ABSTRACT

LEE, GINA. Comparison of Five Hydromulches and Polyacrylamide to Straw for Erosion Control and Vegetation Establishment on Steep Slopes. (Under the direction of Richard A. McLaughlin).

Soil erosion and sediment pollution can be big problems in and around construction sites due to land disturbing activities that leave areas of unprotected soil during active construction. Establishing vegetation to control erosion can be difficult due to poor soil, steep slopes, and no irrigation. Our study was conducted on four construction sites in North Carolina to evaluate different treatments on steep slopes for erosion control and vegetative establishment. Site 1 was located in the mountain region and the remaining three were in the Piedmont near Raleigh, with two being 2:1 cut slopes and two being 2:1 fill slopes. On all sites the area was divided into 20 plots that were either 3 m wide and 6 m long (site 2) or 3 m wide and 9 m long (sites 1, 3 and 4). After seeding a grass mixture, erosion control treatments were applied in a randomized complete block design and included: 3,000 kg ha^{-1} wheat straw+tackifier (straw) and 3,000 kg ha^{-1} wheat straw+ tackifier with 22.4 kg ha^{-1} of granular, linear, anionic polyacrylamide (straw+PAM) were applied at all four sites; 3,900 kg ha^{-1} flexible growth medium (FGM) and 3,900 kg ha^{-1} stabilized mulch matrix (SMM) were applied at three sites; 3,900 kg ha^{-1} bonded fiber matrix (BFM), 2,800 kg ha^{-1} wood fiber/cellulosic blend (WCB) and 3,360 kg ha^{-1} wood fiber mulch (WFM) were applied at two sites. Runoff volumes, turbidity levels, eroded sediment and nutrient concentration data were collected after natural rain events, and grass growth and cover was evaluated once it reached a height of 10-12 cm. At site 1, there were no differences between treatments most likely due to the combination of sandy soil texture (average 72% sand) and relatively light rainfall events that occurred there. At site 2, there was a trend of straw having higher runoff volume, turbidity, TSS and in general higher concentrations and amount of nutrient loss

compared to all hydromulch treatments, and straw+PAM having higher losses than FGM. In contrast, at site 3 the straw treatment reduced runoff compared to FGM, WCB and WFM, while the only difference between treatments in reducing nutrient loss was between straw+PAM and WFM for total phosphorus (TP). The same trend of WFM and WCB ground covers producing higher turbidity, TSS and TSL compared to straw and straw+PAM was found on site 4. Addition of PAM did not have an effect on runoff volumes at any site, with turbidity reductions evident at two sites but only for individual storms and no significant reduction overall. Sites 1 and 3 had poor grass establishment with mean grass cover of 42 and 41%, while sites 2 and 4 had good grass establishment (67 and 85% cover, respectively). The reason for lower grass establishment under the hydromulches was explored further in a greenhouse study where our objective was to determine the effects of mulch type and rate on grass growth, resistance to penetration, and moisture holding capacity. The results suggest that straw maintains sufficient soil moisture for plant growth for a longer period than hydromulch. Further, even when water is not a limiting factor, hydromulch may inhibit vegetation possibly by creating a crusted layer that is difficult to penetrate.

Comparison of Five Hydromulches and Polyacrylamide to Straw for Erosion Control and Vegetation Establishment on Steep Slopes

by
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BIOGRAPHY

Gina Lee was born July 20, 1982, in Uzice, Serbia and was raised in the small town of Bajina Basta, located in western Serbia. After graduating High School in 2001, Gina attended Faculty of Forestry - University of Belgrade where she received her Engineering degree: Engineer of Forestry for Erosion Protection in 2008. Following graduation, she got a job as a Junior Design Engineer. After working two years, she moved to the Unites States of America and began graduate school in Soil Science at N.C. State University under the direction of Dr. Rich McLaughlin.

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CHAPTER 1: LITERATURE REVIEW

Introduction

Accelerated erosion occurs whenever the soil surface is disturbed. Construction site preparation typically includes: removing the vegetative cover, altering the natural topsoil, and changing the shape of the slope. This can greatly increase the potential for erosion, increased runoff rates; and significant sediment delivery to rivers and lakes. Erosion decreases the productive value of the soil as well as reducing the quality of the waters that receive the sediment. Sediments created by accelerated erosion clog streams, fill lakes, and often can carry pollutants to these waters.

Individual construction sites can contribute massive loads of sediment to small areas in short periods of time (Kaufman 2000; Clark and Pitt 2004). Sediment runoff rates from construction sites are typically 10 to 20 times greater than those of agricultural lands, and 1,000 to 2,000 times greater than those of forest lands (US EPA 2000, revised 2005). The National Water Quality Inventory Report states that 12% of assessed rivers and streams (31% of the impaired rivers) and 9% of assessed lakes (21% of the impaired lakes) were affected by sedimentation. Sources of sedimentation include agriculture, urban runoff, construction and forestry. For example, excess sediment can quickly fill rivers and lakes, requiring dredging and destroying aquatic habitats. In urban areas construction sites are major sources of sediment. Typical sediment loading from construction sites varies from 250 to 500 Mg ha^{-1} $year^{-1}$ and can range up to 2,500 Mg ha^{-1} $year^{-1}$ (Broz et al. 2003).

Using temporary ground cover like straw, compost, hydromulch, or rolled erosion control products (erosion control mats and blankets) has proven to be effective for controlling erosion and sedimentation (Benik et al. 2003; Soupir et al. 2004; Faucette et al. 2006). The North Carolina Sediment Pollution Control Act from 1973 states that "…In any event, slopes left exposed will, within 21 calendar days of completion of any phase of grading, be planted or otherwise provided with temporary or permanent ground cover, devices, or structures sufficient to restrain erosion." (North Carolina General Statutes, 113A-57). Since August 2011, the Construction General Permit NCG 01 requires groundcovers to be put down within 7 or 14 days of disturbance depending on the slope length and steepness (Construction General Permit NCG 01, Section II.B.2).

Polyacrylamide (PAM)

Polyacrylamide is a broad class of organic chemicals based on the acrylamide monomer. They vary in polymer chain length and number and kinds of functional group substitutions, as well as molecular conformation, the most important conformation variation being linear or cross-linked conformation. About 800,000 ha of US irrigated land use PAM for erosion and/or infiltration management. In recent years, PAM has been deployed for uses beyond agricultural erosion control, including construction site erosion control, and in storm water runoff ponds to accelerate water clarification. Polyacrylamide used for erosion control is a large (12–15 Mg mol^{-1}) water soluble (noncross-linked) anionic molecule, containing <0.05% acrylamide monomer (Sojka et al. 2007).

In PAMs used for erosion control and infiltration management, the PAM homopolymer is copolymerized. Some of the spliced chain segments replace PAM amide functional groups with groups containing Na^+ ions or protons that freely dissociate in water, providing negative charge sites along the polymer chain (Sojka et al. 2007). Cation bridging (PAM-Ca-clay) is the major bonding mechanisms between anionic PAM and clay mineral surfaces (Laird 1997). They found that efficacy of anionic PAM as a flocculent varied with saturating cation (Ca >> Na), mineralogy (kaolinite > illite >> quartz), and treatment (acid > salt > H_2O > base).

The effectiveness of the PAM is related to clay content of the soil (Vacher et al. 2003). They found that increasing clay content increase the effectiveness of PAM because the number of charge sites increased. Relationships between PAM effectiveness and particle size distribution were found to be strong, with increasing sand content having a negative effect on turbidity reduction (McLaughlin and Bartholomew 2007). They also found that extractable Fe and Ca are correlated with turbidity reduction, as well as pH to a lesser extent. The Coastal Plain subsoil had different statistical relationships between turbidity reduction and chemical properties than the Piedmont and Mountain subsoil, and a critical minimum for some properties (extractable Fe and kaolinite content) appeared necessary for a single anionic PAM to be effective.

Application rate of 0.7 kg ha^{-1} of PAM in irrigation water reduced furrow erosion by 85-99% and increased infiltration by 30% (Trout et al. 1995). Since construction sites often have very steep slopes, recommended application rates of PAM on construction sites are greater than those used in agriculture. Published research suggests that 22 kg ha^{-1} is the minimum required for significant benefits in reducing erosion (McLaughlin 2006).

Partington and Mehuys (2005) found that PAM applied at 10 and 20 kg ha^{-1} provided no significant erosion control after natural rainfall on a loam soil. They also found that in the simulated rainfall experiment, PAM applied at both 10 and 20 kg ha^{-1} reduced soil erosion by 84 and 76%, respectively, and the turbidity of runoff water by 99% on a silt loam soil. Polyacrylamide has also been found to increase infiltration rates (Green et al. 2000). They found that 12 Mg mol^{-1} molecular weight PAM worked best for the Cecil sandy loam (clayey, kaolinitic, thermic Typic Kanhapludult) compared with: Heiden clay (fine, smectitic, thermic Udic Haplustert) and Fincastle silt loam (fine-silty, mixed, mesic Aeric Epiaqualf). Green et al. (2000) also found that different PAM molecular weight provided differing degrees of soil protection, varying between soils. Tout et al. (1995) found that PAM of a high molecular weight (15 Mg mole^{-1}) moderately anionic (18%) applied at low concentrations (10 mg L^{-1}) in level furrows in Hanford sandy loam does not reduce aggregate breakdown and surface seal formation sufficiently to result in increased infiltration.

The PAM was found to significantly increase total infiltration under rainfall, reduce surface hardness, and reduce sediment entrainment and erosion (Vacher et al. 2003). Thompson et al. (2001) found that surface application of PAM at rates up to 10 kg ha^{-1} can be effective in reducing the time to initiate runoff, total runoff volume, and total sediment transport for a bare and otherwise unprotected soil on 4% slope. The aqueous PAM solution at application rate of 1.7 kg ha^{-1} and 3.4 kg ha^{-1} was most effective in reducing runoff compared with the bare soil. (Soupir et al. 2004). They also found that straw mulch (2,500 kg ha^{-1}) and the dry PAM (20 kg ha^{-1}) reduced total suspended solids losses by 92% and 82%, respectively.

In studies reported by Lee et al. (2011) polyacrylamide reduced soil loss for all slopes. A higher rate of PAM (40 kg ha^{-1}) had less soil loss than a lower rate of PAM (20 kg ha^{-1}) at slopes of 20% and 40% (Lee et al. 2011). They also found that applications of 20 and 40 kg ha^{-1} significantly increased time to initial runoff compared to the untreated control at slopes 20% and greater but not at a 10% slope. No difference in time to initial runoff was found for soils at slopes up to 20% between 20 and 40 kg ha^{-1}.

The PAM+gypsum amendment (20 kg ha^{-1} PAM + 5 Mg ha^{-1} gypsum) was found to be the best irrespective of soil Ca^{++} content compared to gypsum only (5 Mg ha^{-1}) and PAM only (20 kg ha^{-1} or 40 kg ha^{-1} PAM) in tests on the 20% slope (Lee et al. 2010). They also found that this amendment increased the time to initial runoff and decreased cumulative runoff and cumulative sediment loss. Yamamoto et al. (2006) found that PAM alone was more effective than PAM+gypsum or gypsum alone in reducing soil losses from sodic soils under saline or non-saline raindrop. They also found PAM was not effective in reducing runoff of the sodic soil. Gypsum+PAM was more effective in reducing runoff than soil loss on a Cecil sandy loam (Zhang et al. 1998). They mixed PAM+gypsum, 1 kg m^{-3} PAM and in 2.5 mol m^{-3} gypsum in solution and applied it at the 20 kg PAM ha^{-1} rate and reduced runoff (due to preventing clay dispersion and stabilizing soil aggregates). The extended observations

(126 to 163 days after application) indicated that runoff volumes from the gypsum and PAM treatments were less than from the control.

Akbarzadeh et al. (2009) found that application rate of PAM+gypsum (25 kg ha^{-1} PAM + 10 Mg ha^{-1} gypsum, 50 kg ha^{-1} PAM + 20 Mg ha^{-1} gypsum and 75 kg ha^{-1} PAM + 30 Mg ha^{-1} gypsum) and application rate of PAM (25, 50 and 75 kg ha^{-1} PAM) on steep slopes (30%) and under intense rain intensities (75 mm h^{-1}) has no effect on runoff reduction compared with the control. They also found that application of PAM + gypsum the same like the application of PAM only in those rates lost its effectiveness in reducing of runoff rapidly due to soil saturation, surface sealing and soil consolidation.

Yu et al. (2003) found that PAM and gypsum increase the infiltration rate of silty loam soils and decreased runoff volume. They also found that increasing the PAM application rate requires a higher amount of gypsum to achieve the best infiltration result. Lapore et al. (2009) suggested that the use of PAM in conjunction with lime or gypsum can be an effective erosion control tool, reducing sediment and nutrient losses and that coating lime or gypsum with PAM may have added benefit.

On a constructed 32% slope on initially dry, bare soil, 80 kg ha^{-1} PAM and 80 kg ha^{-1} PAM+ 5 Mg ha^{-1} gypsum significantly reduced runoff by almost 90% and sediment yield by 99%, compared to the control (Flanagan et al. 2002a). Total runoff was reduced by 40% to 52%, and sediment loss was reduced by 83% to 91%, respectively. At the same application rate on 35% slope and 45% slope soil loss was reduced in the range of 40% to 54%, compared to the control. PAM and PAM with gypsum increased grass establishment and growth (Flanagan et al. 2002b). These results indicate that the use of anionic PAM (with or without gypsum) can provide substantial benefits in reducing runoff and soil loss, and enhancing vegetation growth on very steep embankments.

