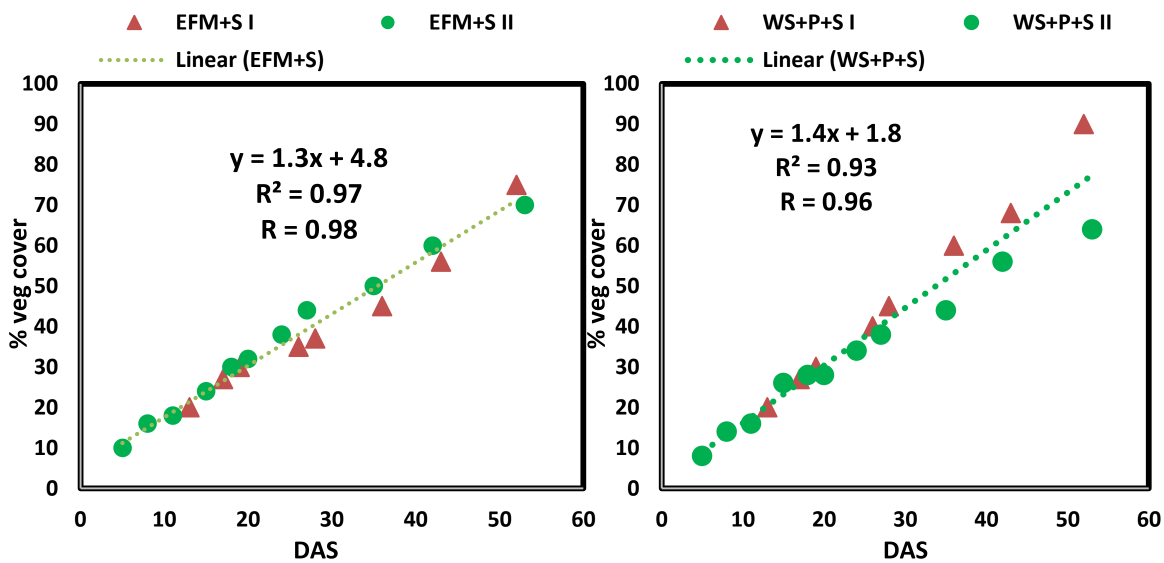


Figure 4.14: Comparison of MTSS of WS+P and WS+P+S treatments with DAS (Combined test periods I and II)

4.3 Percent vegetation cover with time

Percent vegetation cover was measured and recorded using the line-point intercept method. The percent vegetation cover versus DAS is presented in Figure 4.15 (a) and (b) for EFM+S and WS+P+S, respectively, for combined test periods I and II. The highest value of percent vegetation cover was 90% and 64% in WS+P+S treatment in test periods I and II, respectively. Similarly, McLaughlin and Brown (2006) reported higher vegetation cover in straw than measured in a BFM treatment. The EFM with seed treatment in the present study resulted in a maximum vegetation cover of 75% and 70% in test periods I and II, respectively. Higher R-square and postive slope indicates consistent growth of vegetation cover over time in seeded treatments in this study.



(a) % veg. cover of EFM+S versus DAS **(b) % Veg cover of WS+P+S versus DAS**

Figure 4.15: Percent vegetation cover of seeded treatments versus DAS (Combined test periods I and II)

4.4 Cover factor

The cover factor is a parameter used in the Revised Universal Soil Loss Equation (RUSLE) to represent the cover condition compared to an unprotected bare soil (Clopper et al., 2001). The RUSLE cover factor characterizes the effect of surface cover and roughness on soil erosion. The cover factor is calculated as the ratio of sediment yield of a given cover or surface condition to the sediment yield of an unprotected bare soil condition. Cover factor is the most common factor used to test the effectiveness of BMPs for erosion reduction (Renard et al., 1997). Table 4.4 summarizes the estimated cover factor for test periods I and II separately for all the treatments normalized to a bare soil (BS) control. The value of all cover factors lies between 0 and 1 in which 0 means the treatment resulted in 100% reduction of erosion and 1 means that the treatment is equivalent to bare soil conditions and did not result in any reduction of erosion. Table 4.4 shows the ranking of treatments in test period II from most to least effective with respect to cover factor as: (1) EFM+S (0.0025) (2) EFM (0.0029) (3) WS+P+S (0.0041) (4) WS+P (0.0063) (5) BS+P (0.7747).

Table 4.4: Cover factor for all the treatments

Treatment[5]	Test period I		Test period II	
	MTSS (grams/plot)[1]	cover factor (C)[2]	MTSS (grams/plot)[3]	cover factor (C)[4]
EFM+S	3.71	0.0015	6.52	0.0025
EFM	5.99	0.0024	7.43	0.0029
WS+P+S	7.07	0.0029	10.61	0.0041
WS+P	8.77	0.0036	16.24	0.0063
BS+P	2188.00	0.8920	1998.00	0.7747

[1]Cumulative MTSS from test period I
[2]C factor normalized to bare soil value of 2453 g/plot for test period I
[3]Cumulative MTSS from test period II
[4]C factor normalized to bare soil value of 2579 g/plot for test period II
[5]EFM (Engineered Fiber Matrix), EFM+S (EFM with seed), WS+P (Wheat Straw with PAM) WS+P+S (WS with PAM and seed), BS+P (Bare soil with PAM)

4.5 Percent vegetation cover combined effect

Figure 4.16 shows the response of seeded treatments for both test periods versus percent vegetation cover indicating a declining trend in runoff volume with increased percent vegetation cover ($r = -0.49$), as expected in this study. Some of the values are higher initially in test period I due to non-uniformity of the raked surface for the non-seeded surface. In general, all seeded treatments values decreased with increased percent vegetation cover. This graphical representation also shows the impact of growing vegetation on runoff volume over the course of the study period. Numerous studies report similar runoff reduction with increase in percent vegetation cover (Adekalu et al., 2007; Foltz and Copeland, 2009).

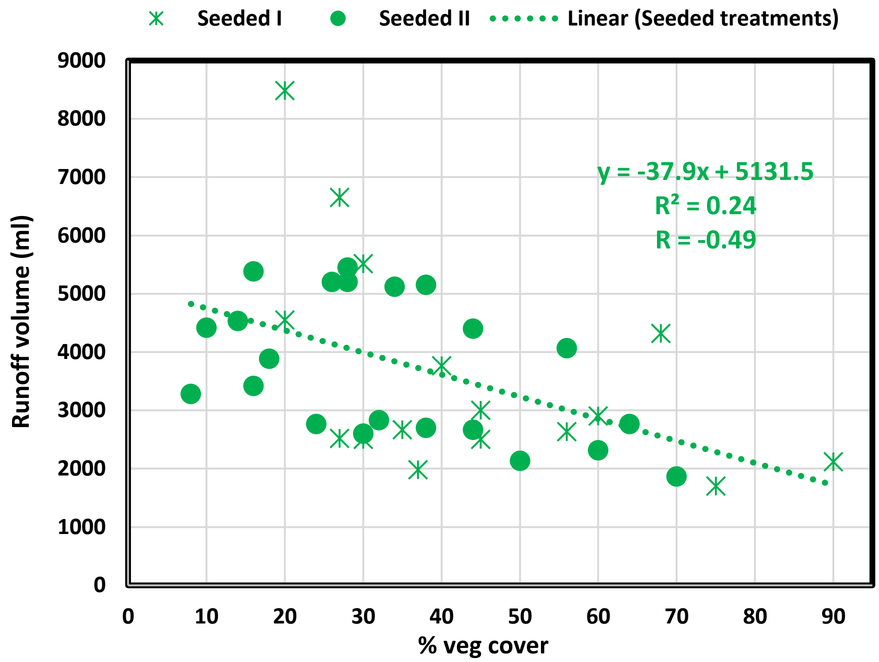


Figure 4.16: Effect of percent vegetation cover on runoff volume of seeded treatments (Combined test periods I and II)

Figure 4.17 illustrates the effect of percent vegetation cover on turbidity over the study period. The correlation coefficient (r = -0.47) indicates a turbidity reduction with increased percent vegetation cover, as expected.

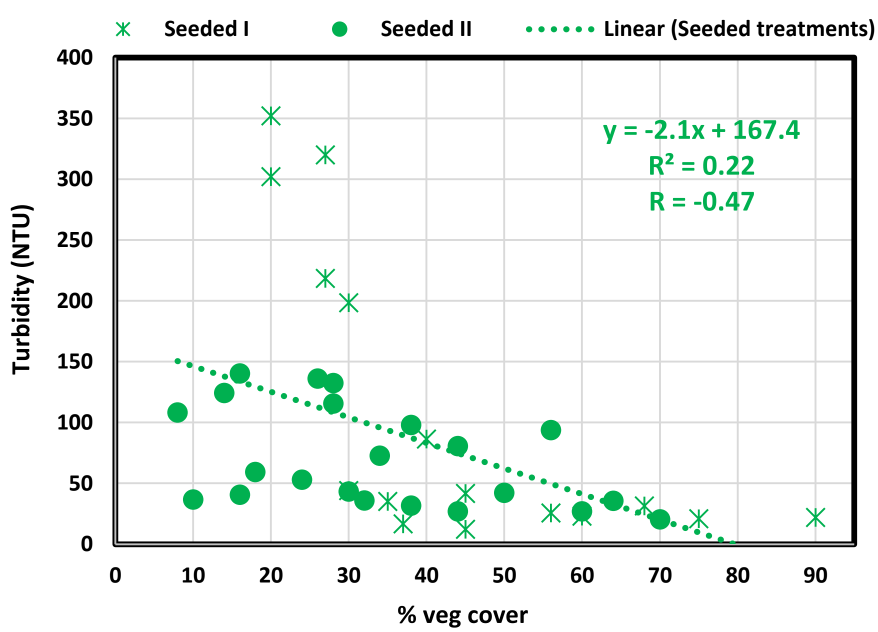


Figure 4.17: Effect of percent vegetation cover on turbidity of seeded treatments (Combined test periods I and II)

Figure 4.18 shows the effect of increased vegetation cover on MTSS for seeded treatments during combined test periods I and II. The correlation of percent vegetation with MTSS reduction was higher (r = -0.63), as compared to runoff volume and turbidity. Similar sediment yield reductions were confirmed by other researchers with increased percent vegetation cover (Liu et al., 2010; Pan and Shangguan, 2006).