Hayes et al. (2005) found that on a 20% cut slope, PAM did reduce the average turbidity. No other PAM effects were found. The study results suggest that PAM application rates of 10.5 kg ha^{-1} or less may not have significant benefits on moderate to steep slopes in the Piedmont of North Carolina. The polyacrylamide (CFM 2000, PAM) with mulch/seeding applied to dry soil with 10% slope reduce sediment yield by 93% (Roa-Espanosa et al. 1999). They also found that polyacrylamide (CFM 2000, PAM) in solution applied to moist soil reduce sediment yield by 77%. Polyacrylamide (CFM 2000, PAM) applied to dry soil reduced sediment by 83% and decreased runoff by 16%. They concluded that polyacrylamide (CFM 2000, PAM) is effective in reducing sediment yield regardless of the application method.

The application of PAM in solution at 19 kg ha^{-1} to straw only occasionally had significant effects on runoff parameters but does significantly increase vegetative coverage overall (McLaughlin and Brown 2006). They also found that the straw cover provided significantly better coverage compared to either bare soil or the MBFM, with or without PAM. Polyacrylamide applied before or after straw application did not indicate a clear advantage of either approach. Babcock and McLaughlin (2011) evaluated different erosion control methods on steep slopes (2:1) consisting of straw, straw plus 37 kg ha^{-1} (33 lb ac^{-1}) linear anionic polyacrylamide , and excelsior blankets based on runoff water quality and vegetative establishment. They found that the straw+PAM treatment reduced mean runoff turbidity at three of four sites and mean TSS at two of the four sites compared to straw. Runoff from the excelsior plots had significantly lower turbidity and TSS than straw plots in one of three sites. Compared to straw+PAM, excelsior had significantly higher turbidity at two of three sites and higher TSS at one of three sites. Neither vegetative cover nor biomass was affected by treatment, and average cover was 60% or less for five of the six sites. Rainfall patterns were largely responsible for vegetative growth, with heavier rainfall soon after seeding tending to reduce cover.

Overall polyacrylamide has been found to preserve surface aggregate structure, prevent surface crusting, increase infiltration, decrease runoff volume, reduce soil loss, and encourage vegetative growth (Akbarzadeh et al. 2009; Babcock and McLaughlin 2011; Flanagan et al. 2002a, 2002b; Green et al. 2000; Zhang et al. 1998). PAM effectiveness varies depending on application rate, treatment (applied in solution or dry) and soil conditions: cation saturation, mineralogy and particle size distribution. However, throughout the literature a specific PAM rate for optimum PAM performance in terms of erosion control and vegetation establishment on steep slopes was never specified and whether adding PAM to the straw mulch would increase its effectiveness.

Mulch (straw and different types of hydromulch)

Wheat straw mulch reduced soil surface sealing as evidenced by higher infiltration rates, and decreased rainfall and runoff energy for particle detachment and transport as evidenced by reduced soil content in the runoff (Mannering and Meyer 1963). They applied different application rates of wheat straw mulch on the 5% slope. At application rates of 2.4, 4.4 and 9 Mg ha^{-1} wheat straw mulch maintained high infiltration rate resulting in no erosion, while at application rates of 0.6 and 1.1 Mg ha^{-1} soil loss was 6.7 and 2.2 Mg ha^{-1} respectively. The soil loss on the control without mulch was 27 Mg ha^{-1}.

Bautista et al. (1996) evaluated straw mulch (2,000 kg ha^{-1}) in order to establish its efficiency in protecting soil and preventing runoff generation in a semiarid area affected by a wildfire. Total runoff from control plots was between 3.2 and 15 times greater than the runoff from mulched plots. Soil losses from control plots ranged from 2 to 16 times the losses from mulched plots. Total plant cover in control plots 1 and 2 years after the passage of the fire was only 34% and 52%, respectively. Plant cover in mulched plots was only slightly higher than in control plots but mulch increased ground cover to about 80%.

Dougherty et al. (2010) found that erosion control blankets, hydromulch and loose straw reduced first year average annual sediment loss by 58, 53 and 66%, respectively. The addition of PAM to hydromulch significantly decreased total suspended solids yield and turbidity during the first four rain events after planting. On a 50% fill slope, turbidity and sediment loss were significantly decreased with application of seed/mulch (by 83%) but not PAM alone at relatively low (<10 kg ha^{-1}) rates (Hayes et al. 2005).

Compost erosion control blankets retained 80% of the simulated rainfall applied and reduced cumulative storm runoff by 60%, while the wood mulch blankets reduced runoff by 34% and straw with PAM by 27% (Faucette et al. 2007). Any combination of compost and mulch reduced runoff volume, runoff rate, and soil loss relative to a straw blanket with PAM.

The greater percent of compost used in an erosion control blanket, the lower the total runoff and the slower the runoff rate. Holt et al. (2005) compared conventional wood and paper hydro-mulches with cottonseed hulls and three types of processed cotton gin by-products in a rainfall simulated study. The mulches were applied at two rates, 1,120 and 2,240 kg ha^{-1}. The lowest average sediment loss occurred on the plots containing cottonseed hulls (6,100 kg ha^{-1}), which had significantly lower sediment losses than either the paper (35,400 kg ha^{-1}) or wood hydro-mulches (28,900 kg ha^{-1}). Also a lower percentage of the cotton-based mulches were washed-off during the rain event than with the conventional wood and paper hydro-mulches. Overall, the cotton-based mulches showed promise in erosion control applications.

Vegetation

The presence of the vegetation is effective in reducing runoff and sediment loss (Marques et al. 2007). Pan and Shangguan (2006) found that plots with different grass coverage (35%, 45%, 65% and 90%) reduced runoff by 14–25% and sediment loss by 81–95% compared to bare plot. Establishing vegetation to control erosion on construction sites can be difficult due to poor soil, steep slopes, and no irrigation. Water availability is crucial for seed germination and as a resource for developing seedlings (Neil et al. 2003). García-Fayos et al. (2000) found that the main factor limiting plant colonization on five badland sites in southeast Spain was the very short duration of available water in the soil, due to the physical and chemical characteristics.

Formation of a full ground cover was a prerequisite for adequate erosion protection during intense precipitation from large storms (Lemly 1982). They also found that treatments as asphalt-tacked straw, jute netting, mulch blanket, wood chips and excelsior blankets seeded with fescue grass (2 kg ha^{-1}) on red clay soils reduced erosion and sedimentation by as much as 75% compared with the bare soil control. After three months all treatments had grass coverage in excess of 75%, while the bare soil control only had 40% grass coverage.

Dougherty et al. (2008) found that incorporation of lime, fertilizer, and seed in the hydromulch treatment resulted in a 48% reduction in average and total sediment yield over the corresponding non-incorporated treatment. They also found that the establishment of a 75% bermudagrass cover took approximately 90 days from planting with the growth of the vegetation divided in three general stages of cover establishment, including: 1) 0% to 50% of vegetation cover that had the highest sediment yields; 2) 50% to 75% of vegetation cover with decreasing sediment yields; and 3) 75% to 100% cover with significantly decreased sediment yields. Dougherty et al. (2010) found that adding PAM to hydromulch did not significantly improve grass establishment, however, hydromulch treatment had faster grass establishment than either the erosion control blanket or the loose straw treatment.

Harrel and Miller (2005) found that compost mulch can effectively prevent soil displacement from roadside slopes, but may not promote establishment or enhancement of permanent vegetative cover. Benik et al. (2003) evaluated straw mulch, wood-fiber blanket, a straw/coconut blanket and BFM on a 19.8° slope. They found that under conditions with a little vegetation erosion from the blanket and BFM plots was roughly ten times smaller than from the straw mulch plots. After vegetation was established erosion from straw mulch plots was greatly reduced. They also found that the greatest above–ground biomass was obtained for the bare and straw–mulch treatments. The smallest above–ground biomass was measured from BFM plots. Bochet and Garcı´a-Fayos (2004) studied the effect of slope type (road fill vs. road cut) on vegetation cover on 47 motorway slopes (<45^o) and they found that road fills were better for plant establishment than road cuts with higher cover 59.4 ± 4.7% and 7.4 ± 1.2%, respectively, averaged across slopes.

Greater plant growth using mulch may be attributed to the mulch's effect on microclimate conditions on the soil surface. Mulch can reduce soil surface temperature by up to 20°C by intercepting incoming radiation (Ross et al. 1985). They also found that mulch prolongs the process of evaporation from the soil surface. The resulting higher soil water content also decreases soil surface temperature through its effects on soil thermal properties. Grigg et al. (2006) found that straw mulch application improved infiltration, increased soil moisture retention and reduced surface crust strength. Establishment and survival of plants in semi-arid regions depends initially on successful germination of seeds under low and ephemeral water condition (Ronald and Faeth 2003). Water availability was most influential on germination of Prosopis caldenia seeds when temperatures were a lot above or below optimum temperature (De Villalobos and Pelaez 2001). They also found that Prosopis caldenia seeds can apparently germinate and initiate early growth under conditions of water stress. However, water stress may reduce the probability of seedling establishment because of the effect of low soil water emergence, content on seedling survival, and growth of surviving seedlings.

Fay and Schultz (2009) planted seeds of two grasses and six forbs in prairie soil and watered at 1, 2, 4, or 7 day intervals (I). They found that seed germination peaked at $I = 4$ whereas leaf growth in grasses and forbs, and final biomass in grasses peaked at $I = 7$, suggesting that growth and biomass were favored at greater soil moisture variability than seed germination.

Nutrient loss

If the load of nutrients to estuarine, coastal and marine systems exceeds the capacity for assimilation, nutrient enhanced production and water-quality degradation occurs (Rabalais 2002). Impacts can include noxious and toxic algal blooms, increased turbidity with a subsequent loss of submerged aquatic vegetation, oxygen deficiency, disruption of ecosystem functioning, loss of habitat, loss of biodiversity, shifts in food webs, and loss of harvestable fisheries. Fertilizers are used on construction sites when vegetating graded or disturbed areas. Fertilizers contain nitrogen and phosphorus, which in large doses can adversely affect surface water quality, causing eutrophication (EPA, 2005). Eutrophication caused by excessive inputs of phosphorus (P) and nitrogen (N) is the most common impairment of surface waters in the United States (U.S. EPA 1990, National water quality inventory). Based on the review of the scientific literature, Carpenter et al. (1998) are certain that (1) eutrophication is a widespread problem in rivers, lakes, estuaries, and coastal oceans, caused by overenrichment with P and N; and (2) nonpoint pollution, a major source of P and N to surface waters of the United States, results primarily from agriculture and urban activity, including industry.

Li et al. (2006) found that on sloping lands rainfall intensity had a small influence on nutrient concentrations in runoff, but a significant influence on the runoff flow, the slope length influence the nutrient loss by soil erosion on areas that receive rainfall and the slope gradient influence the nutrient loss by runoff flux and velocity on sloping land. Faucette et al. (2005) found that materials high in inorganic nitrogen (N) released greater amounts of nitrogen in storm runoff; however, these materials showed reduced N loss over time. Hydroseeding generated significantly higher total phosphorus (P) and dissolved reactive P loads compared to compost in storm runoff during the first storm event. Mostaghimi et al. (1994) found that straw mulch was the most effective in reducing runoff and losses of sediment, N, and P from eroded land compared to hydroseed, and two commercial synthetic polymers (SoilTex and Soil Master WR).

Overall, any type of mulch will significantly reduce erosion rates and increase grass biomass compared to bare soil. The majority of previous studies analyzed different types of mulches (straw mulch, erosion control blankets, compost erosion blankets, wood mulch blankets, etc.) compared to bare soil for erosion protection and not as many for vegetation establishment. Only few studies evaluated hydromulches for vegetation establishment and nutrient loss. Also, there are not a lot of studies on the differences between different types of hydromulches and different types of hydromulches and straw.

CHAPTER 2: EVALUATION ON CONSTRUCTION SITE SLOPES

Introduction

Soil erosion is considered the biggest contributor to nonpoint source pollution in the United States according to the U.S. Environmental Protection Agency and the federally mandated National Pollution Discharge Elimination System. By volume, sediment is the greatest pollutant entering our surface waters, and causes multiple problems (USGS 2006).

Erosion occurs when soil is exposed to water or wind energy. Raindrops hit exposed soil with great energy and launch soil particles along with the water into the air. Raindrop splash and resulting sheet erosion remove a thin film of soil from the land surface. Each year, about 75 billion Mg of soil is eroded from the world's terrestrial ecosystems. Soil erosion reduces the productivity of the land by loss of water, soil organic matter, nutrients, biota, and depth of soil (Pimentel and Kounang 1998). They also found that land areas covered by plant biomass, living or dead, are protected and experience reduced soil erosion because raindrop and wind energy are dissipated by the biomass layer. When erosion occurs, the runoff rate increases significantly, and with less water entering the soil, less is available to support the growing vegetation (Pimentel and Kounang 1998).

Soil erosion and stream sedimentation are persistent problems in and around construction sites (Kaufman 2000). Soil loss rates from construction sites are 10 to 20 times that of agricultural lands (Faucette et al. 2006). Federal rules implemented through the National Pollutant Discharge Elimination System Program require sediment control plans for disturbances greater than 0.4 ha (EPA 2000, revised 2005).

Factors that contribute increasing erosion on construction sites are removing of vegetative cover that was reducing rain drop energy and roots that were holding the soil in the place. Also, heavy equipment compact soil resulting in increased runoff volume (Owens et al. 2000). Since steep slopes are often bare during active construction, construction sites are often a major source of sediment (Babcock and McLaughlin 2011). Biodegradable blankets are commonly used on steep slopes as mulch to minimize the risk of washout of soil, seeds, and ameliorants during grass establishment to control erosion (Gyasi-Agyei 2004).