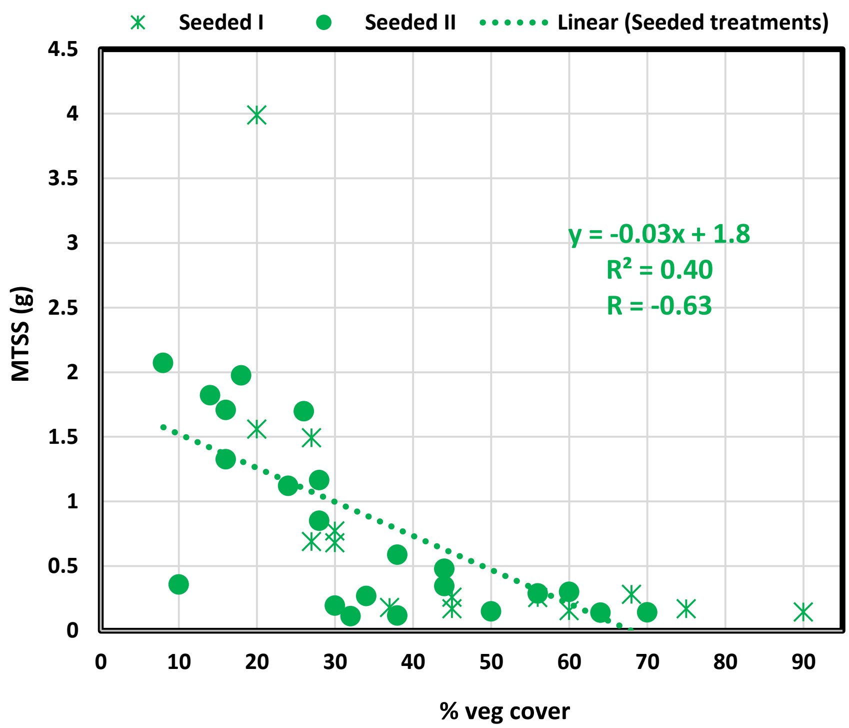


Figure 4.18: Effect of percent vegetation cover on MTSS of seeded treatments (Combined test periods I and II)

4.6 Comparison of seeded and non-seeded treatments

Additional analysis was performed on the response data to compare all seeded versus all non-seeded treatments, as a function of DAS. Since not all treatments received seeding, differences can be evaluated based on equal time period after seeding dates. Regression and correlation patterns for runoff volume, turbidity and MTSS delivered indicate a response from seeded treatments over non-seeded treatments and provide evidence across independent time periods of the water quality benefits of seeding in conjunction with other temporary covers, irrespective of species.

Runoff volume

Figure 4.19 indicates that the runoff volume of all seeded treatments for test period I and II combined correlate negatively (r = - 0.48), as compared to the flat response of non-seeded treatments (r = 0.10) with DAS. The vegetation intercept the rainfall falling on it, which results in low runoff volume. The slopes of data sets were significantly different from each other (p-value = 0.025), confirming the impact of vegetation over time, as compared to non-seeded treatments.

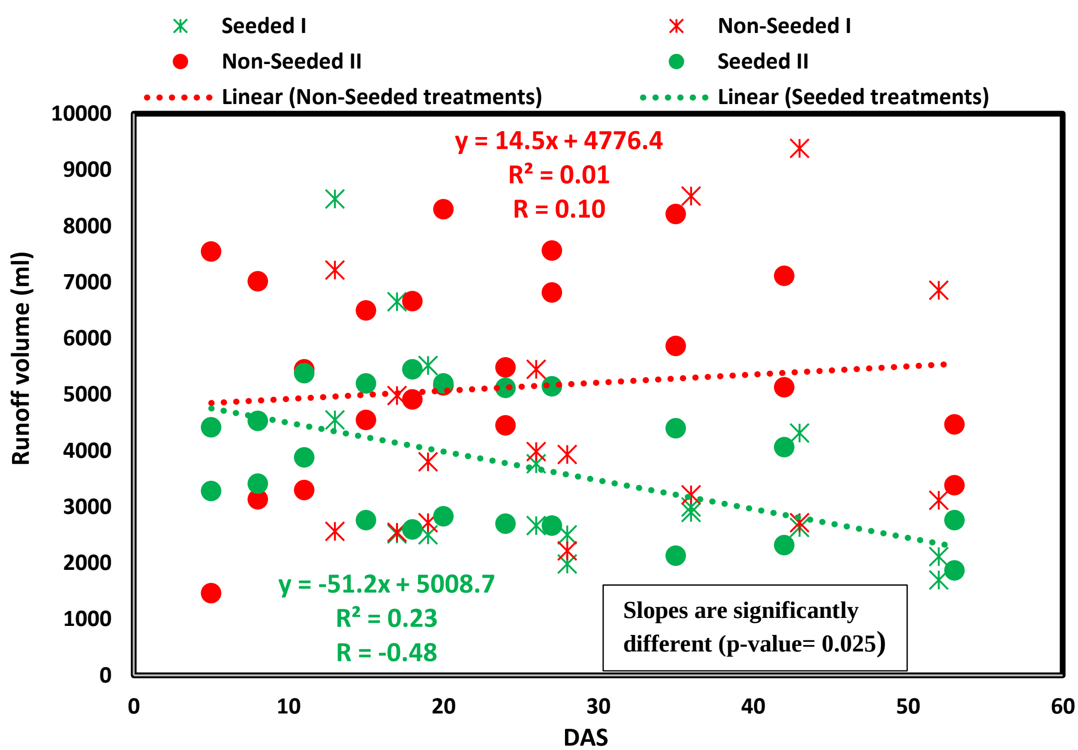


Figure 4.19: Comparison of runoff volume of seeded and non-seeded treatments with DAS (Combined test periods I and II)

Turbidity

Figure 4.20 plots mean turbidity of seeded and non-seeded treatments over time for test periods I and II combined. The correlation between seeded treatments and DAS (r = -0.47) was higher than non-seeded treatments (r = 0.01). Root structure of the vegetation have strengthen the soil and keeping the sediment on its place. The slopes of both the treatments were significantly different (p-value = 0.016) indicating the impact of seeded vegetation on turbidity reduction over time.

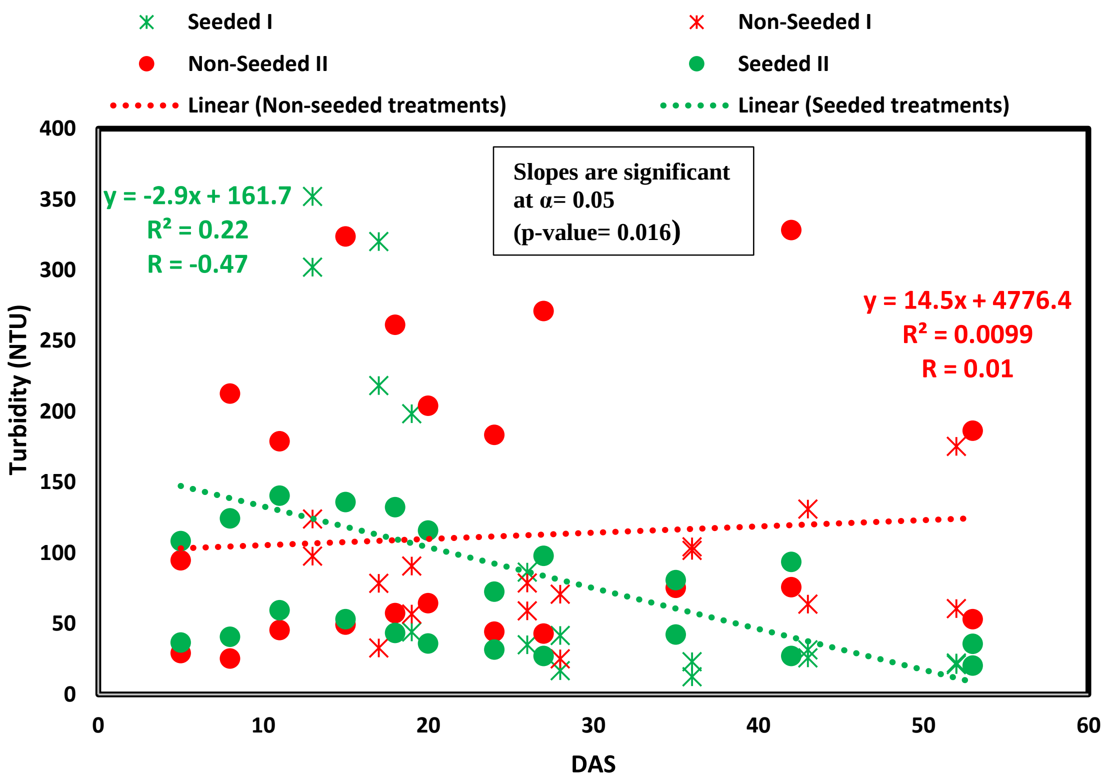


Figure 4.20: Comparison of turbidity of seeded and non- seeded treatments with DAS (Combined test periods I and II)

MTSS

Figure 4.21 illustrates MTSS treatment means for both test periods of seeded and non-seeded treatments versus DAS. Seeded treatments have the highest correlation (r = -

0.63) of all study responses. Non-seeded treatments showed consistent performance over time (r = 0.02), as expected. The vegetation helps restrict the sediment movement from one place to another, thus reducing the soil loss. The slope of seeded treatments was significantly lower than the slope of non-seeded treatments (p-value = 0.0016). So, vegetation was helpful for continued stabilization of disturbed slopes, as compared to non-.seeded treatments.

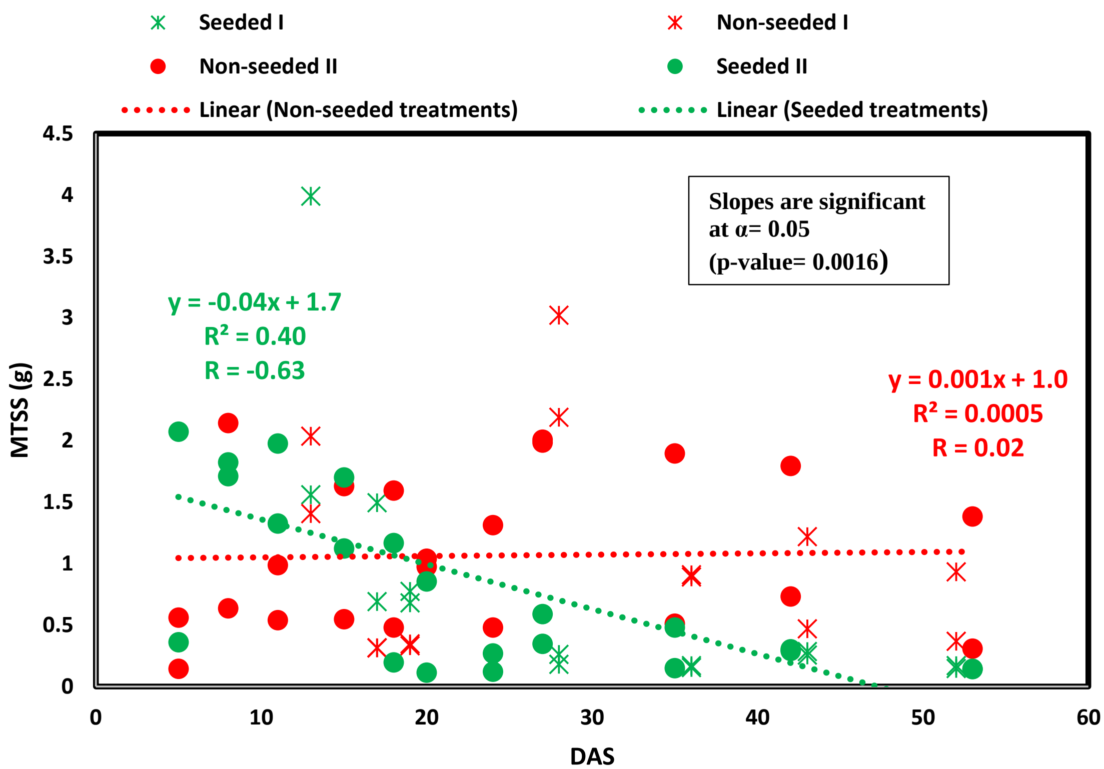


Figure 4.21: Comparison of MTSS of seeded and non-seeded treatments vs DAS (Combined test periods I and II)

4.7 Cost benefit analysis

ArcMap by Environmental Systems and Research Institute (ESRI®), Redlands, CA was used to create maps of BMP cost per square meter by county for each product evaluated in this study. Plots are presented as Figures 4.22 to 4.26.