Faucette et al. (2006) found that compost blankets provided an average of 2.75 times more vegetative cover than hydrosided after three months. Holt et al. (2005) found that the cotton based hydromulch preformed equal to or better that conventional wood and paper mulches in reducing soil loss. Under conditions with a little vegetation erosion from the bonded-fiber matrix (BFM) plots was roughly 10% of that from straw mulch plots (Benik et al. 2003). They also found that under the same conditions erosion from straw mulch plots was roughly 10% of that from the bare soil. Mannering and Meyer (1963) found that higher application rates of straw (2.2, 4.4 and 9 Mg ha^{-1}) maintained very high infiltration rates resulting in no erosion while low application rates, 1.1 and 0.6 Mg ha^{-1} lost 2.2 ton and 6.7 Mg ha^{-1} on a 5% slope, respectively. Lemly (1982) compared five treatment methods used to stabilize seeded areas at urban and highway construction sites (asphalttacked straw, jute netting, mulch blanket, wood chips, excelsior blanket). He found that reductions in the total sediment concentration of runoff ranged from 28 % (asphalt-tacked straw, 50 % slope) to 90 % (multiple treatments, 40 % slope).

Mostaghimi et al. (1994) investigated the effectiveness of straw mulch, hydroseed, and two commercial synthetic polymers (SoilTex and Soil Master WR) in reducing runoff, sediment, nitrogen (N) and phosphorus (P) losses from eroded land. They found that neither polymer was as effective as mulch or hydroseed in reducing runoff and erosion. They also found that straw mulch was the most effective in reducing runoff and losses of sediment, N, and P from eroded land.

Soil amendments have the potential to protect the soil during critical periods of vegetation establishment, thus reducing on–site damages and costs as well as reducing off–site impacts on water quality (Flangan et al. 2002b). Application of polyacrylamide (20 kg ha^{-1}), gypsum (5 Mg ha^{-1}), or in combination, generally decreases erosion and runoff (Lee, et al. 2010). Use of an anionic polyacrylamide (PAM) could significantly reduce runoff and soil loss under the extreme condition of a large rainfall event occurring immediately after PAM application. Total soil loss for plots treated with PAM was reduced in the range of 40% to 54%, compared to the untreated control (Flangan et al. 2002a, 2002b). They also found that PAM and PAM with gypsum increased grass establishment and growth on treated plots compared to the control. Babcock and McLaughlin (2011) found that applying PAM with straw reduced mean runoff turbidity at 3 of 4 sites compared to straw. Application of different rates of PAM (25, 50 and 75 kg ha^{-1}) and gypsum (10, 20, 30 Mg ha^{-1}) on steep slopes (30%) and under intense rain (75 mm h^{-1}) has insignificant effect on runoff reduction compared with the control (Akbarzadeh et al. 2009).

The use of mulch and polymers has been found to reduce erosion rates and improve runoff water quality on construction sites. In studies that were evaluating erosion control products (straw, bonded fiber matrix, compost blankets, cotton based hydromulch, wood and paper based hydromulch) it was found that covered plots had significantly less soil loss than bare plots (Faucette et al. 2006; Holt et al. 2005; Benik et al. 2003; Lemly 1982; Stern at al. 1991).

The North Carolina Sediment Pollution Control Act from 1973 states that "…In any event, slopes left exposed will, within 21 calendar days of completion of any phase of grading, be planted or otherwise provided with temporary or permanent ground cover, devices, or structures sufficient to restrain erosion." (North Carolina General Statutes, 113A-57). Since August 2011, the Construction General Permit NCG 01 requires groundcovers to be put down within 7 or 14 days of disturbance depending on the slope length and steepness (Construction General Permit NCG 01, Section II.B.2).

The objectives of this study were to 1) evaluate different types of hydromulch for erosion control and vegetation establishment on steep slopes and to determine whether they will be cost effective compared to straw, and 2) to determine if adding polyacrylamide to the straw would increase its effectiveness for erosion control and vegetation establishment.

Materials and Methods

Description of Study Sites

This study was conducted on four road construction sites. The first site was located on the mountain region near West Jefferson, NC (Figure 1) and was a 2:1 cut slope (50% slope). The remaining three sites were all located in the Piedmont region near Raleigh, NC. The second site was a 2:1 fill slope located near Garner, NC, (Figure 2). The third site was a 2:1 cut slope in Apex, NC (Figure 3). The fourth site was a 2:1 fill slope in Holly Springs, NC. Runoff volumes, turbidity levels, and eroded sediment data were collected after natural rain events, and grass growth and cover were evaluated once vegetation reached a height of 10-12 cm.

Plot Setup

The first site was evaluated from the beginning of September to November 2010, the second site from mid-May to August 18, 2011, the third site from mid-November to February 22, 2011, and the fourth from Jun 22, to mid-August 2012. All sites were prepared by the North Carolina Department of Transportation. Slopes were graded to a 2:1 slope and tracked by a bulldozer. The area selected had been limed (dolomitic pulverized lime 4,480 kg ha^{-1}) fertilized with N:P:K (10:20:20) at 560 kg ha^{-1} and seeded (Table 1). Wheat straw was applied by hand or with a straw blower (site 3, Figure 4) and sprayed with tackifier (Tackifier specifications are given in Appendix 3.) according to North Carolina Department of Transportation (NCDOT) guidelines (Table 1) one day prior to installation. At sites 2 and 3, the straw was raked off of the plots receiving hydromulch in order to apply the planned treatments. To account for possible loss of seed during this process, plots were re-seeded prior to hydromulching with tall fescue at 56 kg ha^{-1}.

The area at sites 2 was divided into 20 plots (3 m wide x 6 m long). The area at sites 1, 3 and 4 were divided into 20 plots (3 m wide x 9 m long). After seeding, treatments were applied in a randomized complete block design. Treatments included: 3,000 kg ha^{-1} wheat straw+tackifier (straw) and 3,000 kg ha^{-1} wheat straw+ tackifier with 22.4 kg ha^{-1} of granular, linear, anionic polyacrylamide (straw+PAM) (PAM 705, Applied Polymer Systems, Woodstock, GA) applied at all four sites; 3,900 kg ha^{-1} flexible growth medium (FGM; Soil Guard, Profile Inc., Chicago, IL) and 3,900 kg ha^{-1} stabilized mulch matrix (SMM; Soil Guard, Profile Inc., Chicago, IL) applied at three sites; 3,900 kg ha^{-1} bonded fiber matrix (BFM; Soil Guard, Profile Inc., Chicago, IL), 2,800 kg ha^{-1} 70:30 wood fiber/cellulosic blend (WCB; Enviroblend, Profile Inc., Chicago, IL) and 3,360 kg ha^{-1} wood fiber hydromulch (WFM; Conwed Fibers 1000, Profile Inc., Chicago, IL) applied at two sites. Table 2 summarizes treatments by site. Treatments were selected based on the results of tests of hydromulch performance performed in a previous study (Whitley, 2011). Several of the paper-based hydromulches were eliminated as potential products due to poor coverage and grass germination in soil boxes placed on a slope.

Even though the straw application recommended rate was 3,000 kg ha^{-1} we noticed that straw cover was lower on the second site (Garner, NC) compared to the third and forth sites (Figure 5 and Figure 6) providing less erosion protection. On site 4, after the straw was applied by hand, tackifier was excessively applied on straw plots (Figure 7). On one plot with

WCB treatment, straw was also applied accidentally together with tackifier therefore that plot was excluded from further analysis.

Hydromulches were applied using a hydroseeder (TurfMaker 420, TurfMaker Corp., Rowlett, TX) at the manufacturer-recommended rates of 70:30 wood fiber/cellulosic blend—2,800 kg ha^{-1}, wood fiber hydromulch—2,240 kg ha^{-1}, bonded fiber matrix—3,920 kg ha^{-1}, straw treatments—3,360 kg ha^{-1}, PAM—22.4 kg ha^{-1}, and tackifier—560 kg ha^{-1}. The hydromulches were also mixed at manufacturer recommended rates of WCB, BFM, SMM and FGM: 48 g L^{-1} and WFM: 36 g L^{-1}. To determine hydromulch application rates, the hydromulch spray rate was measured (seconds per liter) and the appropriate time was calculated to apply the desired amount of hydromulch. The mulch was applied from the top and bottom of the plots each for half the time needed for the target application rate. The amount of mulch and water added to each tank was calculated to exceed the amount needed for all of the plots to avoid running out, with the excess applied outside the plot area.

Bulk Density and Soil Texture

At all four sites, 20 soil samples were taken from the surface using a soil corer (7.5 cm depth with diameter of 4.8 cm) in alternating locations from the bottom to the top of the plots. Each sample was used for bulk density and particle size tests (core method, Dane and Topp 2002; hydrometer method, Gee and Or 2002).

Runoff Collection

On each plot, two 1.2 m pieces of edging were inserted into the soil in the plot center in a “V” formation to direct water flow into a 10.2 cm diameter pipe. On site 1 runoff from the pipe flowed by gravity into 38 L containers. Excess water from the 38 L containers flowed into a hose leading to 378.5 L tanks. Flow was divided with half going into the containers and the other half flowing onto the ground in order to prevent overflow in the large tubs during heavy runoff events. The idea behind this set up was that the majority of the sediment would settle in the first container and excess water would accumulate in the 378.5 L tanks. Sediment from the container were deposited into the larger tanks and mixed prior to collecting samples for analysis. On sites 2, 3 and 4 runoff from the pipes flowed into 38 L containers that were placed inside 378.5 L tanks (Figure 8). When there was no overflow from the small container into the tanks, samples were taken from the containers. When there was overflow from the containers, they were emptied into the tanks and mixed before samples were taken. Both, the 38 L containers and the 378.5 L tanks are calibrated such that each depth corresponded to appropriate runoff volume. Calibration was performed by adding a known volume of water to the container or tank and recording the depth. The data for different volumes were plotted against depth and the regression line that had the best fit was chosen. Conversion of depth to volume of water was done using equation 1 for 38 L container and equation 2 for 378.5 L tank.

$$Y = 0.0685X^2 + 4.092X - 0.6777 \qquad (1)$$

$$Y = 0.0002X^2 + 0.5286X - 4.4695 \qquad (2),$$

where X is depth of water in inches and Y is the runoff volume in L (Figure 9 and Figure 10).

The amount of runoff was then corrected for the amount of water captured from the rain. For site 1, rainfall data were estimated from the NC Climate Office Multi-Sensor

Precipitation Estimates system, which combines radar and rain gauge data to provide an estimate of precipitation amounts. For sites 2, 3 and 4 rain gauges were installed on the site to measured rainfall.

Turbidity was measured using an ANALITE NEP-160 portable turbidity meter (Figure 11). Measured turbidities were corrected with a standard curve based on formazine standards. Total suspended solids was determined following the standard methods for the examination of water and wastewater (Clesceri et al. 1998). Samples were filtered with 47 mm glass fiber ProWeigh filters from Environmental Express (Mt. Pleasant, SC) and dried overnight at 103-105° C in order to get TSS (Figure 12). Total sediment delivery was calculated by multiplying the runoff volume by the TSS concentration.

Biomass and Vegetative Cover

Above-ground grass biomass and cover were evaluated once grass reached a height of 10-12 cm. Biomass was determined for each treatment using a square grid 1 m by 1 m divided into 20 squares of 20 cm by 20 cm. Vegetation was clipped from randomly selected 20 cm x 20 cm squares (Figure 13). The grid was placed onto each plot 3 times; once towards the top, a second time towards the middle, and a third time towards the bottom. Three randomly selected squares were clipped at each sample location, for a total sample of nine squares per plot. The samples were collected, oven-dried overnight at 105^{o}C and weighed. Using the weight of the samples along with the calculated area of the nine squares, biomass was estimated for the total plot area. Biomass for site 1 was determined 60 days after seeding, on November 2, 2010, for site 2 80 days after seeding on July 29, 2011, for site 3

165 days after seeding on April 30, 2012 and for the site 4 one 55 days after seeding on August 15, 2012.

Vegetative cover on site 1 and 3 was assessed by independent visual estimation from four observers who estimated the amount of cover (%) on each plot. The independent estimates were averaged to obtain a single cover estimate for each plot. On site 2 and 4 photos were taken and vegetation analysis was done using GIS. Every photo was separated into two sub-groups of digital pixels, grass and not grass, and the grass cover was estimated from the resulting pixel counts. The GIS method is more precise than independent visual estimation even though in our case neither of the methods were 100% accurate. Since our sites were 2:1 slopes, both visual estimation and photos for GIS analysis, were taken from the bottom of the slope creating the illusion of higher percent cover than it really was.

Nutrient Loss

Nutrients analysis was performed on runoff samples from site 2, 3 and 4 for the first five rain events. The analyses included nitrogen (NH_4, NO_3 and Total Kjeldahl Nitrogen-TKN), phosphorous (PO_4 and total P-TP) and total organic carbon (TOC).

For Nitrate: 4500-NO3 I. Cadmium Reduction Flow Injection Method; Ammonium: 4500-NH3 H. Flow Injection Analysis; Phosphate: 4500-P G. Flow Injection Analysis for Orthophosphate; TOC: 5310 B. Total Organic Carbon-Combustion-Infrared Detection Method; TKN/TP: 4500-Norg D. Block Digestion and Flow Injection Analysis (Greenberg et al. 2005).

For statistical analysis on site 2 we excluded data from one FGM plot during storm 5. The justification was that PO_4 and NH_4 concentrations were more than 30 times greater than the ones from all other plots and 20 and 3 times greater than concentrations in spike sample.

Statistical Analysis

The data from each site were analyzed separately to determine treatment effects. All data were analyzed using SAS software and the GLM procedure (SAS version 9.2, SAS Institute, Cary, NC). Data were log transformed to ensure normality and equality of variance. Analysis of variance was used to analyze treatment effects. Differences among treatments were evaluated ($p \leq 0.05$) for biomass and cover percentage, average runoff, turbidity, TSS and nutrients loss among treatments using LSD for mean separation. The ANOVA tables for average runoff, turbidity, TSS across all storm events are given in Appendix 2. Mean runoff volumes, turbidity and TSS for each sampling/storm event are given in Appendix 3.

Results

The soil at sites 1, 2 and 4 were relatively uniform across the test area while the soil at site 3 had substantial differences in soil texture and color from the bottom to the top of the slope (Table 3). This was due to the nature of these slopes, with sites 2, and 4 being composed of fill material and site 3 being a cut slope. The process of obtaining fill material can homogenize the soil as it is excavated, loaded, deposited, and spread. However, the soil on a cut slope is the native material, which usually has layers with different properties. The bulk densities at all of the sites varied widely, possibly due to localized impacts of equipment traffic during slope preparation and the application of seed, lime, and fertilizer. Some of the higher bulk density values may have been limiting to root penetration and growth. Brown (2012) found that the above ground vegetation mass of the compacted treatment was 40% less than that of tilled treatments and also short and thick roots extending to only 2.5 to 7.5 cm on compacted plots while on short tilled (15 cm) plots had an abundance of finer roots in the upper 15 cm; the deep tilled (30 cm) plots showed similar root abundance at the 15-30 cm depth.

<u>Runoff Volume</u>

Site 1 - West Jefferson, NC

Site 1 was over 3 h drive from Raleigh, so the local NC DOT staff monitored the runoff after each event and notified us if runoff was present in the containers. Over the monitoring period, only three runoff events occurred due to the relatively light, even rainfall pattern during the monitoring period (Table 4). There were no differences among treatments in runoff volume for these three events and the average runoff amount was very small at <2% of rainfall (Table 5).

Site 2 - Garner, NC

There were ten storm events during the monitoring period, eight of which produced runoff (Table 6). Runoff volumes averaged across all storm events were different among the treatments (0.0084). The FGM and SMM ground cover produced less runoff than the straw (p=0.0006 and 0.02, respectively), while runoff volume from the BFM plots was almost (p=0.052) less than from the straw. The SMM or BFM ground covers had the same runoff volume compared to straw+PAM, but the FGM had lower runoff volume (0.0078). Average runoff volumes across all storm events from straw and straw+PAM were not different; PAM had lower runoff volume during the fourth storm events. We did not observe differences between straw treatment with and without PAM. For individual storm events FGM had lower runoff volume compared to straw in 7 out of 8 rain events, BFM and SMM in 2 out of 8. Mean runoff volumes are given in Table 5.

Site 3 - Apex, NC

There were eleven storm events during the monitoring period and eight of them produced runoff (Table 7). Average runoff volume across all storm events was different among the treatments (p=0.0206). By a factor of almost 3, the straw had less runoff volume than the WCB and WFM treatments, and a reduction of about 2.5 times less than the FGM. There was no difference between straw and straw+PAM treatments. Compared to straw in individual storm events, WFM had higher runoff volume in 5 out of 8 rain events that produced runoff, WCB in 4 out of 8. This was somewhat expected since according to the manufacturer Wood Fiber Mulch had about 45% erosion control effectiveness and Cellulose (Paper) Mulch has about 25% erosion control effectiveness. Where greater than 50% erosion control effectiveness is desired, paper or simple wood fiber mulches should not be used but instead use SMM, BFM, FGM (Profile Inc. 2012, Appendix 1). There were no differences in runoff volume between straw and straw+PAM treatments for individual storms.

Site 4 – Holly Springs

There were five storm events during the monitoring period (Table 8). The last three storm events occurred on consecutive days, resulting in very high runoff volumes during the fourth and fifth storm events. There was some damage to the plot barriers during the fourth event, resulting in leakage, and all of the collection tubs overflowed during the fifth event. The runoff volume data from these events was not included in any statistical analyses. Runoff volume means across all storm events were not different (p=0.1148). No differences were found during individual storm events (p=0.6734, 0.3568 and 0.1107). While the actual volume of runoff was unknown for the last two events, a minimum amount can be calculated using the volume of the full tubs and the amount of rainfall. During the fourth storm event runoff was up to 70% of precipitation on the WFM plots, while during the fifth rain event runoff was at least 71% of rainfall.

<u>Turbidity</u>

Site 1 – West Jefferson, NC

There were no differences among treatments (p=0.4883) in runoff turbidity for three runoff events that occurred at this site and the average runoff turbidity was very low at <60 NTU's (Table 9). The rain events were relatively small and non-erosive during the monitoring period.

Site 2 – Garner, NC

Runoff turbidity averaged across all storm events were different among the treatments (p=0.0180). The FGM ground cover had lower turbidity compared to straw, straw+PAM, BFM and SMM (p=0.0022, 0.0047, 0.0195 and 0.0433, respectively). By a factor of almost 3, the FGM had lower turbidity than the straw and straw+PAM treatments, and about 2 times less than the SMM and BFM. No other differences were found. We did not observe differences between straw treatment with and without PAM during any storm event, although there was a large difference between straw (986 NTU) and straw+PAM (7.9 NTU) for the second storm event. During the first storm event (26 mm), FGM and SMM had lower turbidity compared to BFM, straw and straw+PAM treatment. During the second storm event (12 mm), FGM had lower turbidity compared to SMM and straw, while during the third storm event (40 mm) all three types of tested hydromulches (FGM, SMM and BFM) had lower turbidity compared to straw and straw+PAM treatment. During storm 4 and 5 FGM had lower turbidity compared to straw and straw+PAM, during storm 8 FGM compared to BFM and SMM. Storm events 6 and 7 did not produce runoff and storm events 9 and 10 did produce runoff but there were no differences, probably due to good grass establishment by then. For the second event turbidity was lower in the straw+PAM runoff compared to straw, but the difference was not significant.

Site 3 – Apex, NC

Average runoff turbidity across all storm events were different among the treatments at this site (p=0.0003). By a factor of around 3, the WCB and WFM treatments had higher turbidity than the straw and straw+PAM, and the FGM had a increase of about 2 times more. FGM reduced turbidity compared to WCB and WFM (p=0.029 and 0.057, respectively). The runoff turbidity from the straw+PAM plots was lower than that of the straw plots (p=0.0327). During first storm event (30 mm), there were no differences between treatments. Compared to straw in individual storm events, WFM and WCB had higher turbidity in 3 out of 8 runoff events. The straw+PAM treatment reduced turbidity compared to straw during the second, fourth and eighth storm events (third, sixth and seventh storm events did not produce runoff). Mean turbidity values are given in Table 9.

Site 4 – Holly Springs

There were five storm events during the monitoring period (Table 8). The last three storm events occurred on consecutive days, resulting in very high runoff volumes during the fourth and fifth storm events. There was some damage to the plot barriers during the fourth event, resulting in leakage, and all of the collection tubs overflowed during the fifth event. The runoff volume data from these events were not included in any statistical analyses but turbidity and TSS data were included in analysis. Runoff turbidity means across all storm events were different (p=0.0.245). By a factor of almost 4, the straw and straw+PAM treatment had lower turbidity than the WCB and WFM treatments, and a non-significant reduction of about 3 times less than the SMM. Compared to straw in individual storm events, straw+PAM treatment had lower turbidity only during the first storm, while in other four storms the turbidity was similar. Compared to straw and straw+PAM in individual storm events, WFM and had higher turbidity in 3 out of 5 storm events and WCB in 2 out of 5 storm events.

Total Suspended Sediment (TSS) and Total Sediment Loss (TSL)

Site 1 - West Jefferson, NC

Over the monitored period there were no differences among treatments (p=0.2504 and 0.7436) in TSS or TSL due to light rain events and sandy soil. Mean values of TSS and TDL are given in Table 10 and Table 11.

Site 2- Garner, NC

Total suspended sediment and TSL, averaged across all storm events, were different between treatments (p=0.0356 and 0.0149). The FGM ground cover produced less TSS and TSL than the straw, straw+PAM and BFM. By a factor of around 4, FGM had less TSS than straw and reduction of about 2.6 times less than straw+PAM. Differences between treatments were even higher when looking at the TSL where FGM had less TSL by a factor around 12 than straw, reduction of about 5 times less TSL than BFM and reduction of about 3.5 times less than straw+PAM. Addition of PAM reduced TSL for about 3.5 times compared to straw but due to variation within treatments were not different. During first and third storms a lot of sediment coming from the straw (10,159 kg ha^{-1}), SMM (1,537 kg ha^{-1}) and BFM (3,423 kg ha^{-1}) plots was settled at the bottom of the small container (Table 11) while other treatments, straw+PAM and FGM did not produce this significant amount of sediment. When looking at only these two storms the addition of PAM made big difference controlling erosion. Compared to straw in individual storm events, FGM treatment significantly reduced TSS in 7 out of 8 storms that produced runoff.

Site 3 - Apex, NC

Average TSS and TSL across all storm events were different among the treatments (p=0.0165 and 0.0326). The addition of PAM reduced TSS compared to straw about 30% although not different at p=0.10. FGM, WCB and WFM increased TSS and TSL compared to straw+PAM treatment but not compared to straw. WCB had the highest TSS and TSL values. The addition of PAM in individual storm events reduced TSS during the second and the eight storm events compared to straw. The WFM, WCB and FGM treatments had higher TSS compared to the straw in three out of eight storms that produced runoff, while WFM and FGM had higher TSS compared to the straw+PAM during six and WCB during five out of eight storms that produced runoff.

Site 4 – Holly Springs

Average TSS and TSL across all storm events were not different among the treatments ($p=0.088$ and 0.0776). TSS was analyzed for all five storm events while TSL was analyzed only for the first three storm events since we could not estimate runoff volume for storm 4 and 5. Both WFM and WCB had higher TSS and TSL compared to the straw, straw+PAM and SMM by factor of 3 and 7. Addition of PAM did not reduce TSS during any out of five storm events.

<u>Nutrient Loss</u>

Site 2- Garner, NC

During the first five storm events all treatments tended to have lower nitrogen losses compared to straw (Appendix 4). FGM was the only cover that had lower concentrations and amount of loss for all parameters, and the SMM cover had lower values for NH_4 and TKN concentration. For total loss, all covers resulted in lower amounts of NO_3 and TP than straw, and FGM, and SMM had lower NH_4 and TKN loss. Phosphorus concentrations in runoff were reduced for all treatments compared to straw (Table 15). While PO_4 losses were not different among the treatments, losses of TP were higher in the straw treatment compared to all others. The FGM cover had less TP loss compared to the straw+PAM cover. The straw and straw+PAM covers had higher TOC losses compared to the FGM cover (Table 16). All treatments, including straw+PAM, reduced nutrient loss compared to straw. Bjorneberg et al. (2000) found that applying a much lower rate of PAM (2 kg ha^{-1}) to 70% straw cover did not reduce phosphorus losses compared to straw alone. Compared to the amount of N and P that were added as fertilizer, the straw treatment lost more compared to FGM. Overall, the FGM was the most effective cover in reducing nutrient loss due to runoff (Table 17).

Site 3- Apex, NC

There was no difference between treatments in reducing concentration or amount of NH_4, TKN and PO_4 (Table 15 and 16). Among the few differences, the WFM cover had higher concentrations and amount of loss for TOC than straw and straw+PAM treatments. Nitrate-N concentration was higher in the WCB cover compared to the FGM, and TP concentrations higher for the WCB cover compared to straw+PAM. Compared to the amount of N and P that were added as fertilizer, the losses were much lower at this site compared to site 2 (Table 17). Again, unlike site 2, the straw treatment has the lowest losses of nutrients, although the differences were not different.

Site 4, Holly Springs

There was no difference between treatments in the concentration or amount of NH_4, NO_3, TKN, PO_4 and TOC in runoff (Table 15 and 16). The only difference was that the straw+PAM cover had lower concentrations and amount of loss for TP than the WCB cover. Although not statisticlly different, the WCB cover had almost double the nitrate-N and P loss compared to the other covers due to higher runoff volumes. Compared to the amount of N and P that were added as fertilizer, the losses were lower at this site compared to site 2 and higher compared to site 3 (Table 17). The WCB cover lost more TKN and TP than other covers.

Biomass and Vegetative Cover

Site 1- West Jefferson, NC

Biomass was assessed two months after setup, on November 2, 2012. There were no differences in biomass or cover percentage between treatments (p=0.6499 and 0.1515). Biomass for all treatments was between 313 and 454 kg ha^{-1}, and cover was between 32 and 56% (Table 13 and Table 14).

Site 2 - Garner, NC

Biomass was assessed 81 days after setup on July 29, 2011. The only significant difference among the treatments was a reduction in above-ground biomass in the FGM plots compared to the straw plots (Table 13 and Table 14).