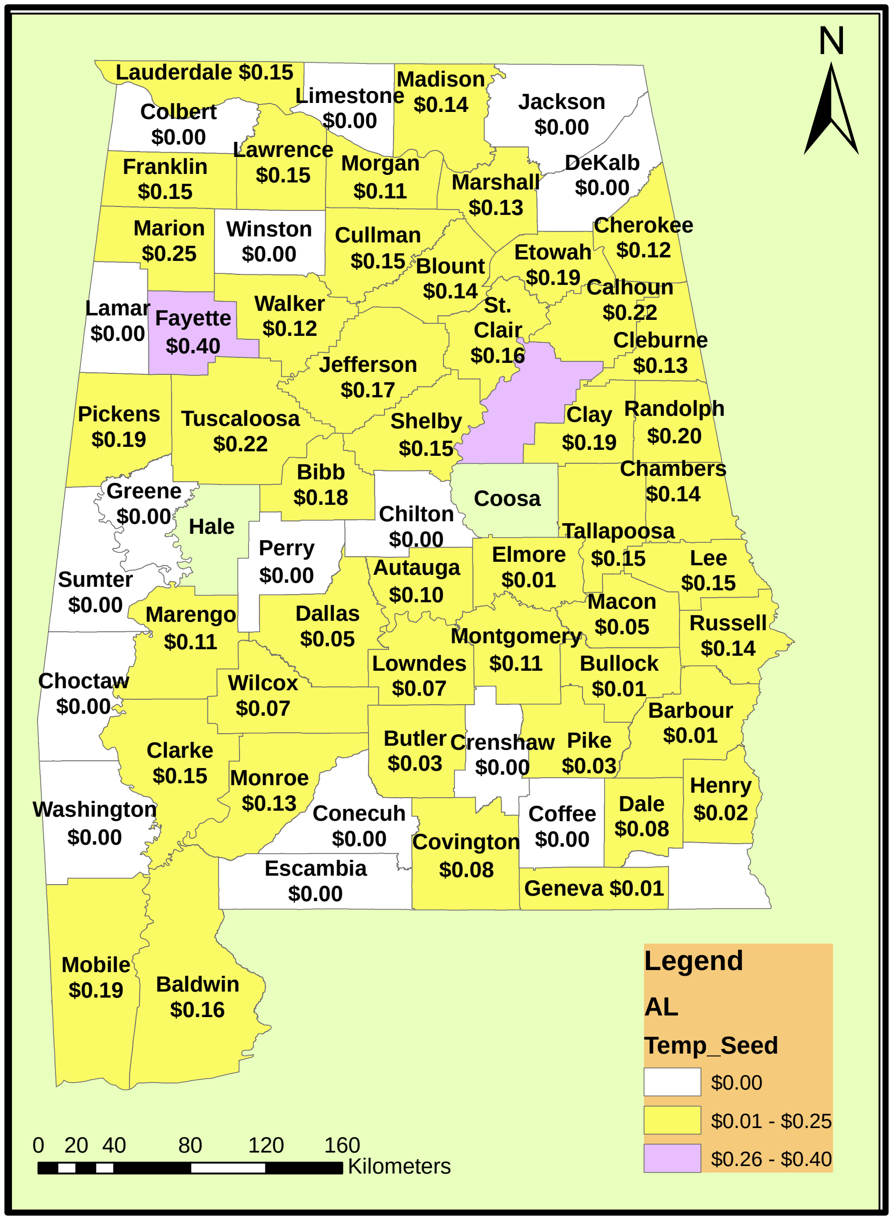


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Figure 4.22: Unit cost of seeding per sq. mt. for ALDOT projects (ALDOT, 2014)

$ 0 – Data not available

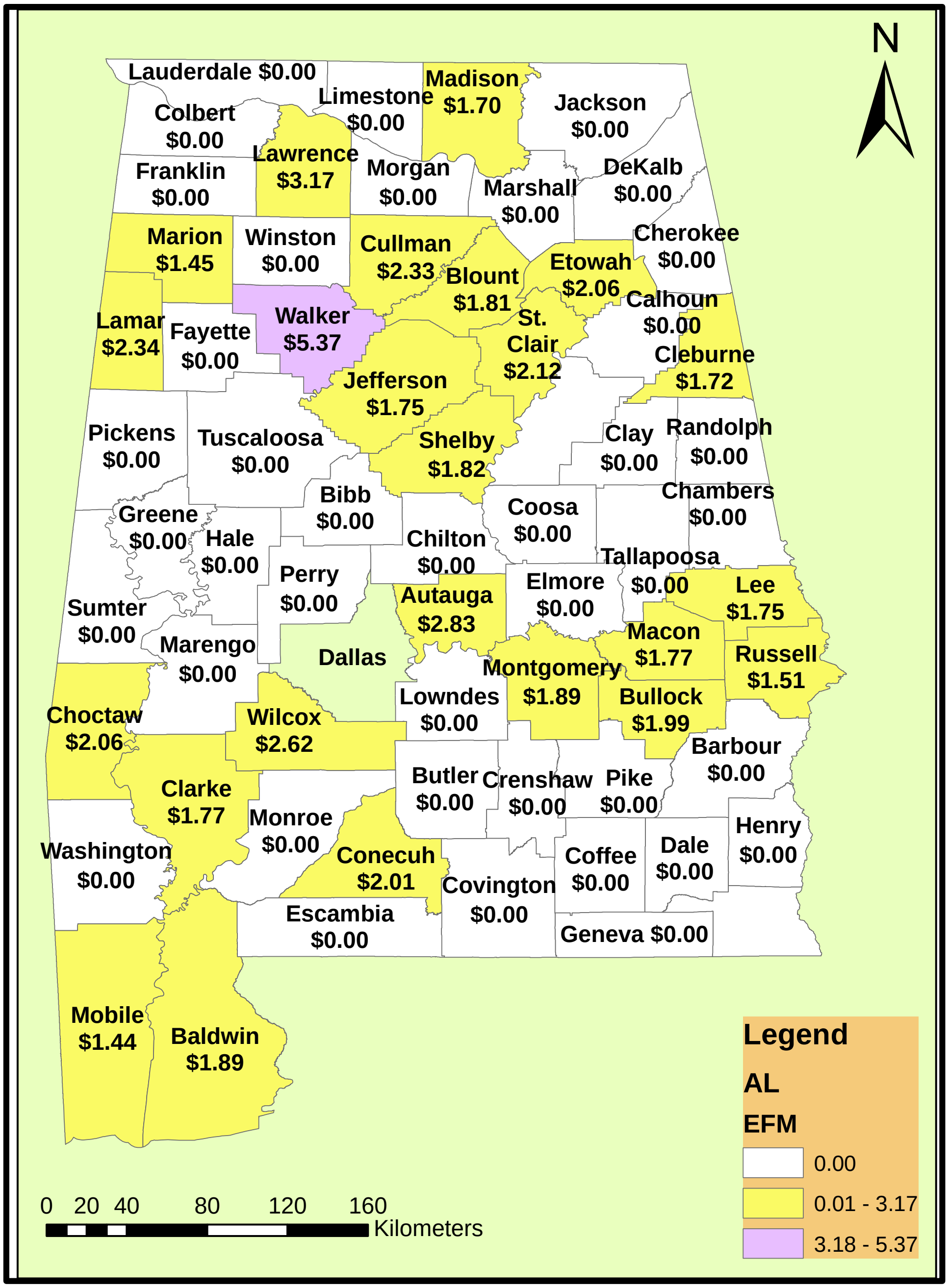


Figure 4.23: Unit cost of EFM per sq. mt. for ALDOT projects (ALDOT, 2014)

$ 0 – Data not available

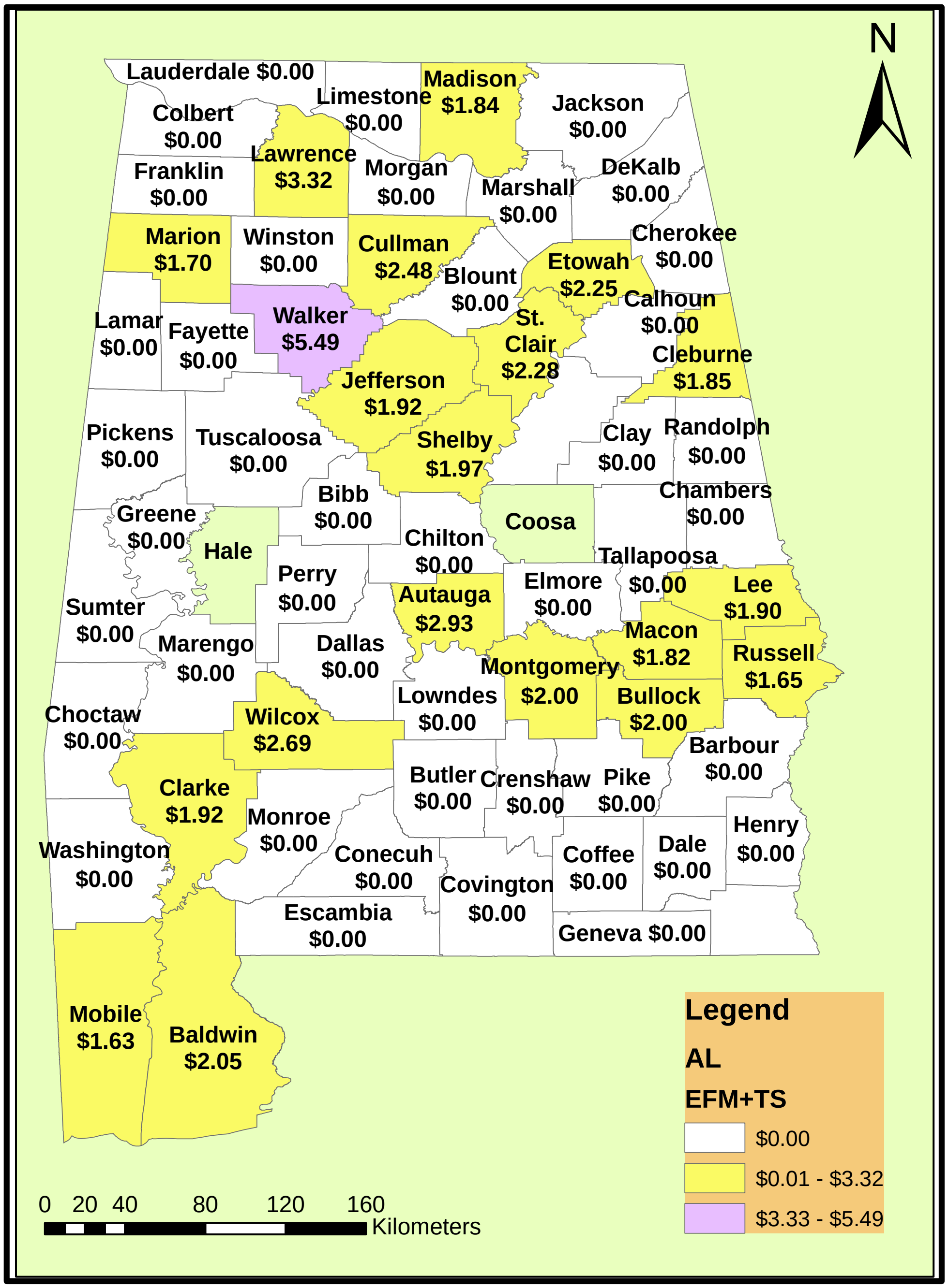


Figure 4.24: Unit cost of EFM+S per sq. mt. for ALDOT projects (ALDOT, 2014)

$ 0 – Data not available

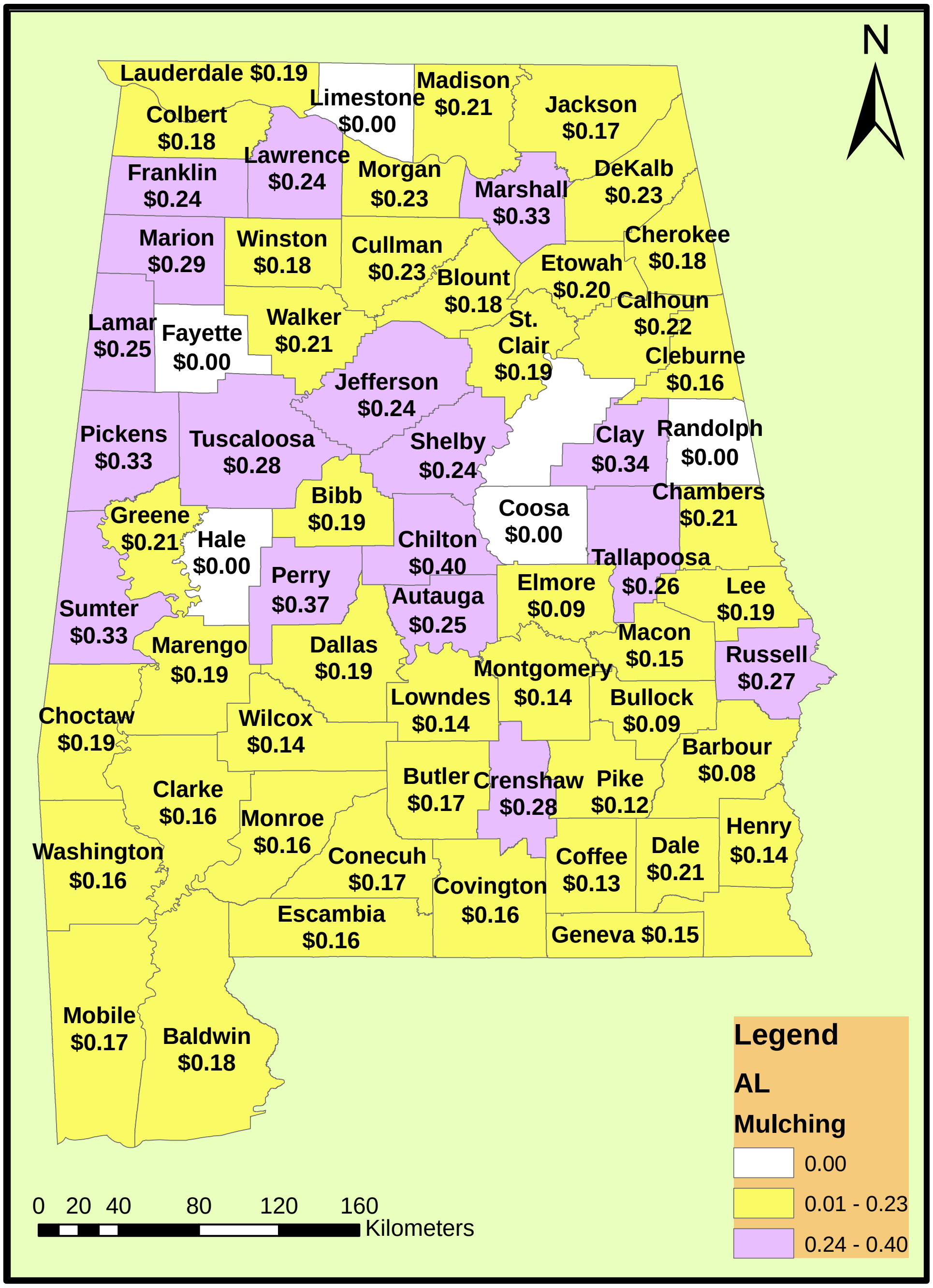


Figure 4.25: Unit cost of mulching per sq. mt. for ALDOT projects (ALDOT, 2014)

$ 0 – Data not available

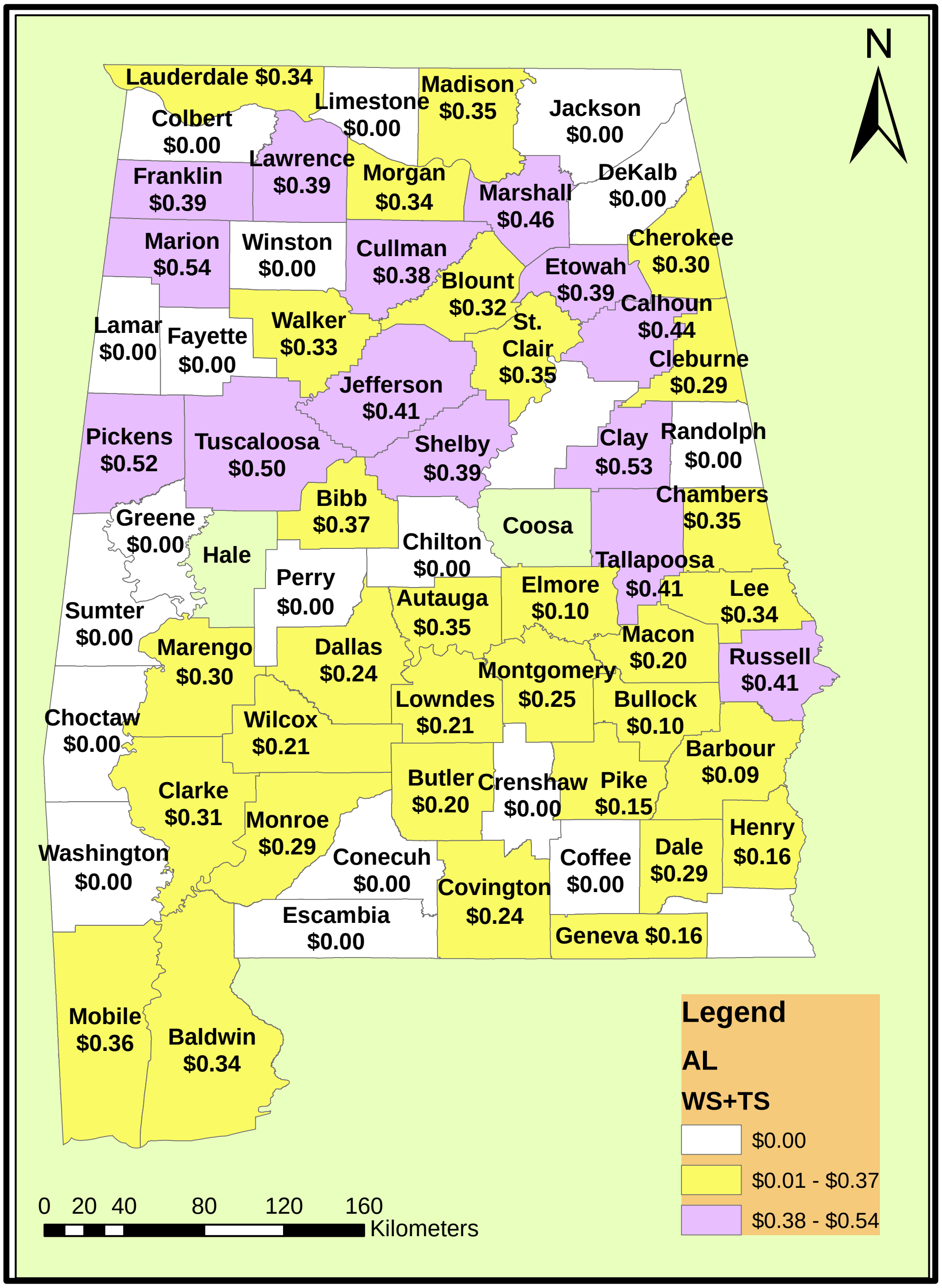


Figure 4.26: Unit cost of mulching with seed per sq. mt. for ALDOT projects (ALDOT, 2014)

$ 0 – Data not available

MTSS delivery during test period II was used exclusively for cost evaluation of treatments. Reduction in MTSS (grams delivered per plot) was calculated and compared to the bare soil control. Resulting MTSS reduction values by treatment were converted to kg ha^{-1}. The cost of each treatment derived from the ALDOT bid item summary in $ per ha (Table 4.5) was divided by kg ha^{-1} MTSS reduction values (Table 4.5) to determine the dollar spent per kg of MTSS reduction. Tables 4.5 presents the resulting cost analysis for all temporary seeded and non-seeded cover treatments analyzed in this study. Results indicate that BS+P was the most cost-effective treatment with $0.38 spent for each kg of sediment reduced compared to the bare soil. However, as BS+P was not significantly different from a bare soil control in terms of total sediment delivery reduction, BS+P is not considered beneficial as a water quality protection BMP, at least at the application rates used in this study (10 kg ha^{-1}). WS+P, the next most cost effective treatment ($0.67 kg^{-1}) can be recommended where quick inexpensive cover is needed for slope stabilization, but regular disturbance with 30 days does not justify the cost of seeding. EFM treatment ($6.00 kg^{-1}), which was more expensive than the wheat straw treatments, can be applied for the slopes adjacent to the sensitive streams requiring quick stabilization to prevent water quality degradation.