Site 3 - Apex, NC

Biomass was assessed five months after setup on April 30, 2012. Five months was passed before biomass was assessed on this site because the grass establishment was really poor due to cold weather after planting on November 18, 2011. The FGM and WCB ground cover produced less above ground biomass than the straw (p=0.001 and 0.087, respectively). The WFM or WCB ground covers did not reduce biomass compared to straw+PAM, but the FGM did have lower biomass (p=0.0152). Average biomass between straw and straw+PAM was not different. The FGM, WFM and WCB had less cover than straw and straw+PAM (28%, 34%, 32% compared to 56% and 54%, respectively).

Site 4 - Holly Springs

Biomass was assessed two months after setup on August 15, 2012. The SMM, WFM and WCB ground cover produced more above ground biomass than the straw+PAM (p=0.0287, 0.0269 and 0.0309, respectively; Table 13 and Table 14). At 0.1 significant the SMM, WFM and WCB treatments produced more above ground biomass compared to the straw. Addition of PAM did not result in a change. The cover was estimated based on a GIS analysis of the photos taken on July 30, 2012. The SMM, WFM and WCB treatments produced more cover compared to the straw and straw+PAM (93, 94, 96, 75 and 67 %, respectively).

Discussion

<u>Water Quality</u>

At site 1 there was no difference between treatments most likely due to the sandy soil texture (average 72% sand) and relatively light rainfall events that occurred there. Expected rainfall for September-October based on State Climate Office of North Carolina (Appendix 6) for the West Jefferson area would be around 200 mm and total rainfall during experiment was 120.7 mm, with only one rain event that exceeded 10.1 mm. There was a trend of straw having higher runoff volume, turbidity and TSS compared to hydromulch treatments at site 2, with straw cover runoff volumes higher by 100% compared to FGM and 60% compared to BFM and SMM. Also, in general straw had higher concentrations and amount of loss of nutrients compared to all hydromulch treatments, and straw+PAM was higher than FGM.

Babcock (2008) also found that straw had about 1.6 times more runoff than BFM. On this site FGM cover produced lower turbidity by more than half compared to straw and straw+PAM. The FGM treatment had lower TSS with decreases by factor of 4.5 compared to straw and 2.6 compared to straw+PAM. The FGM treatment had lower TSL by factor of 12 compared to straw and 3.3 compared to straw+PAM. There were no differences between BFM, straw and straw+PAM treatments. Babcock (2008) also did not find any differences in TSS or TSL between straw, straw+PAM and BFM treatments. The FGM treatment also had lower concentration of TKN by a factor of 2.4 and TP by a factor of 4 and amount of TKN loss by factor of 4.5 and TP by factor of 6 compared to straw and also TOC loss was lower from FGM cover compared to straw. During the first storm events erosion rates were really high and straw, SMM and BFM treatments produced 10,159, 1,537 and 3,423 kg ha^{-1} of sediment which was more than all the sediment measured from these treatments after that. During this storm FGM and straw+PAM treatments produced less than 400 kg ha^{-1}. During this storm event addition of PAM was highly effective.

In contrast, at site 3 the straw treatment had lower runoff compared to FGM and WCB by about 200% and 300% compared to WFM; whereas TKN concentration and amount off loss was equal for all treatments and the only difference between treatments was between straw+PAM and WFM. The FGM, WCB and WFM treatments had higher turbidity and TSL compared to straw and straw+PAM treatments, and TSS compared to straw+PAM. The same trend of WFM and WCB having higher turbidity, TSS and TSL compared to straw and straw+PAM was found on site 4. This was probably caused by different application rates of straw on these sites. Based on the GIS analysis of photos taken at each site, the site 2 straw cover appears to be about 75% while the cover on sites 3 and 4 was about 95% (Figure 5 and Figure 6). Mannering and Meyer (1963) found that at application rate of 2.4 Mg ha^{-1} wheat straw, similar to our target rate, maintained high infiltration rates and resulted in no erosion, while application at lower rates resulted in considerable erosion. The addition of PAM to the straw did not affect runoff volumes on any of four sites. The straw+PAM treatment only had lower turbidity compared to straw on site 3. The addition of PAM did reduce TSS for about 30% on the same site although not different at p=0.10. Polyacrylamide has been found to preserve surface aggregate structure, prevent surface crusting, increase infiltration and decrease runoff volume (Sojka et al. 2007; Green et al. 2000; Vacher et al. 2003; Yu et al. 2003; Flanagan et al. 2002a, 2002b). Some studies reported that the addition of PAM to ground covers did not reduce runoff volume on steep slopes (McLaughlin and Brown 2006; Hayes et al. 2005). We also did not observe overall differences between straw treatment with and without PAM at any site. This may have been due to the dry-granular PAM washing off before it had a chance to dissolve and get activated. Traces of PAM granules were evident in runoff from the first and second storm events on site 2. In some studies it was shown that PAM in solution is more effective in controlling runoff and erosion than the dry granular application of PAM (Peterson et al. 2002; Babcock 2008). PAM did not reduce turbidity on average at site 2 and 4 likely due to the coarse soil texture, while on site 3 application of PAM did have significant effect on turbidity probably due to a higher clay content compared to site 2 and 4 . There is a strong relationship between PAM effectiveness and particle size distribution, with increasing of sand content effect on turbidity reduction decrease (McLaughlin and Bartholomew 2007; Vacher et al. 2003). Partington and Mehuys (2005) suggested that PAM provided no significant erosion control after natural rainfall on a loam soil. On the site 4, PAM was effective in turbidity reduction only during first storm event but not the other four. McLaughlin and Brown (2006) had similar results, where the addition of PAM reduced turbidity during the first event but not for the following events.

The higher-performance hydromulches FGM and SMM resulted in lower turbidity than the more economical WFM and WCB at site 3 and 4. At site 4 the TSS and TSL was also lower in the SMM plots compared to WFM and WCB. These results suggest that the more expensive materials may provide significantly higher erosion protection and improve runoff water quality. However, at both sites the straw covers performed as well as the FGM and SMM covers. Only at site 2 did the high-performance hydromulch (FGM) perform better than straw cover for turbidity and sediment losses. In contrast Whitley (2011) did not find differences among straw, straw+PAM, BFM, WCB and WFM for runoff volumes, turbidity, TSS or biomass.

In general, nutrient concentrations and amount of loss were much lower on site 3 than on site 2, while on site 4 concentrations of nutrients were higher than on site 2 but losses were lower due to lower runoff volumes. Also, on site 4 nutrients losses were recorded only during the first three storm events since runoff volumes for storm 4 and 5 were unknown. On site 2 percent of N lost was 2.6-12% while on the site 3 was less than 1% and on site 4 was around 1% except for WCB that had 2.8%, and P lost on site 2 was 0.6-3.6% while on the site 3 was <0.15% and on site 4 was 0.2-0.8%. On site 2 the first storm event occurred only three days after setup, "washing" the nutrients of off the site. On site 3 the first storm event occurred 10 days after setup and it is possible there was a condensation of water vapor (dew) during this period, providing moisture for nutrients to dissolve and move down the soil profile before first storm event. The first several rain events were similar total amounts, but the intensities may have been less for site 3. On site 4 there was light rain one day after setup and another light rainfall 12 days later that did not produce runoff. Runoff occurred during the rain event 3 days later and this sequence of rain events would suggest lower nutrient levels in runoff at site 4 than at site 2 but they were actually higher. We did not add fertilizer to our site, so there is no way to know if the same rate was applied at each site, even if the targeted rate is usually the same for all NC DOT projects.

At sites 2 and 4 where we had a good grass establishment, there were no differences in runoff water quality between treatments during the last two or last storms. On site 3 where grass establishment was poor, differences were apparent even three months after setup.

Biomass and Vegetative Cover

On site 1 there were no differences for above ground biomass and percent cover across treatments. Generally on this site above ground biomass (from 313 to 454 kg ha^{-1}) and percent cover were relatively low (Figure 14). Average mean temperatures for September-October based on State Climate Office of North Carolina for the area around West Jefferson was around 14 ^{o}C. Centipedegrass (*Eremochloa ophiurodes*) and bermudagrass (*Cynodon dactylon*) are warm season grasses. Optimum air temperature for tall fescue (*Festuca arundinacea*) germination is 20-30 ^{o}C. Also, knowing that relatively light rainfall events occurred there during the experiment, good grass establishment was not expected.

On the second and third sites, NCDOT applied straw, seed, fertilizer, and lime on the whole slope area one day before setup. We raked the straw from the plots that were to be covered with hydromulch and added back tall fescue at 56 kg ha^{-1} in case the raking process removed seed. While we expected this might produce more grass on straw plots on sites 2 and 3, on both sites FGM cover produced less above ground biomass compared to straw. This was unexpected since FGM ground cover reduced runoff volumes, turbidity, TSS and TSL compared to the straw cover. Above-ground biomass was lower on the SMM and BFM plots compared to the straw plots, although not statistically different. It is possible that recommended application rate of 3,900 kg ha^{-1} for FGM, BFM and SMM for 2:1 slopes is too high, forming good and strong ground cover for erosion control but inhibiting grass establishment. Several other studies found that BFM had less ground cover and biomass compared to straw (Benik et al. 2003; Babcock 2008; McLaughlin and Brown, 2006). Overall grass establishment was good on site 2 with above ground biomass and percent cover between 875-1,038 kg ha^{-1} and 59-72% (Figure 15). However, on site 3 overall grass establishment was not good with above ground biomass and percent cover between 137-472 kg ha^{-1} and 32-56% (Figure 16) with weed species dominating. Bochet and Garci'a-Fayos (2004) found that road fills are better for plant establishment than road cuts and site 2 was a fill and site 3 a cut. The reason for lower grass establishment under the hydromulches was explored further in Chapter 3.

Site 4 in general had a good grass establishment (67-96% cover) and weeds were the dominant vegetation on the straw and straw+PAM plots, probably as a result of seeds from the straw. While not statistically different, SMM, WFM and WCB ground cover had higher above ground biomass compared to the straw and straw+PAM by a factor of almost 2, and grass cover was higher. This was probably due to excessive tackifier application on the straw and straw+PAM plots. The rest of the slope that was not tested had straw ground cover with tackifier applied the same day as the plots. In areas where less tackifier was applied, grass establishment looked much better than on the straw and straw+PAM tested plots, while on some other areas where more tackifier was applied grass establishment similar to our test plots with straw ground cover (Figure 17).

Sites 1 and 3 that had poor grass establishment (with mean percent cover of 42 and 41%) were tested during the cooler season (September-November and November-February). Both sites had low rainfall amounts with poor distribution. Site 1 had 60% of normal rainfall, while on site 3 rainfall occurred 10 days after seeding and it was another 10 days before the second rain event. Sites 2 and 4 had good grass establishment (67 and 85% cover, respectively) and were tested during warm periods (May-July and Jun-July). At site 2 there was a light sprinkling the day after seeding and rainfall two days later, with only three more days until the following rain event. Similar to site 2, site 4 had a light sprinkling one day after seeding and first rainfall 12 days later did not produce runoff, and 3 days after there was 22.9

mm of rain, followed by another 3 days before next rain event. This is similar to the results cited by Babcock and McLaughlin (2011), finding that weather factors are more important than ground cover treatment factors in successfully establishing vegetation. They linked rainfall deficit to the poor vegetative growth and found that delayed rainfall after planting also results in low biomass over time.

However, even percent cover of near 41-42% is not ideal since it leaves >50% of the soil exposed. According to the USLE, a 30% cover reduces soil loss about 72 % (Renard et al. 1991). Pan and Shangguan (2006) found that grass covers of 35, 45, 65 and 90% reduced soil loss 81, 85, 87 and 94%, respectively.

It might be expected that PAM would improve vegetation establishment since it has been shown to increase infiltration, reduce surface hardness and preserve soil structure (Sojka et al. 2007; Green et al. 2000; Vacher et al. 2003; Yu et al. 2003; Flanagan et al. 2002a, 2002b). Some studies found that PAM did improve vegetation establishment (McLaughlin and Brown 2006; Flanagan et al. 2002b). In our study, PAM did not have any effects on grass establishment at any study site. This may be explained by the relatively low clay content and the poor soil structure due to the grading activities on these sites. Previous work has shown that PAM effectiveness can be influenced by both molecular weight and charge density of the PAM used as well as by the clay content of the soil (Vacher et al. 2003).

Conclusions

- No clear advantage of any mulch type was found. Performance of any mulch type depends on specific site conditions, but was largely determined by the weather.
- More economical hydromulches (WFM and WCB) were less effective in erosion control than straw and FGM on 2:1 slopes.
- Straw application rate (cover percentage) is very important.
- Weather (temperature and rainfall) appears to be the most influential on grass establishment.
- PAM did not improve grass establishment compared to straw alone but in some cases it did have good impact on erosion control.

TABLES AND FIGURES

Table 1: North Carolina Department of Transportation seed and mulch specifications for eastern North Carolina.

Addition	**Rate (lb acre^{-1})**	**Rate (kg ha^{-1})**
Tall Fescue	50	56
Centipedegrass	5	5.6
Bermudagrass	25	28
Wheat straw	2,670	3,000
Lime	4,000	4,480
N: P: K (10:20:20)	500	560

Table 2: Summary of treatments at each site.

	straw	**straw+ PAM**	**FGM**	**SMM**	**BFM**	**WFM**	**WCB**
Site 1, West Jefferson	x	x	x	x	x	-	-
Site 2, Garner	x	x	x	x	x	-	-
Site 3, Apex	x	x	x	-	-	x	x
Site 4, Holly Springs	x	x	-	x	-	x	x

Note: x = treatment present. – = treatment absent. PAM=Polyacrylamide. FGM=flexible growth media. SMM=stabilized mulch matrix. BFM=bonded fiber matrix. WFM=wood fiber mulch. WCB=70:30 wood fiber/cellulose blend.