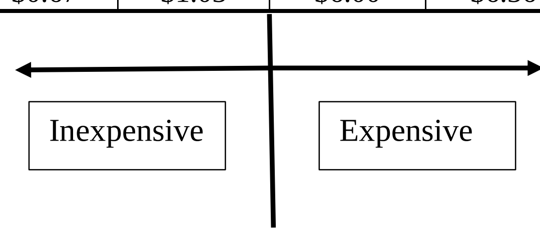
Vegetation provides a practical long term solution for slope stabilization and erosion control on disturbed sites (Pitt et al., 2007). Seeded treatments in this study (WS+P+S, EFM+S) were compared to recommend a roadside slope stabilization option for similar study site conditions. Because neither of the seeded treatments (WS+P+S and EFM+S) were significantly different from each other in terms of percent cover establishment (Figure 4.15), differences in MTSS delivery were used to quantify the most beneficial BMP in terms of cost and water quality benefits from erosion reduction. The EFM+S treatment delivered 39% less MTSS per ha than WS+P+S (Table 4.5) however WS+P+S (cost of $3,657 ha^{-1}) was approximately 84% less expensive than EFM+S (cost of $22,594 ha^{-1}).

Consequently, unless there is a special need or site consideration for hydro-applied product, EFM+S does not appear as economical when nearly the same performance can be achieved with WS+P+S. Therefore, WS+P+S can be considered as cost effective option compared to EFM+S in terms of water quality protection by reduced sediment delivery under similar slopes, soil, and rainfall conditions for the small scale test conditions.

Table 4.5: Average cost comparison by mean treatment MTSS

	BS[3]	**BS+P[4]**	**WS+P[5]**	**WS+P+S[6]**	**EFM[7]**	**EFM+S[8]**
MTSS/plot (g)[1]	235	182	1.48	0.97	0.68	0.59
MTSS/ha (g)	3,560,606	2,757,576	22,424	14,697	10,303	8,939
MTSS reduction (g/ha)[9]	0	803,030	3,538,182	3,545,909	3,550,303	3,551,667
MTSS reduction (kg/ha)[9]	0	803	3,538	3,546	3,550	3,552
Cost /ha[2]	NA	$307[10]	$2,369	$3,657	$21,306	$22,594
Dollar/sediment reduction ($/kg)		$0.38	$0.67	$1.03	$6.00	$6.36

[1]MTSS for test period II
[2]ALDOT bid summary, 2014
[3]Bare soil
[4]Bare soil with PAM
[5]Wheat straw with PAM
[6]Wheat straw with PAM and seed
[7] Engineered fiber matrix
[8] Engineered fiber matrix with seed
[9] MTSS reduction compared to the bare soil control
[10]ALDOT bid summary, 2012



CHAPTER 5 SUMMARY AND FUTURE RECOMMENDATIONS

5.1 Summary and conclusions

The main objective of the study was to test the erosion control performance of selected erosion control covers (EFM, EFM+S, WS+P, WS+P+S and BS+P) compared to the bare soil (BS) control in terms of water quality response (runoff volume, turbidity and MTSS delivery) under simulated rainfall. The most cost effective treatment was determined for roadside and similar construction sites under conditions similar to this study. Test plots of 1.2 m x 0.6 m were constructed of pressure treated lumber and placed on 3:1 slope under shelter. The soil in each test plot was compacted to approximate the in-situ dry bulk density (0.9 g cm^{-3}) of the native soil. Soil test and manufacturer's recommendations for fertilizer, lime, seed, and PAM application rate were converted to equivalent test plot scales for each. Seed was incorporated into the soil before cover placement. Wheat straw was applied at one half of the recommended application rate to ensure seed germination. EFM treatments were applied using a Turf Maker® 380 (Rowlett, TX) hydromulcher and USDA-ARS precision applicator. Data was gathered from two test periods using annual ryegrass (*Lolium multiflorum*) and browntop millet (*Panicum ramosum*), respectively, in seeded treatments.

Runoff was generated using a rainfall simulator run for 15 minutes on three replicates of each treatment. Runoff was collected in buckets through metal flumes with runoff samples taken to the laboratory for turbidity measurement. Runoff samples filtered in the field through 1 µm filter bags were subsequently dried in the laboratory for 24 hours to determine MTSS. Filtered water volume measured in the field provided a measure of total runoff volume from each plot. Percent vegetation cover data was collected throughout the study on runoff sample dates using the line-point intercept method. Cost per ha data for each treatment was assembled from ALDOT bid summaries and used to determine the most cost effective treatment in terms of MTSS reduction compared to bare soil.

The first objective of the study was to compare runoff volume, turbidity, and MTSS response of each treatment to determine the water quality benefits of each. Test period II data was used for ranking treatments in terms of water quality response as it provided a more complete set of data points than test period I. Ranked runoff volume reduction in treatments compared to control was: (1) EFM+S (68%), (2) WS+P+S (49%), (3) WS+P (46%), (4) EFM (30%), and (5) BS+P (16%). Runoff volume of the EFM+S treatment was significantly lower than WS+P, EFM, BS+P, and BS treatments. Runoff volume of EFM+S and WS+P+S treatments were not significantly different from each other. Ranked turbidity reduction in treatments compared to control was: (1) EFM+S (98.7%) (2) EFM (98.3%), (3) WS+P+S (96.5%), (4) WS+P (92.4%), and (5) BS+P (16.9%). The turbidity of the EFM+S treatment was significantly lower than the other treatments. All cover treatments except BS+P reduced sediment delivery by over 99%, as compared to control with the following rankings: (1) EFM+S (99.8%) (2) EFM (99.7%) (3) WS+P+S (99.6%) (4) WS+P (99.4%) (5) BS+P (22.6%). A cover factor was calculated for all cover treatments with ranked results from most to least effective are as follows: (1) EFM+S (0.0025), (2) EFM (0.0029), (3) WS+P+S (0.0041), (4) WS+P (0.0063), and (5) BS+P (0.7747).

The second objective of this study was to quantify the beneficial impact of seeded treatments compared to non-seeded treatments in terms of runoff, turbidity, and MTSS response. Water quality response of the WS+P+S treatment was negatively correlated with DAS with respect to runoff volume (r = -0.57), turbidity (r = -0.60), and MTSS (r = -0.71). Compared to the non-seeded WS+P treatment, WS+P+S significantly reduced mean turbidity only. Consequently, the seeded WS+P+S treatment had a significant effect on turbidity but not much effect on runoff volume or MTSS reduction, as compared to WS+P. Water quality response of seeded treatments combined (EFM+S and WS+P+S) were negatively correlated with DAS with respect to runoff volume (r = -0.48), turbidity (r =-0.47), and MTSS (r = -0.63). There was a flat correlation of corresponding responses with DAS in non-seeded treatments (r = 0.10, 0.01, and 0.02, respectively), documenting the important water quality benefit of seeding as an erosion control practice.

The third objective of the study was to evaluate the cost effectiveness of temporary covers in terms of sediment delivery reduction and offer recommendations based on water quality and budget requirements. Average cost of treatments derived from ALDOT bid summaries were used to determine the most cost effective treatment in this study. Cost effectiveness was defined in terms of MTSS sediment delivery reduction compared to the bare soil control. The most cost effective treatment was BS+P, with a cost of \$0.38 kg^{-1} sediment reduction compared to the control. However, since mass load reduction in BS+P was not observed to be significantly different from the bare soil control, the BS+P treatment at test rates used in this study (10 kg ha^{-1}) was not recommended. The EFM treatment (cost \$6.00 kg^{-1} sediment reduction) at almost 16 times the normalized cost of BS+P is widely used as a temporary cover for slopes adjacent to sensitive areas because of its documented performance. Although EFM+S (cost \$6.36 kg^{-1} sediment reduction) was significantly more effective than WS+P+S in terms of MTSS sediment reduction (39% less MTSS delivered), EFM+S was 84% more expensive. Therefore, in this study WS+P+S (cost \$1.03 kg^{-1} sediment reduction) provided good water quality protection benefits and was considered the most economical of the treatments tested. Consequently, the seeded WS+P+S treatment can be recommended as a cost effective sediment delivery reduction option for roadside slopes under conditions similar to this small scale study.

5.2 Future recommendations

The following future work can be performed to provide further data to reduce erosion and sedimentation while providing long term slope stability.

1. This study focused on the short period of vegetation establishment for erosion and sediment reduction. Future studies should also focus on longer vegetation establishment periods.
2. Higher application rates of PAM, along with more than one application to minimize chemical degradation can be a future research focus.
3. Cover treatments need to be tested under natural rainfall and field scale conditions to better assess effectiveness under more realistic conditions.
4. Different species of vegetation can be evaluated to test the effect of species on runoff water quality response.
5. Wheat straw with lower than recommended application rates may leave some soil exposed, so application rates can be adjusted and evaluated with seed to quantify runoff water quality benefits and long term slope stabilization success.

6. Evaluate treatments with sodded turf for applications where immediate cover is required for maximum protection or stringent water quality requirements.
7. RUSLE cover factors can be estimated for any treatment on a weekly or daily basis for potential RUSLE II modelling.

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Note: References are according to the ASABE guidelines

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APPENDIX A: EXPERIMENTAL SETUP AND RESULTS

A. 1: Description of cover treatments

Treatments	Description
BS+P	Bare soil with PAM at 4 kg ha^{-1} with salt shaker
EFM	Engineered Fiber matrix at 3362 kg ha^{-1} applied with hydromulcher system
EFM + S	Engineered Fiber matrix at 3362 kg ha^{-1} applied with hydromulcher system Annual Ryegrass: (67 kg ha^{-1}) Browntop Millet : (45 kg ha^{-1})
WS+P	Wheat straw with PAM at 2240 kg ha^{-1} applied by hand
WS+P+S	Wheat straw with PAM at 2240 kg ha-1 applied by hand Annual Ryegrass: (67 kg ha^{-1}) Browntop Millet : (45 kg ha^{-1})

A.2: Soil test recommendations (17 August, 2013)

Soil Textural Analysis						
	%	%	%		cm^3/cm^3	%
Sample I.D.	Sand	Silt	Clay	Textural Class	H_2O availability	Organic Matter
Surface AGC Site	46.30	15.60	38.10	Sandy Clay	0.11	1.0

				SOIL TEST RESULTS					RECOMMENDATIONS			
LAB No.	Sample Designation	Crop	Soil Group*	pH**	Phosphorus P***	Potassium K***	Magnesium Mg***	Calcium Ca***	LIME-STONE	N	P_2O_5	K_2O
					Pounds/Acre				Tons/Acre	Pounds/Acre		
23890	Surface AGC site See Comment 1 See Comment 2	Bermuda Hay	2	4.8	VL 3	M 114	H 358	M 192	3.5	100	100	200
	Surface AGC site See Comment 1 See Comment 3	Bermuda Pasture	2	4.8	VL 3	M 114	H 358	M 192	3.5	60	80	40

A. 3: Soil test recommendations (16 May, 2014)

	Soil Textural Analysis					
	%	%	%		cm^3/cm^3	%
Sample I.D.	Sand	Silt	Clay	Textural Class	H_2O availability	Organic Matter
Soil AGC	45.63	16.25	38.13	Sandy Clay	0.11	2.2

					SOIL TEST RESULTS				RECOMMENDATIONS			
LAB No.	Sample Designation	Crop	Soil Group*	pH**	Phosphorus P***	Potassium K***	Magnesium Mg***	Calcium Ca***	LIME-STONE	N	P_2O_5	K_2O
					Pounds/Acre				Tons/Acre	Pounds/Acre		
19726	Soil AGC See Comment 1 See Comment 2	Ryegrass	2	4.6	VL 3	H 128	H 369	M 229	3.0	100	110	0

Comment No.1: Soil acidity (low pH) can be corrected with either dolomitic or calcitic lime.