Table 3: Particle size distributions and bulk density for all four sites.

	Site 1, West Jefferson	Site 2, Garner	Site 3, Apex	Site 4, Holly Springs
Bulk density (g cm^{-3})				
Range	1.19-1.58	1.41-1.73	1.25-1.57	1.37-1.69
Mean	1.36	1.57	1.33	1.52
Stand. Dev.	0.093	0.095	0.32	0.088
Particle Size Analysis				
Clay (%)				
Range	3-12	8-16.5	3-29	8-24
Mean	6.6	13.0	11.1	16.3
Stand. Dev.	2.6	2.5	8.7	5.0
Silt (%)				
Range	14-32	7-17	11-36	24-44
Mean	21.6	12.6	27.45	28.7
Stand. Dev.	6.4	3.0	6.7	4.2
Sand (%)				
Range	58-80	67-8	44-75	46-61
Mean	72.2	74.4	61.4	55.0
Stand. Dev.	7.1	3.7	8.4	5.1
Texture Class	LS, SL	LS, SL	LS, SL, L, SCL	SL, L,SCL

Note: Sample depth 0-10 cm. Stan. Dev.=Standard Deviation.

Table 4: Rain and Sampling events for Site 1, West Jefferson, NC.

Date	Rain event/ **Sampling (in)**	Rain event/ **Sampling (mm)**
9/8/2010	0.3	6.6
9/13/2010	0.4	1.2
9/27/2010	1.4	35.6
9/28/2010	0.4	10.2
9/28/2010	**2.5**	**62.5**
9/30/2010	0.7	17.8
10/5/2010	**0.7**	**17.8**
10/14/2010	0.2	5.1
10/20/2010	0.2	5.1
10/21/2010	0.1	2.5
10/25/2010	0.2	5.1
10/26/2010	0.2	5.1
10/27/2010	0.4	10.2
10/28/2010	0.3	7.6
11/2/2010	**1.6**	**41.6**
Total	4.8	121.9

Table 5: Averaged mean runoff volumes for all four sites. Means with same letter are not significantly different within each site at ($\alpha = 0.05$) using LSD test.

Treatment	Site 1, West Jefferson	Site 2, Garner	Site 3, Apex	Site 4, Holly Springs
Runoff volumes (% of precipitation)				
Straw	1.5a	23.6a	3.1c	12.9b
Straw+PAM	0.9a	18.8ab	3.5bc	15.6ab
SMM	1.1a	15.3bc	N/A	20.2ab
BFM	1.3a	16.6ab	N/A	N/A
FGM	0.9a	11.1c	7.9a	N/A
WFM	N/A	N/A	9.0a	23.4ab
WCB	N/A	N/A	7.2ab	29.4a

Note: PAM=Polyacrylamide. FGM=flexible growth media. SMM=stabilized mulch matrix. BFM=bonded fiber matrix. WFM=wood fiber mulch. WCB=70:30 wood fiber/cellulose blend.

Table 6: Storm events for site 2, Garner, NC.

Rain Event	Date	Rain event (in)	Rain event (mm)	
1	5/14/2011	1.0	26.3	
2	5/17/2011	0.5	12.3	
3	5/28-29/2011	1.6	39.6	
4	6/19/2011	0.5	13.7	
5	6/27-28/2011	1.0	25.9	
6	7/5/2011	0.4	10.1	No runoff
7	7/7/2011	0.1	3.0	No runoff
8	7/26/2011	0.6	16.5	
9	7/31/2011	1.4	35.6	
10	8/6/2011	2.7	69.8	
Total		9.8	252.8	

Table 7: Storm events for site 3, Apex, NC.

Rain Event	Date	Rain event (in)	Rain event (mm)	
1	11/28/2011	1.2	30.5	
2	12/8/2011	0.4	9.9	
3	12/12/2011	0.4	10.1	no runoff
4	1/5/2012	1.0	25.4	
5	1/12/2012	1.0	25.4	
6	1/18/2012	0.2	5.1	no runoff
7	1/21/2012	0.4	10.1	no runoff
8	1/26-27/2012	0.5	11.9	
9	2/4/2012	0.7	16.5	
10	2/17 and 22/2012	0.9	22.6	
11	2/24 and 27/2012	0.5	13.7	
Total		7.2	181.2	

Table 8: Storm events for site 4, Holly Springs, NC.

Rain Event	Date	Rain event (in)	Rain event (mm)	
	7/04/2012	0.1	2.5	no runoff
1	7/10/2012	0.9	22.9	
2	7/13/2012	0.7	17.8	
3	7/21 and 22/2012	1.3	33.0	
4	7/23, 24 and 25/2012	1.3	33.0	
5	1/28 and 29/2012	2.5	63.5	
Total		6.8	172.7	

Table 9: Averaged mean runoff turbidity for all four sites. Means with same letter are not significantly different within each site ($\alpha = 0.05$) using LSD test.

Treatment	**Site 1, West Jefferson**	**Site 2, Garner**	**Site 3, Apex**	**Site 4, Holly Springs**
Turbidity (NTU)				
Straw	43a	1,247a	450c	410ab
Straw+PAM	42a	1,122a	265d	365b
SMM	47a	777a	N/A	463ab
BFM	55a	888a	N/A	N/A
FGM	50a	389b	592b	N/A
WFM	N/A	N/A	938ab	1,765a
WCB	N/A	N/A	1,018a	1,212a

Note: PAM=Polyacrylamide. FGM=flexible growth media. SMM=stabilized mulch matrix. BFM=bonded fiber matrix. WFM=wood fiber mulch. WCB=70:30 wood fiber/cellulose blend.

Table 10: Averaged mean TSS (mg L^{-1}) for all four sites. Means with same letter are not significantly different within each site ($\alpha = 0.05$) using LSD test.

Treatment	**Site 1, West Jefferson**	**Site 2, Garner**	**Site 3, Apex**	**Site 4, Holly Springs**
Total suspended sediment (mg L^{-1})				
Straw	355a	3,034a	801ab	1,520b
Straw+PAM	225a	1,812a	373b	1,104b
SMM	346a	1,579ab	N/A	1,670b
BFM	319a	2,297a	N/A	N/A
FGM	382a	655b	1,113a	N/A
WFM	N/A	N/A	1,722a	4,127ab
WCB	N/A	N/A	1,977 a	4,561a

Note: PAM=Polyacrylamide. FGM=flexible growth media. SMM=stabilized mulch matrix. BFM=bonded fiber matrix. WFM=wood fiber mulch. WCB=70:30 wood fiber/cellulose blend.

Table 11: Averaged mean TSL (kg ha^{-1}) for all four sites. Means with same letter are not significantly different within each site ($\alpha = 0.05$) using LSD test.

Treatment	Site 1, West Jefferson	Site 2, Garner	Site 3, Apex	Site 4, Holly Springs
Total sediment load (kg ha^{-1})				
Straw	13a	3,685a	51bc	36b
Straw+PAM	8a	1,261ab	29c	29b
SMM	11a	959bc	N/A	35b
BFM	12a	1,930ab	N/A	N/A
FGM	14a	333c	164ab	N/A
WFM	N/A	N/A	237a	120ab
WCB	N/A	N/A	221ab	210a

Note: PAM=Polyacrylamide. FGM=flexible growth media. SMM=stabilized mulch matrix. BFM=bonded fiber matrix. WFM=wood fiber mulch. WCB=70:30 wood fiber/cellulose blend.

Table 12: Sediment found cemented on the bottom of the small container from the straw, SMM and BFM plots during first and third storm events.

Treatment	Sediment (kg ha^{-1})
First storm event (26.3 mm)	
Straw	10,159 (from 3 plots)
SMM	1,537 (from 1 plot)
BFM	3,423 (from 1 plot)
Third storm event (39.6 mm)	
Straw	121 (from 1 plot)

Note: SMM=stabilized mulch matrix. BFM=bonded fiber matrix.

Table 13: Averaged above biomass mean for all four sites. Means with same letter are not significantly different within each site (α = 0.05) using LSD test.

Treatment	Site 1, West Jefferson	Site 2, Garner	Site 3, Apex	Site 4, Holly Springs
Biomass (kg ha^{-1})				
Straw	429a	1,308a	472a	1,184ab
Straw+PAM	454a	1,097ab	309ab	1,047b
SMM	314a	1,018ab	N/A	2,155ab
BFM	364a	1,110ab	N/A	N/A
FGM	313a	875b	137c	N/A
WFM	N/A	N/A	257ab	2,177a
WCB	N/A	N/A	1,92bc	2,284a

Note: PAM=Polyacrylamide. FGM=flexible growth media. SMM=stabilized mulch matrix. BFM=bonded fiber matrix. WFM=wood fiber mulch. WCB=70:30 wood fiber/cellulose blend.

Table 14: Averaged cover percentage mean for all four sites. Means with same letter are not significantly different within each site (α = 0.05) using LSD test.

Treatment	Site 1, West Jefferson	Site 2, Garner	Site 3, Apex	Site 4, Holly Springs
Cover (%)				
Straw	49a	72a	56a	75b
Straw+PAM	56a	68a	54a	67b
SMM	32a	65a	N/A	93a
BFM	36a	70a	N/A	N/A
FGM	37a	59a	28b	N/A
WFM	N/A	N/A	34b	94a
WCB	N/A	N/A	32b	96a

Note: PAM=Polyacrylamide. FGM=flexible growth media. SMM=stabilized mulch matrix. BFM=bonded fiber matrix. WFM=wood fiber mulch. WCB=70:30 wood fiber/cellulose blend.

Table 15: N, P and Total Organic C concentration in runoff from experimental plots at site 2, 3 and 4. Means with same letter are not significantly different within each site (α = 0.05) using LSD test.

Treatment	NH_4	NO_3	TKN	PO_4	TP	TOC
				mg L^{-1}		
Site 2, Garner						
Straw	3.2a	4.2a	11.8a	0.34a	2.41a	20.9ab
Straw+PAM	1.8bc	3.0a	8.3ab	0.23ab	1.47b	18.3ab
FGM	1.3c	1.5bc	4.9c	0.12c	0.61c	15.3b
SMM	1.9b	2.8ab	7.1b	0.20abc	1.02b	21.2a
BFM	2.1b	1.4c	9.4ab	0.17bc	1.32b	19.4ab
Site 3, Apex						
Straw	0.9a	0.2ab	2.9a	0.05a	0.50ab	8.53b
Straw+PAM	0.9a	0.2ab	2.8a	0.10a	0.40b	7.04b
FGM	0.7a	0.2b	2.9a	0.07a	0.58ab	12.2a
WFM	0.8a	0.3ab	2.8a	0.04a	0.68ab	12.1a
WCB	1.0a	0.3a	3.4a	0.04a	0.85a	9.0b
Site 4, Holly Springs						
Straw	5.2a	1.7a	10.3a	0.74a	2.23ab	19.2a
Straw+PAM	4.6a	1.5a	8.5a	0.63a	1.40b	18.5a
SMM	4.9a	1.1a	10.2a	1.15a	2.45ab	23.4a
WFM	4.3a	1.4a	10.1a	0.45a	1.89ab	18.2a
WCB	4.2a	1.4a	10.7a	0.76a	2.71a	19.5a

Note: PAM=Polyacrylamide. FGM=flexible growth media. SMM=stabilized mulch matrix. BFM=bonded fiber matrix. WFM=wood fiber mulch. WCB=70:30 wood fiber/cellulose blend.

Table 16: N, P and Total Organic C loss from experimental plots at site 2, 3 and 4. Means with same letter are not significantly different within each site ($\alpha = 0.05$) using LSD test.

	NH_4	**NO_3**	**TKN**	**PO_4**	**TP**	**TOC**
Treatment				**Kg ha^{-1}**		
Site 2, Garner						
Straw	1.41a	3.04a	6.66a	0.15a	1.55a	10.06a
Straw+PAM	0.79ab	1.58b	3.85ab	0.12a	0.80b	7.88ab
FGM	0.46b	0.78b	1.46c	0.06a	0.25c	5.77b
SMM	0.56b	1.08b	2.28bc	0.08a	0.53bc	9.12a
BFM	0.79ab	0.81b	4.41ab	0.1a	0.73bc	7.82ab
Site 3, Apex						
Straw	0.05a	0.01b	0.12a	0.007a	0.020ab	0.47b
Straw+PAM	0.10a	0.03ab	0.35a	0.007a	0.014b	0.65b
FGM	0.16a	0.02ab	0.35a	0.02a	0.057ab	1.36ab
WFM	0.15a	0.04ab	0.44a	0.009a	0.063a	1.88a
WCB	0.19a	0.05a	0.42a	0.009a	0.059ab	1.29ab
Site 4, Holly Springs						
Straw	0.30a	0.10a	0.63a	0.05a	0.14ab	1.18a
Straw+PAM	0.38	0.15a	0.70a	0.04a	0.10b	1.79a
SMM	A0.31a	0.07a	0.73a	0.09a	0.19ab	1.95a
WFM	0.36a	0.13a	0.86a	0.03a	0.13ab	1.97a
WCB	0.62a	0.23a	1.54a	0.12a	0.36a	3.22a

Note: Sediment from site 2 and 3 was lost during 5 storms while sediment from site 4 was lost during three storms since runoff volumes from storm 4 and 5 were unknown. PAM=Polyacrylamide. FGM=flexible growth media. SMM=stabilized mulch matrix. BFM=bonded fiber matrix. WFM=wood fiber mulch. WCB=70:30 wood fiber/cellulose blend.

Table 17: Percentage of N and P fertilizer input that was lost due to runoff at site 2, 3 and 4 due to runoff.

Treatment	% N lost	% P lost
Site 2, Garner		
Straw	11.9	3.6
Straw+PAM	6.9	1.9
FGM	2.6	0.6
SMM	7.9	1.2
BFM	4.1	1.7
Site 3, Apex		
Straw	0.2	0.05
Straw+PAM	0.6	0.03
FGM	0.6	0.13
WFM	0.8	0.15
WCB	0.8	0.14
Site 4, Holly Springs		
Straw	1.1	0.3
Straw+PAM	1.3	0.2
SMM	1.3	0.4
WFM	1.5	0.3
WCB	2.8	0.8

Note: PAM=Polyacrylamide. FGM=flexible growth media. SMM=stabilized mulch matrix. BFM=bonded fiber matrix. WFM=wood fiber mulch. WCB=70:30 wood fiber/cellulose blend.

Figure 1: Site 1, West Jefferson, NC.

Figure 2: Site 2, Garner, NC.


Figure 3: Site 3, Apex, NC.


Figure 4: Straw blower.

Figure 5: Straw cover at site 2, Garner, NC.

Figure 6: Straw cover at Site 3, Apex, NC.

Figure 7: Straw cover and excessively applied tackifier at Site 4, Holly Springs, NC.

Figure 8: Captured runoff.

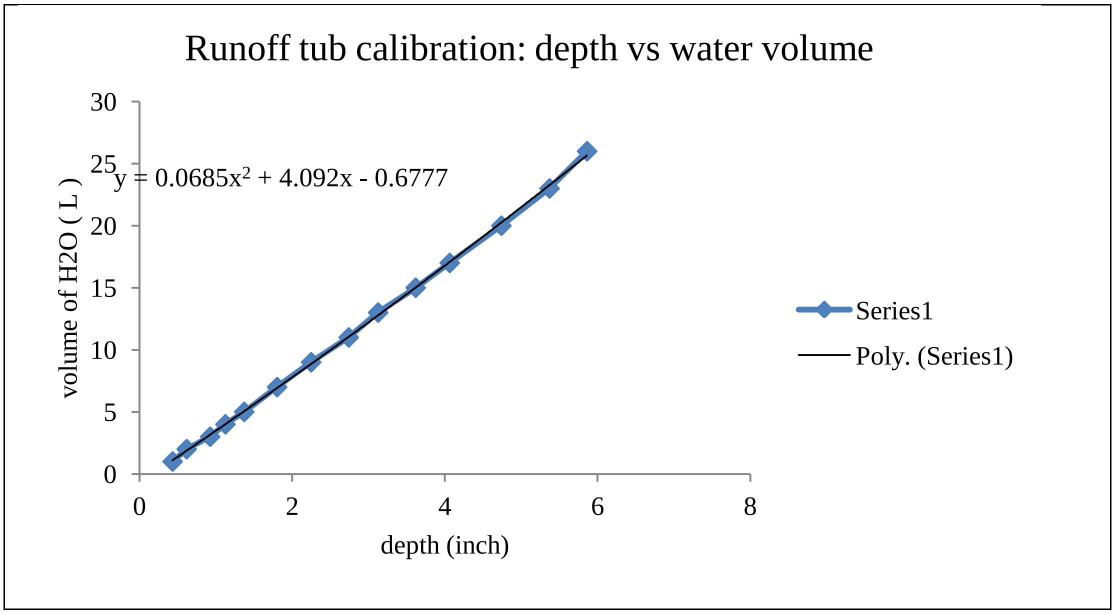

Figure 9: Equation 1 used to convert runoff depths to volumes for small container.

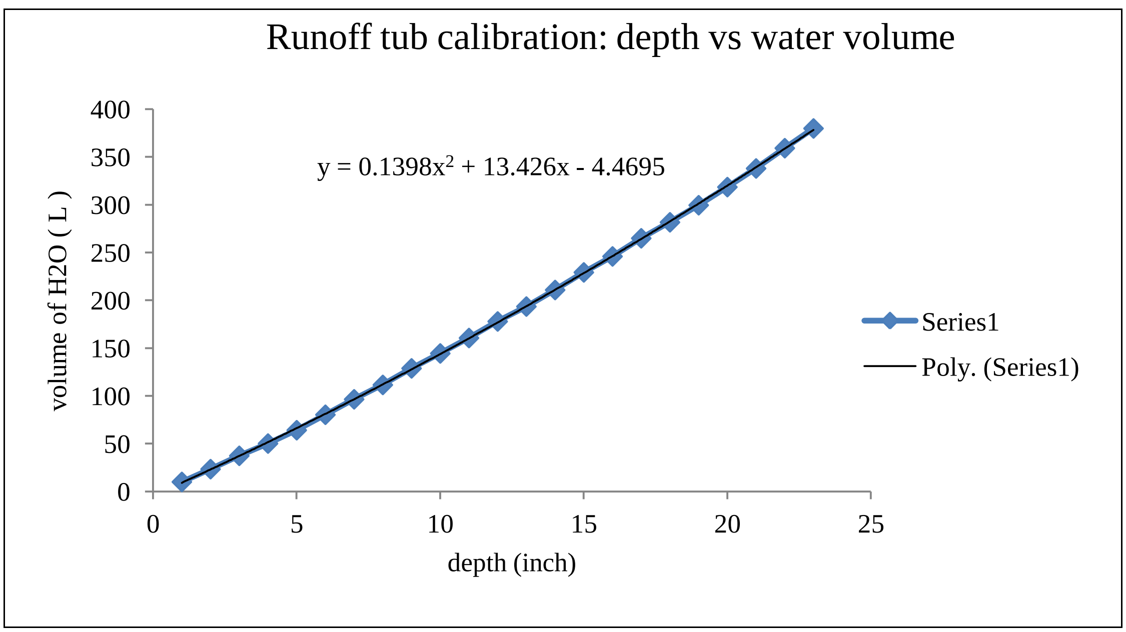

Figure 10: Equation 2 used to convert runoff depths to volumes for tank.

Figure 11: ANALITE NEP-160 portable turbidity meter.

Figure 12: Vacuum filter device – TSS.

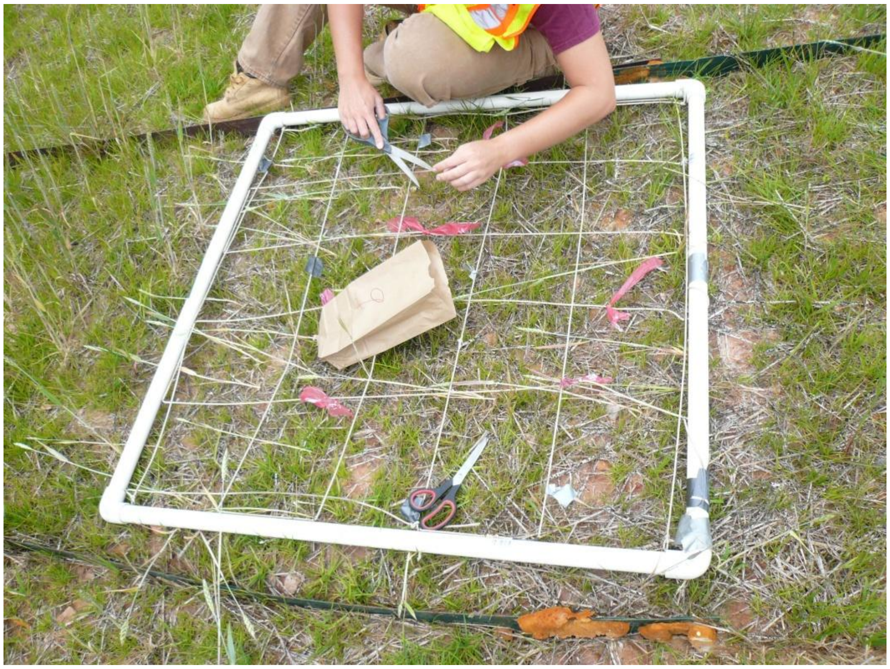
Figure 13: Biomass sampling at Site 3, Apex, NC.


Figure 14: Site 1, West Jefferson, NC two months after setup, November 2, 2010.

Figure 15: Site 2, Garner, NC two months and 20 days after setup, July 29, 2010.

Figure 16: Site 3, Apex, NC five months after setup, April 30, 2010.

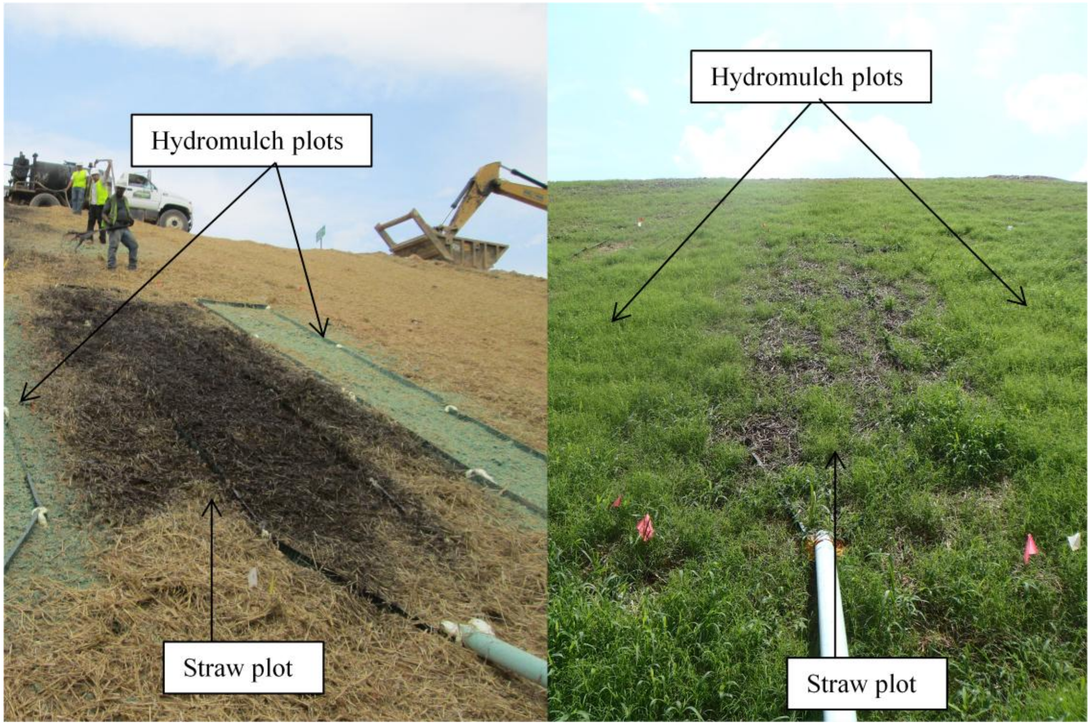

Figure 17: Difference between straw plot and hydromulch plots at the time of setup and when grass was established.

CHAPTER 3: GREEN HOUSE EXPERIMENT

Effects of Hydromulches on Grass Germination and Growth

Introduction

Study of erosion control techniques is necessary for the reduction of sediment loss from construction sites and other disturbed slopes. One of the most effective methods of reducing erosion is to establish a vegetative cover as soon as possible (Dougherty et al. 2008).

Straw is often used for erosion control on slopes because it can be effective and inexpensive. Alternatives to straw mulch are primarily erosion control blankets (ECBs) and hydraulically applied paper or wood fiber, known as hydromulch. These alternatives have been found to significantly reduce erosion relative to straw under some conditions (Benik et al. 2003; Lemly 1982).

Dougherty et al. (2010) found that a hydromulch ground cover resulted in quicker grass establishment than either erosion control blanket or loose straw treatments, 84%, 59% and 33% at day 55, respectively. Kwok et. al. (2008) conducted a study to determine whether or not hydromulch had any significant negative effects on post-fire chaparral vegetation recovery. In the field experiment they found no significant differences in plant density between plots with and without hydromulch. Babcock and McLaughlin (2011) found that neither vegetative cover nor biomass were affected by treatment (straw, straw plus 37 kg ha^{-1} linear anionic polyacrylamide, and excelsior blankets), and average cover was 60% or less for five of six sites.

Manufacturer claims that Flexterra's (flexible growth media, FGM) combination of wood fiber and particles of co-polymer gel provide loft and water holding capacity up to 1,500% of its own weight. These benefits translate to better vegetation establishment in the field (Profile Inc. 2007).

Soil crusting is a severe problem worldwide (Green et al. 2000). Soil crusts are relatively thin, dense, somewhat continuous layers of non-aggregated soil particles on the surface of tilled and exposed soils. Structural crusts develop when a sealed-over soil surface dries out after rainfall or irrigation (USDA, 2008). Surface treatment influences the nature and extent of seal/crust formation (Zhang et al. 1998). Soil crusts affect seedling emergence and reduce the infiltration rate causing loss of water and crop yield (Awadhwal and Thierstein 1985). Surface sealing of bare soils often reduces rain infiltration (Ruan et al. 2001). Hanks and Thorp (1956) found that limiting crust strength for wheat seedling emergence was between 200 and 500 millibars (2.04 and 5.1 kg m^{-2}) and appeared to decrease as the amount of available moisture decreased.

At site 2 the FGM treatment significantly reduced overall turbidity and TSS compared to straw alone. In previous research by other, grass cover was greater when the ground cover was straw compared to hydromulch. This suggested that the flexible growth media may inhibit the germination and growth of grass, but it was not clear what the cause was or if this was an atypical result. The purpose of this study was to determine how mulch type and rate affects grass growth and soil sealing.