Comment No.2: For small grains or small grains plus ryegrass planted on fallowed fields in early September for grazing, apply 100 pounds of N at planting and 60 pounds N in late winter to early spring. Ryegrass planted alone for grazing should receive no more than 60 pounds of N in the fall and up to 100 pounds N in late winter to early spring. For grain only, apply 20 pounds N per acre in the fall and 60 to 80 pounds in the spring. The fall N can be eliminated following a good soybean crop or other legume.

A. 4: Fertilizers recommendation for roadside turf establishment for Alabama crops

(Crop Code No. 47)

Phosphorus	Potassium				
	Very high	High	Medium	Low	Very low
	Pounds N-P_2O_5-K_2O per acre				
Very high	120-0-0	120-0-40	120-0-80	120-0-160	120-0-160
High	120-40-0	120-40-40	120-40-80	120-40-160	120-40-160
Medium	120-80-0	120-80-40	120-80-80	120-80-160	120-80-160
Low	120-160-0	120-160-40	120-160-80	120-160-160	120-160-160
Very Low	120-160-0	120-160-40	120-160-80	120-160-160	120-160-160

A. 5: Temporary vegetation grown in Alabama (Source: Pitt et al. 2007)

Species	Seeding rate ($kg\ ha^{-1}$)	Seeding dates		
		North Alabama	Central Alabama	South Alabama
Millet (Browntop or German)	44	May 1-Aug 1	Apr 1-Aug 15	Apr 1-Aug 15
Rye	188	Sep 1-Nov 15	Sep 15-Nov 15	Sep 15-Nov 15
Annual Ryegrass	34	Aug 1-Sep 15	Sep 1-Oct 15	Sep 1 -Oct 15
Sorghum-Sudan Hybrids	45	May 1-Aug 1	Apr 15-Aug 1	Apr 1-Aug 15
Sudangrass	45	May 1-Aug 1	Apr 15-Aug 1	Apr 1-Aug 15
Wheat	201	Sep 1-Nov 1	Sep 15-Nov 15	Sep 15-Nov 15

A. 6: Runoff volume (ml) for test period I

Date	BS	BS+P	EFM	EFM+S	WS+P	WS+P+S
26 March	11100	9933	2567	4550	7217	8483
30 March	9200	9100	2550	2517	4983	6650
1 April	9683	9700	2717	2500	3800	5517
8 April	10167	8667	3983	2667	5450	3767
10 April	10967	10583	2217	1983	3933	2500
19 April	8933	9500	3217	3000	8533	2900
26 April	10117	7533	2717	2633	9383	4317
5 May	8433	7717	3117	1700	6858	2117

A.7. Runoff volume (ml) for test period II

Date	BS	BS+P	EFM	EFM+S	WS+P	WS+P+S
27 May	4500	3025	7550	4417	1467	3283
30 May	6400	4467	7017	3417	3133	4533
3 June	6433	5933	5450	3883	3300	5383
7 June	9917	9267	6500	2767	4550	5200
10 June	10600	9600	6667	2600	4917	5450
12 June	13133	10800	8300	2833	5167	5200
16 June	9667	7450	5483	2700	4450	5117
19 June	12117	10083	7567	2667	6817	5150
27 June	8733	7967	5867	2133	8217	4400
3 July	10817	8867	5133	2317	7117	4067
14 July	6517	5967	3383	1867	4467	2767

A.8. Turbidity (NTU) for test period I

Date	BS	BS+P	EFM	EFM+S	WS+P	WS+P+S
26 March	2730	2289	124	302	98	352
30 March	2090	2070	33	218	78	320
1 April	2547	2526	57	44	91	198
8 April	2252	1886	59	35	79	86
10 April	2080	2050	25	17	71	42
19 April	1592	1428	102	12	104	23
26 April	2274	2916	64	26	131	31
5 May	2304	1797	61	21	175	22

A.8. Turbidity (NTU) for test period II

Date	BS	BS+P	EFM	EFM+S	WS+P	WS+P+S
27 May	682	253	29	37	95	108
30 May	3365	2328	25	41	213	124
3 June	2582	2454	45	59	179	140
7 June	3996	3602	49	53	324	136
10 June	2872	2806	57	43	261	132
12 June	3004	2220	64	36	204	116
16 June	2466	2136	44	32	183	73
19 June	2698	2120	43	27	271	98
27 June	3318	2636	75	42		81
3 July	4166	3832	76	27	328	94
14 July	3262	2554	53	20	186	36

A.9. MTSS (g) for test period I

Date	BS	BS+P	EFM	EFM+S	WS+P	WS+P+S
26 March	559.943	533.930	1.407	1.560	2.037	3.990
30 March	445.763	381.950	0.313	0.690	0.317	1.495
1 April	335.280	333.250	0.347	0.680	0.330	0.773
10 April	366.703	298.937	2.193	0.180	3.020	0.260
19 April	196.627	194.980	0.890	0.170	0.910	0.155
26 April	271.843	227.847	0.470	0.257	1.220	0.280
5 May	277.463	217.253	0.367	0.170	0.933	0.147

A.10. MTSS (g) for test period II

Date	BS	BS+P	EFM+S	EFM	WS+P	WS+P+S
27 May	62	52	0.36	0.15	0.56	2.07
30 May	332	366.58	1.7	0.64	2.14	1.82
3 June	330.19	227.83	1.97	0.54	0.987	1.32
7 June	315.03	199.64	1.12	0.55	1.63	1.7
10 June	137.07	176.89	0.2	0.48	1.6	1.17
12 June	237.64	163.81	0.12	1.04	0.97	0.89
16 June	152.49	89.5	0.12	0.48	1.31	0.27
19 June	194.44	153.59	0.34	2.01	1.98	0.5
27 June	325.23	190.92	0.15	0.51	1.89	0.48
3 July	309.87	226.37	0.3	0.73	1.79	0.29
14 July	183.66	151.29	0.14	0.31	1.38	0.14

APPENDIX B: MANUFACTURERS SPECIFICATIONS

B.1. PRESSURE REGULATOR SPECIFICATIONS

PMR-MF[Regulators

The medium flow Pressure-Master Regulator® is ideal for installations requiring mid-range flows [2 - 20 gpm] including solid-set, drip or other low-volume irrigation systems as well as center pivot and other mechanical-move irrigation systems.

FEATURES:

- Maintains a constant preset outlet pressure while handling varying inlet pressures
- Very low hysteresis and friction losses
- Maximum flow path resists plugging
- 100% water-tested for accuracy (no adjustments ever needed)
- Two-year warranty on materials, workmanship AND performance
- Can be installed above or below ground.

PMR-MF CMS models are designed specifically for mining applications where pH solutions are less than or equal to 4.0 PMR-MF EFF models (lavender top) are designed specifically for wastewater applications.

PMR-MF - Pressure-Master Regulator® Medium-Flow

Model Number	Preset Oper. Press. psi	[bar]	Maximum Inlet Press. psi	[bar]	Flow Range gpm	[L/hr]	Inlet Sizes	Outlet Sizes
PMR-6 MF	6	0.41	100	6.90	4 - 16	907.2 -3628.8	3/4" F NPT, 1" F NPT, 1"M NPT, 1"F BSP	3/4" F NPT, 1" F NPT, 1"F BSP
PMR-10 MF	10	0.69	120	8.28	4 - 16	907.2 -3628.8	3/4" F NPT, 1" F NPT, 1"M NPT, 1"F BSP	3/4" F NPT, 1" F NPT, 1"F BSP
PMR-12 MF	12	0.83	135	9.31	2-20	453.6-4536.0	3/4" F NPT, 1" FNPT, 1"M NPT, 1"F BSP	3/4" F NPT, 1" F NPT, 1"F BSP
PMR-15 MF	15	1.04	150	10.35	2-20	453.6-4536.0	3/4" F NPT, 1" F NPT, 1"M NPT, 1"F BSP	3/4" F NPT, 1" F NPT, 1"F BSP
PMR-20 MF	20	1.38	150	10.35	2-20	453.6-4536.0	3/4" F NPT, 1" FNPT, 1"M NPT, 1"F BSP	3/4" F NPT, 1" F NPT, 1"F BSP
PMR-25 MF	25	1.73	150	10.35	2-20	453.6-4536.0	3/4" F NPT, 1" F NPT, 1"M NPT, 1"F BSP	3/4" F NPT, 1" F NPT, 1"F BSP
PMR-30 MF	30	2.07	150	10.35	2-20	453.6-4536.0	3/4" F NPT, 1" F NPT, 1"M NPT, 1"F BSP	3/4" F NPT, 1" F NPT, 1"F BSP
PMR-35 MF	35	2.42	150	10.35	2-20	453.6-4536.0	3/4" F NPT, 1" F NPT, 1"M NPT, 1"F BSP	3/4" F NPT, 1" F NPT, 1"F BSP
PMR-40 MF	40	2.76	150	10.35	2-20	453.6-4536.0	3/4" F NPT, 1" F NPT, 1"M NPT, 1"F BSP	3/4" F NPT, 1" F NPT, 1"F BSP
PMR-50 MF	50	3.45	150	10.35	2-20	453.6-4536.0	3/4" F NPT, 1" F NPT, 1"M NPT, 1"F BSP	3/4" F NPT, 1" F NPT, 1"F BSP
PMR-60 MF	60	4.14	150	10.35	2-20	453.6-4536.0	3/4" F NPT, 1" F NPT, 1"M NPT, 1"F BSP	3/4" F NPT, 1" F NPT, 1"F BSP

Regulated pressure is 1/2 psi (0.03 bar) higher with increasing inlet pressure than with decreasing inlet pressure

Senninger Irrigation Inc. Call (407) 877-5655 • Web: www.senninger.com • E-Mail: info@senninger.com

B.2 WATER FILTER SPECIFICATIONS

3/4" Filter

Manual Disc Filter

Features

- Durable filter element
- Corrosion free
- All Plastic
- Precise disc filtration

Technical Data

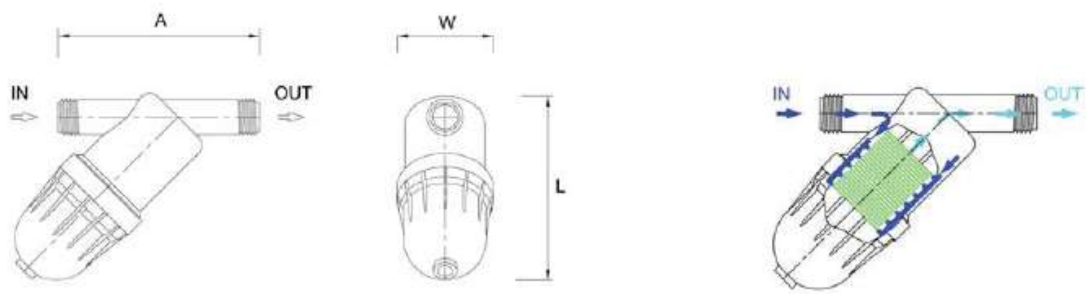
	METRIC		US	
Connection diameter	mm	20	in	3/4
Filtration surface area	cm^2	160	in^2	24.8
Filtration volume	cm^3	95	in^3	5.8
Pressure rating	bar	10	psi	145
Max. temp.	°C	60	°F	140

Maximum Filtration Flow Rate / Water Quality

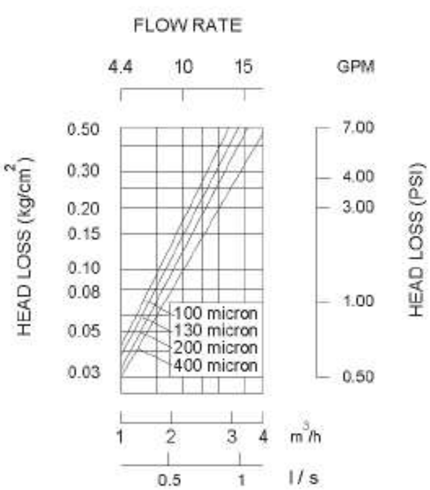
Filtration Grade	Water Quality	m^3/h	gpm
400-130 μ	Good	4	17.6
	Average	3	13.5

Dimensions and Weights

D Inlet\Outlet diameter	mm	20	inch	¾
L Length	mm	144	inch	5 11/16
W Width	mm	74	inch	2 29/32
A	mm	150	inch	5 29/32
Shipping weight (approx.)	kg	0.37	lbs	0.8



Head Loss Chart, Clean State



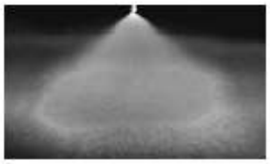
¾'' Filter is available in:
Polyester.

B.3 RAINFALL SIMULATOR NOZZLE

FullJet® Spray Nozzles • Wide Angle Square Spray

Small Capacity

FULL CONE NOZZLES



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

1/4 = Inlet Conn.; HH = Nozzle Type; SS = Material Code; 14WSQ = 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.

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APPENDIX C: TREATMENTS MANUFACTURERS SPECIFICATIONS

C.1 ENVIROPAM Specifications

EnviroPam

EnviroPam is a safe, non-toxic linear anionic polymer that binds hydroseeding media to the soil particles, helps maintain soil structure and reduces soil erosion.

CONTENT ANALYSIS
Sodium Acrylate / Acrylamide Copolymer

GENERAL INFORMATION
EnviroPam is used to bond the components of a hydroseeding system. By holding the components together and preventing loss of material through wind and water erosion.

PRECAUTIONS
Wash with soap and water after contact. Prolonged repeated skin contact may cause irritation/dry skin.

Eye contact will cause irritation. Keep out of the reach of children.

STORAGE AND HANDLING
ENVIROPAM is stable for more than two years when **stored below 110°F under cool, dry conditions**

Spill Cleanup: ENVIROPAM spills should be collected **without** the use of water **due to resulting slippery conditions.** Thoroughly collect spilled granular material. Flush residuals to the drain with water, for normal biological wastewater treatment.

DIRECTIONS FOR USE

Introduce the appropriate amounts of ENVIROPAM into the hydroseeding mixing tank according to machine manufacturer's directions, agitate mixture thoroughly. The total amount of ENVIROPAM added will vary depending on amount of area to be covered as shown in the table below and desired viscosity of the mix.

Application Rate

Slope	Flat	4:1	3:1	2:1	1:1
Lbs./Acre	5	7	9	12	15

Always read and follow label directions before buying or using this product. Notice to Buyer: The statements contained herein, including all descriptions of products and methods, test results, and suggestions are provided for your consideration only as a general information reflecting Innovative Turf Solutions' experience with its products and are not to be construed to constitute a representation or warranty, express or implied, by Innovative Turf Solutions. Users assume full responsibility for determining the appropriate application of any products, method, or suggestions and for adopting such precautions against damage to property or injury to persons area as necessary or advisable under the circumstances. No statement contained herein is to be construed to constitute the permission, recommendation or encouragement of any use or application that may infringe on patents now or hereinafter in existence. NO WARRANTY OF MERCHANTABILITY OR WARRANTY OF SUITABILITY OR FITNESS FOR A PARTICULAR PURPOSE IS MADE BY INNOVATIVE TURF SOLUTIONS. No warranty, express or implied, is made by INNOVATIVE TURF SOLUTIONS except as may be provided in the Sales Contract or Invoice applicable to the goods in question.

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Net Wt. 55 lbs./25 kg.

C.2 PROMATRIX ® ENGINEERED FIBER MATRIX SPECIFICATIONS

Loading Chart for Profile's Engineered Fiber Matrix

Tank Size (gal)	# of 50-lb bales	(lb)	Displacement (gal)	2,500 lb/ac		3,000 lb/ac		3,500 lb/ac		4,000 lb/ac	
				Sq ft	Acres	Sq ft	Acres	Sq ft	Acres	Sq ft	Acres
250	3	100	280	2,614	0.060	2,178	0.050	1,867	0.043	1,634	0.038
500	6	300	560	5,227	0.120	4,356	0.100	3,734	0.086	3,267	0.075
750	9	450	840	7,841	0.180	6,534	0.150	5,601	0.129	4,901	0.113
1,000	12	600	1,120	10,454	0.240	8,712	0.200	7,467	0.171	6,534	0.150
1,500	18	900	1,680	15,682	0.360	13,068	0.300	11,201	0.257	9,801	0.225
2,000	24	1,200	2,240	20,909	0.480	17,424	0.400	14,935	0.343	13,068	0.300
2,500	30	1,500	2,800	26,136	0.600	21,780	0.500	18,669	0.429	16,335	0.375
3,000	36	1,800	3,360	31,363	0.720	26,136	0.600	22,402	0.514	19,602	0.450
3,500	42	2,100	3,920	36,590	0.840	30,492	0.700	26,136	0.600	22,869	0.525
4,000	48	2,400	4,480	41,818	0.960	34,848	0.800	29,870	0.686	26,136	0.600

Additional Notes:

- Rough surfaces (rocky terrain, cat tracks, ripped soils, etc.) may require additional product to achieve 100% coverage.
- Be sure to allow for residual material in tank on subsequent applications.

Application Rates

Slope Condition	English	SI
≤4H to 1V	2500 lb/ac	2800 kg/ha
≥4H to 1V and ≤3H to 1V	3000 lb/ac	3360 kg/ha
≥3H to 1V and ≤2H to 1V	3500 lb/ac	3920 kg/ha
≥2H to 1V and ≤1H to 1V†	4000 lb/ac	4480 kg/ha

Slope Interruption Limits*

Product Category	Length (ft)	Length (m)
EFM	50	15

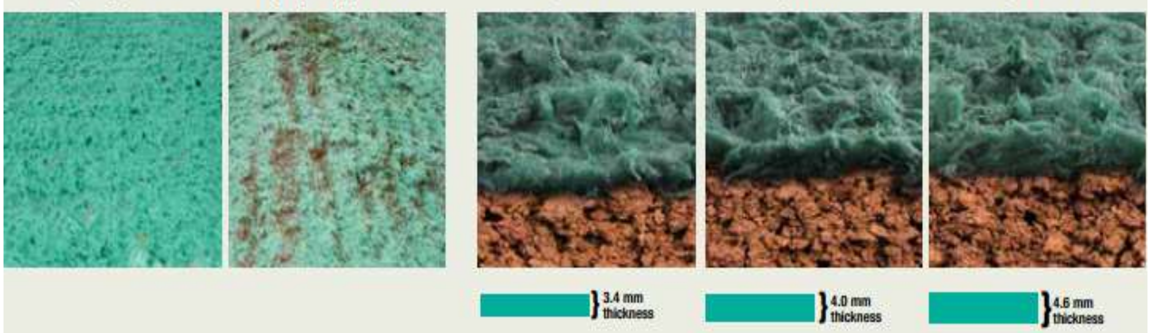
For conversions:
1 lb = 0.454 kg
1 ac = 0.41 ha
lb/ac x 1.12 = kg/ha
1 kg = 2.20 lb
1 ha = 2.47 ac

†EFM not recommended for slopes greater than 1H:1V.

*Listed slope interruption limits are for product applications on a 3H:1V slope. For application on steeper slopes, slope interruption lengths may need to be decreased.

Visual Key for Proper Application

Proper Application | **Improper Application** | **3,000 lb/ac** | **3,500 lb/ac** | **4,000 lb/ac**



Profile
Solutions for your Environment

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APPENDIX D: STATISTICAL ANALYSIS

D.1 TEST PERIOD I RESULTS

RUNOFF VOLUME

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TRT	5	1127245508	225449102	45.2922	<.0001*
Error	138	686917578	4977663.6		
C. Total	143	1814163086			

Ordered Differences Report

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
BS	EFM+S	7131.250	644.0538	5269.87	8992.633	<.0001*
BS	EFM	6939.583	644.0538	5078.20	8800.967	<.0001*
BS+P	EFM+S	6397.917	644.0538	4536.53	8259.300	<.0001*
BS+P	EFM	6206.250	644.0538	4344.87	8067.633	<.0001*
BS	WS+P+S	5293.750	644.0538	3432.37	7155.133	<.0001*
BS+P	WS+P+S	4560.417	644.0538	2699.03	6421.800	<.0001*
WS+P	EFM+S	3576.042	644.0538	1714.66	5437.425	<.0001*
BS	WS+P	3555.208	644.0538	1693.83	5416.592	<.0001*
WS+P	EFM	3384.375	644.0538	1522.99	5245.758	<.0001*
BS+P	WS+P	2821.875	644.0538	960.49	4683.258	0.0003*
WS+P+S	EFM+S	1837.500	644.0538	-23.88	3698.883	0.0552
WS+P	WS+P+S	1738.542	644.0538	-122.84	3599.925	0.0819
WS+P+S	EFM	1645.833	644.0538	-215.55	3507.217	0.1156
BS	BS+P	733.333	644.0538	-1128.05	2594.717	0.8644
EFM	EFM+S	191.667	644.0538	-1669.72	2053.050	0.9997

TURBIDITY

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
BS	24	2914.00	1740.00	121.417	6.291
BS+P	24	2865.00	1740.00	119.375	6.028
EFM	24	1102.00	1740.00	45.917	-3.418
EFM+S	24	868.500	1740.00	36.188	-4.669
WS+P	24	1463.00	1740.00	60.958	-1.482
WS+P+S	24	1227.50	1740.00	51.146	-2.745

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
99.3832	5	<.0001*

Nonparametric Comparisons For Each Pair Using Wilcoxon Method

q*	Alpha
1.95996	0.05

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL
WS+P	EFM+S	10.7500	4.040136	2.66080	0.0078*	43.00	13.00	79.00
WS+P	EFM	10.3333	4.039916	2.55781	0.0105*	34.50	8.00	66.00
WS+P+S	EFM+S	6.6250	4.040136	1.63980	0.1010	18.00	-2.00	70.00
WS+P+S	EFM	2.0833	4.040903	0.51556	0.6062	7.00	-15.00	70.00
BS+P	BS	-1.7917	4.041123	-0.44336	0.6575	-64.00	-443.00	264.00
WS+P+S	WS+P	-3.7083	4.039806	-0.91795	0.3586	-18.50	-59.00	41.00
EFM+S	EFM	-7.2917	4.040465	-1.80466	0.0711	-14.00	-32.00	3.00
WS+P+S	BS+P	-23.7083	4.041233	-5.86661	<.0001*	-1947.50	-2151.00	-1651.00
EFM+S	BS+P	-23.7917	4.041233	-5.88723	<.0001*	-2006.50	-2235.00	-1746.00
EFM	BS	-23.9583	4.041123	-5.92863	<.0001*	-2075.00	-2280.00	-1815.00
EFM	BS+P	-23.9583	4.041233	-5.92847	<.0001*	-1999.00	-2231.00	-1769.00
EFM+S	BS	-23.9583	4.041123	-5.92863	<.0001*	-2040.50	-2264.00	-1827.00
WS+P	BS	-23.9583	4.040684	-5.92928	<.0001*	-2030.00	-2248.00	-1777.00
WS+P	BS+P	-23.9583	4.040794	-5.92912	<.0001*	-1960.50	-2193.00	-1753.00
WS+P+S	BS	-23.9583	4.041123	-5.92863	<.0001*	-1991.50	-2227.00	-1778.00

MTSS

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
BS	21	2148.00	1281.00	102.286	5.931
BS+P	21	2073.00	1281.00	98.714	5.417
EFM	20	840.000	1220.00	42.000	-2.648
EFM+S	20	625.500	1220.00	31.275	-4.145
WS+P	21	1047.00	1281.00	49.857	-1.598
WS+P+S	18	647.500	1098.00	35.972	-3.278

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
84.9072	5	<.0001*

Nonparametric Comparisons For Each Pair Using Wilcoxon Method

q*	Alpha
1.95996	0.05

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL
WS+P	EFM+S	9.8595	3.741630	2.63509	0.0084*	0.510	0.130	0.990
WS+P	EFM	4.5881	3.741303	1.22634	0.2201	0.200	-0.170	0.760
WS+P+S	EFM+S	1.2667	3.607789	0.35109	0.7255	0.040	-0.180	0.540
WS+P+S	EFM	-2.7972	3.609172	-0.77503	0.4383	-0.100	-0.500	0.300
BS+P	BS	-3.5238	3.785939	-0.93076	0.3520	-33.810	-142.400	59.900
WS+P+S	WS+P	-5.9325	3.661779	-1.62012	0.1052	-0.295	-0.880	0.150
EFM+S	EFM	-6.0000	3.695111	-1.62377	0.1044	-0.190	-0.610	0.060
WS+P+S	BS	-19.4484	3.662150	-5.31065	<.0001*	-349.650	-388.440	-229.510
WS+P+S	BS+P	-19.4484	3.662150	-5.31065	<.0001*	-274.430	-416.910	-195.700
EFM	BS	-20.4512	3.742282	-5.46490	<.0001*	-349.380	-387.760	-229.410
EFM	BS+P	-20.4512	3.742282	-5.46490	<.0001*	-274.160	-416.230	-195.600
EFM+S	BS	-20.4512	3.741793	-5.46561	<.0001*	-349.635	-388.380	-229.590
EFM+S	BS+P	-20.4512	3.741793	-5.46561	<.0001*	-274.415	-416.850	-195.780
WS+P	BS	-20.9524	3.785939	-5.53426	<.0001*	-349.200	-387.390	-229.330
WS+P	BS+P	-20.9524	3.785939	-5.53426	<.0001*	-273.980	-415.860	-195.520

D.2.TEST PERIOD II RESULTS

RUNOFF VOLUME

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TRT	5	805162339	161032468	26.8218	<.0001*
Error	192	1152729848	6003801.3		
C. Total	197	1957892188			

Ordered Differences Report

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
BS	EFM+S	6112.121	603.2137	4375.64	7848.606	<.0001*
BS+P	EFM+S	4711.364	603.2137	2974.88	6447.848	<.0001*
BS	WS+P+S	4389.394	603.2137	2652.91	6125.878	<.0001*
BS	WS+P	4112.121	603.2137	2375.64	5848.606	<.0001*
EFM	EFM+S	3392.424	603.2137	1655.94	5128.909	<.0001*
BS+P	WS+P+S	2988.636	603.2137	1252.15	4725.121	<.0001*
BS	EFM	2719.697	603.2137	983.21	4456.182	0.0002*
BS+P	WS+P	2711.364	603.2137	974.88	4447.848	0.0002*
WS+P	EFM+S	2000.000	603.2137	263.52	3736.485	0.0138*
WS+P+S	EFM+S	1722.727	603.2137	-13.76	3459.212	0.0532
EFM	WS+P+S	1669.697	603.2137	-66.79	3406.182	0.0671
BS	BS+P	1400.758	603.2137	-335.73	3137.242	0.1903
EFM	WS+P	1392.424	603.2137	-344.06	3128.909	0.1958
BS+P	EFM	1318.939	603.2137	-417.55	3055.424	0.2489
WS+P	WS+P+S	277.273	603.2137	-1459.21	2013.757	0.9974

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Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
BS	33	5469.50	3234.00	165.742	7.564
BS+P	33	5101.50	3234.00	154.591	6.318
EFM	33	1527.00	3234.00	46.273	-5.775
EFM+S	33	999.000	3234.00	30.273	-7.562
WS+P	30	3301.00	2940.00	110.033	1.268
WS+P+S	33	2712.00	3234.00	82.182	-1.765

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
159.9456	5	<.0001*

Nonparametric Comparisons For Each Pair Using Wilcoxon Method

q*	Alpha
1.95996	0.05

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL
WS+P	EFM+S	29.5909	4.623160	6.40058	<.0001*	200.00	152.00	223.00
WS+P+S	EFM+S	28.7576	4.724730	6.08661	<.0001*	63.00	48.00	79.00
WS+P	EFM	28.6682	4.623604	6.20040	<.0001*	183.50	136.00	211.00
WS+P+S	EFM	23.7273	4.725125	5.02151	<.0001*	50.00	33.00	68.00
BS+P	BS	-7.9394	4.725470	-1.68013	0.0929	-420.00	-972.00	84.00
EFM+S	EFM	-12.6667	4.723546	-2.68160	0.0073*	-13.00	-22.00	-4.00
WS+P+S	WS+P	-22.5273	4.623937	-4.87188	<.0001*	-127.00	-161.00	-86.00
WS+P	BS+P	-27.8409	4.623937	-6.02104	<.0001*	-2158.00	-2536.00	-1969.00
WS+P+S	BS+P	-29.7576	4.725569	-6.29714	<.0001*	-2266.00	-2651.00	-2093.00
WS+P	BS	-30.0045	4.624048	-6.48881	<.0001*	-2826.50	-3076.00	-2182.00
EFM	BS+P	-32.0303	4.725421	-6.77830	<.0001*	-2305.00	-2722.00	-2152.00
EFM+S	BS+P	-32.7273	4.724977	-6.92644	<.0001*	-2314.00	-2740.00	-2172.00
WS+P+S	BS	-32.8788	4.725717	-6.95742	<.0001*	-2976.00	-3179.00	-2298.00
EFM	BS	-32.9697	4.725569	-6.97687	<.0001*	-3030.00	-3238.00	-2329.00
EFM+S	BS	-32.9697	4.725076	-6.97760	<.0001*	-3052.00	-3256.00	-2332.00

MTSS

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
BS	33	5397.00	3184.50	163.545	7.615
BS+P	33	5130.00	3184.50	155.455	6.696
EFM	31	1877.00	2991.50	60.548	-3.932
EFM+S	30	1297.00	2895.00	43.233	-5.714
WS+P	33	2702.50	3184.50	81.894	-1.658
WS+P+S	32	2124.50	3088.00	66.391	-3.356

1-way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
137.4143	5	<.0001*

Nonparametric Comparisons For Each Pair Using Wilcoxon Method

q*	Alpha
1.95996	0.05

Level	- Level	Score Mean Difference	Std Err Dif	Z	p-Value	Hodges-Lehmann	Lower CL	Upper CL
WS+P	EFM+S	17.4364	4.621661	3.77275	0.0002*	0.600	0.200	1.320
WS+P	EFM	11.6676	4.656221	2.50582	0.0122*	0.540	0.100	1.270
WS+P+S	EFM+S	11.2375	4.582132	2.45246	0.0142*	0.230	0.040	0.570
WS+P+S	EFM	4.0010	4.617721	0.86645	0.3862	0.100	-0.120	0.480
BS+P	BS	-8.0606	4.725816	-1.70565	0.0881	-47.930	-100.190	7.460
WS+P+S	WS+P	-8.9252	4.690510	-1.90282	0.0571	-0.300	-0.890	0.010
EFM+S	EFM	-10.3962	4.542402	-2.28871	0.0221*	-0.220	-0.380	-0.020
EFM+S	BS	-31.4682	4.622771	-6.80721	<.0001*	-218.235	-269.930	-178.950
EFM+S	BS+P	-31.4682	4.622771	-6.80721	<.0001*	-169.305	-220.260	-138.080
EFM	BS	-31.9687	4.656541	-6.86534	<.0001*	-217.910	-269.800	-178.780
EFM	BS+P	-31.9687	4.656541	-6.86534	<.0001*	-168.980	-220.130	-137.910
WS+P+S	BS	-32.4692	4.690766	-6.92194	<.0001*	-217.825	-268.890	-178.890
WS+P+S	BS+P	-32.4692	4.690766	-6.92194	<.0001*	-168.895	-219.220	-138.020
WS+P	BS	-32.9697	4.725816	-6.97651	<.0001*	-217.370	-267.880	-178.760
WS+P	BS+P	-32.9697	4.725816	-6.97651	<.0001*	-168.440	-218.480	-137.870

D.3. COMPARISON OF SEEDED VS. NON-SEEDED TREATMENTS

RUNOFF VOLUME

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
DAS	4.91984E6	1	4.91984E6	1.63	0.2055
Intercepts	4.09822E7	1	4.09822E7	13.60	0.0004
Slopes	1.57479E7	1	1.57479E7	5.22	0.0252
Model	6.16499E7	3			

TURBIDITY

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
DAS	22277.1	1	22277.1	3.39	0.0696
Intercepts	11785.3	1	11785.3	1.80	0.1845
Slopes	40160.2	1	40160.2	6.12	0.0158
Model	74222.6	3			

MTSS

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
DAS	4.59036	1	4.59036	9.71	0.0027
Intercepts	1.49443	1	1.49443	3.16	0.0799
Slopes	5.13707	1	5.13707	10.86	0.0016
Model	11.2219	3			