Methods and Materials

For this study two different types of mulch were used: 3,000 kg ha^{-1} wheat straw as a control treatment (straw) and bonded fiber matrix (BFM, SoilGuard, Profile Inc., Chicago, IL) at three different rates in order to determine hydromulch impact on grass growth: 1,120 kg ha^{-1} (BFM1), 3,360 kg ha^{-1} (BFM2) and 5,040 kg ha^{-1} (BFM3). These represent low, recommended, and high rates of application. The twelve treatments were replicated three times.

The experiment included three different seeded grasses: tall fescue (*Festuca arundinacea*) at rate of 293 kg ha^{-1}, centipedegrass (*Eremochloa ophiurodes*) at rate of 202 kg ha^{-1} and bermudagrass (*Cynodon dactylon*) at rate of 202 kg ha^{-1}. These three types of grasses were used in this experiment because they are commonly used species in temporary seeding for soil conservation in North Carolina. The application rates were high relative to recommended rates because we wanted to ensure good grass establishment for better comparison. The combination of mulch type and grass resulted in twelve treatments.

The same study was repeated with flexible growth medium (FGM, SoilGuard, Profile Inc., Chicago, IL) instead of bonded fiber matrix with an additional treatment of wood fiber mulch at: 3,360 kg ha^{-1} (WFM).

Approximately 6 kg of air-dry soil was placed in plastic trays with dimensions of 0.5 m x 0.25 m. The clay loam soil was gently packed and leveled by hand, and the final depth of soil was approximately 5 cm throughout the box. After that soil was limed (dolomitic pulverized lime 4,480 kg ha^{-1}), fertilized (N: P_2O_5: K_2O (10:20:20) 560 kg ha^{-1}) and seeded.

After seeding, the straw was applied by hand to each tray. The hydromulch was applied using a commercial Turf Maker 420 hydroseeder (Turf Maker Corp., Rowlett, TX) with the hydromulch and water mixed in the tank at the recommended ratio (48 g L^{-1}). With mixture in one tank we applied all three application rates of BFM but during application of FGM at the highest rate the hydroseeder clogged because the mixture become to tick and we had to empty the tank and make a new mixture of FGM.

The trays were arranged in a completely randomized design in a greenhouse under controlled conditions and watered every day to ensure that water was not a limiting factor for vegetation establishment.

Cover Estimation and Biomass

Photos were taken periodically and vegetation analysis using GIS was performed to show changes in average cover between treatments with time. Using GIS every photo was separated into two sub-groups of digital pixels: grass, and not grass. The pixel counts were used to estimate percent cover for each category (Figure 18). Biomass was also determined for each treatment. The vegetation was clipped from the whole box area, dried over night at 100^{o}C, and weighed.

Surface Crust

The reduced grass growth noted in the field for hydromulched areas may have been due to the hydromulch physically impeding grass emergence. In order to estimate how a hydromulch cover might impede shoot emergence compared to straw we used a pocket penetrometer (CL-700, SOILTEST INC., Chicago-U.S.A.). The pocket penetrometer was used to measure the ease of penetration of an object into a soil in order to estimate the potential difficulty of shoot emergence through the hydromulch. In order to obtain representative data, measurements were taken at three locations in each box.

Data Analysis

The greenhouse study was conducted as a completely randomized design. Data were log transformed to ensure normality and equality of variance. All data were analyzed using SAS software and the GLM procedure, except the mixed procedure was used for analyzing surface crust data (SAS version 9.2, SAS Institute, Cary, NC). Differences among treatments were evaluated ($p \leq 0.05$) for finding differences in biomass and percent cover among treatments. The resulting ANOVA table is provided in Table 18.

Results and Discussion

<u>Tall Fescue</u>

The vegetative cover at18 days after seeding was significantly higher with the straw cover than for all BFM application rates. The difference was maintained up until biomass harvest at 33 days (Table 19). Straw had greater cover than the two higher BFM rates, and the low BFM rate had greater cover than the high rate. Above ground biomass was significantly different among the treatments (0.0008), with the BFM2 and BFM3 ground covers producing significantly less biomass than the straw and BFM1 covers. Benik et al. (2003) also found that the greatest above–ground biomass was obtained for straw–mulch treatments, while the lowest above–ground biomass was measured in BFM plots. It is possible that the high application rates of BFM (3,360 and 5,040 kg ha^{-1}) were hard for tall fescue shoots to penetrate. All hydromulch rates had significantly higher resistance to the penetrometer compared to straw (Figure 19). Crust strength was increased with bonded fiber matrix (BFM) hydromulch compared to straw from under 0.1 up to above 0.9 kg m^{-2}. Hanks and Thorp (1956) found that limiting crust strength for wheat seedling emergence was between 200 and 500 millibars (0.2 and 0.5 kg cm^{-2}) and appeared to decrease as the amount of available moisture decreased. However, our values are only for comparison within different treatments in our study, they are not to be compared to other studies due to different instruments used.

In contrast to the BFM results, FGM applications resulted in no difference in tall fescue biomass or cover between different application rates of FGM or the straw cover (Table 20). This material has a different mixture of proprietary components (Appendix 1) which may have been less inhibiting of growth than BFM. The FGM also had lower maximum penetration strength (0.6 kg cm^{-2} vs 0.9 kg cm^{-2}) than BFM (Figure 19). The straw cover produced much higher grass coverage and biomass during the BFM test than for the FGM test, which may also have been a factor. Unlike the growth with BFM, there was a non-significant trend toward greater growth with higher rates of FGM. Change in cover percentage over time is given in Figure 20.

Centipedegrass and Bermudagrass

Change in cover percentage over time for centipedegrass and bermudagras are given in Figure 21 and 22. Forty days after seeding, centipedegrass cover was the same for all treatments ($p=0.191$), although the highest BFM rate was almost greater ($p=0.0545$) than the straw cover. After 40 days, grass in the BFM3 cover had almost double the biomass of the straw. The same trend was observed for FGM where FGM2 and FGM3 treatments had around 200% more biomass compared to the straw and FGM1. However, unlike the BFM results, the grass cover was significantly greater in the recommended and high FGM application rates compared to straw, low FGM, and WFM with nearly double the coverage. There were no differences in grass coverage between the straw, low FGM, and WFM treatments.

After 13 days, the BFM treatment at any application rate had better bermudagrass cover than the straw, but after 18 days these differences disappeared. Baharanyi (2010) also reported that bermudagrass was established quicker when a hydromulch was used as compared to straw. Above ground biomass was not different between treatments. The low BFM rate resulted in more biomass than straw, BFM2, and BFM3, which were not different. In contrast, FGM2 and FGM3 had more biomass than straw and FGM1 by a factor of almost 2. Collis-George and Hector (1966) found that wetted area of contact is a factor controlling germination of the seed. It is possible that hydromulch provides better contact between seed and soil. In this test all were watered daily to avoid water stress. Due to excess water, hydromulch stayed wet thorough experiment providing more wet contact area for the seed.

Hydromulch Moisture Holding Capacity

Introduction

Formation of a complete sod system is a prerequisite for adequate erosion protection during intense precipitation from large storms (Lemy et al. 1982). Establishing vegetation to control erosion on construction sites can be difficult due to poor soil, steep slopes, and no irrigation. Mulches promotes establishment or enhancement of permanent vegetative cover (Bautista et al. 1996; Harrel and Miller 2005; Lemy et al. 1982). Benik et al. (2003) found that the greatest above–ground biomass was obtained for bare and straw mulch treatments. The smallest above–ground biomass was measured from BFM plots.

Dougherty et al. (2010) found that adding PAM to hydromulch did not significantly improve cover establishment, however, hydromulch treatment had quicker establishment than erosion control blankets or loose straw. Flanagan et al. (2002b) found that PAM and PAM with gypsum increased grass establishment and growth. The application of PAM in solution at 19 kg ha^{-1} to straw only occasionally had effects on runoff parameters but did significantly increase vegetative coverage overall (McLaughlin and Brown 2006). They also found that the straw cover provided better coverage compared to either bare soil or the MBFM, with or without PAM. Babcock and McLaughlin (2011) evaluated different erosion control methods on steep slopes (2:1) consisting of straw, straw plus 37 kg ha^{-1} linear anionic polyacrylamide, and excelsior blankets and they did not find that any of these treatments had advantages over others when it comes to vegetation establishment. They found that rainfall patterns were largely responsible for vegetative growth, with heavier rainfall soon after seeding tending to reduce cover. Greater plant growth on the mulched plots may be attributed to the mulch's effect on microclimate conditions on the soil surface. Mulch can reduce soil surface temperature by up to 20°C by intercepting incoming radiation (Ross et al. 1985). They also found that mulch prolongs the process of slow evaporation from the soil surface. The resulting higher soil water content also decreases soil surface temperature through its effects on soil thermal properties. Grigg et al. (2006) conducted a laboratory study where they found that mulch application improved infiltration, increased soil moisture retention and reduced surface crust strength.

Establishment and survival of plants in semi-arid regions depends initially on successful germination of seeds under low and ephemeral water condition (Neil et al. 2003). Water availability in the germination stage of plants is crucial for seed germination and as a resource for developing seedlings (Neil et al. 2003). Water availability was most influential on germination of Prosopis caldenia seeds when temperatures were a lot above or below optimum temperature (De Villalobos and Pelaez 2001). They also found that Prosopis caldenia seeds can apparently germinate and initiate early growth under conditions of water stress. However, water stress may reduce the probability of seedling establishment because of the effect of low soil water emergence, content on seedling survival, and growth of surviving seedlings.

A controlled greenhouse experiment was conducted to investigate whether or not hydromulch and straw mulch helps with preserving moisture in the soil.

Materials and Methods

Experiment 1

Three treatments included: bare soil (bare), 3,000 kg ha^{-1} wheat straw (straw) and 3,900 kg ha^{-1} flexible growth medium (FGM), each replicated three times in a completely randomized design.

The experiment consisted of nine 800 cm^3 plant pots filled with clay loam soil to a bulk density of 1.1 g cm^{-3}. To achieve the target bulk density, each pot was filled with 880g of air dried soil. Porosity (f) of the soil was determined from $f=1-(\rho_d/\rho_s)$ equation, where ρ_d is bulk density and ρ_s is mean particle density and f=0.6 m^3 m^{-3}. Each pot received 95.2 g of water the first day of the experiment. We measured the total mass of the pot, soil, water and straw or mulch. Subtracting soil+pot+straw/hydromulch weight from the total weight measured provided the mass of water (g). From this information we could calculate volumetric water content on two ways:

1) $\Theta=Vw/Vs$, sample calculation: $\Theta=Vw/Vs= 214.45\ cm^3/800cm^3= 0.263\ cm^3cm^{-3}$, where Θ is volumetric water content, Vw is volume of water and Vs is volume of soil.
2) Getting the mass wetness (w=Mw/Ms). And multiplying mass wetness (w) with ρ_d we would get Θ ($\Theta=w*\ \rho_d$), where w is mass wetness, Mw is mass of water, Ms is mass of soil, Θ is volumetric water content and ρ_d is bulk density.

Experiment 2

Experiment 2 was similar to experiment 1 except that the soil was seeded with mixture of tall fescue (*Festuca arundinacea*) at a rate of 168 kg ha^{-1}, centipedegrass (*Eremochloa ophiurodes*) at a rate of 11.2 kg ha^{-1} and bermudagrass (*Cynodon dactylon*) at rate of 56 kg ha^{-1}. Two treatments are each replicated three times and included: 3,000 kg ha^{-1} wheat straw (straw) and 3,900 kg ha^{-1} flexible growth medium (FGM). Each pot was initially watered until saturated, followed by watering every day, every three days, or every ten days resulting in six different treatments. There were three replicates in each of the treatments.

Volumetric Water Content

Volumetric water content during experiment 1was recorded 9 days in a row by weighing the pots and in experiment 2 for a period of 30 days. In experiment 1 the volumetric water content the first day of the experiment was the same for all treatments (0.3 m^3 m^{-3}).

Biomass

Thirty days after seeding biomass was clipped from the pots, dried overnight at 100^oC and weighed.

Data Analysis

Data were analyzed using SAS software and The Mixed Procedure (SAS version 9.2, SAS Institute, Cary, NC). Differences of least squares means among treatments were determined differences in average volumetric water content. Biomass data were analyzed using SAS software and GLM procedure

Results and Discussions

In experiment 1, the first day volumetric water content was the same for all treatments at 0.3 $m^3 m^{-3}$, which was the estimated field capacity for clay loam (Figure 23). On the second and third days, bare soil had lower ($p \leq 0.01$) water content than both straw and FGM covers while FGM ground cover had lower water content than straw ($p \leq 0.05$). From day four through day six there were differences among all treatments ($p \leq 0.01$), with the straw cover having the highest moisture content. The bare soil moisture content dropped to 0.178 $m^3 m^{-3}$, which was the wilting point for a soil used in this experiment before day 4. Next day, the FGM treatment reached the wilting point, while the straw ground cover remained higher moisture content than both FGM and bare ($p=0.01$). Straw ground cover reached the wilting point one day after FGM cover. Both FGM and straw cover resulted in greater moisture content compared to bare soil. Some other studies also found that mulch inhibits evaporation from the soil surface, resulting in greater soil moisture (Grigg et al. 2006; Ross et al. 1985). However, the FGM ground cover had available water only one day longer than bare soil, while straw ground cover provided available water two days longer than FGM, suggesting that straw ground cover has better water preserving capacity than FGM.

In experiment 2, there was no surviving grass in pots that received water on a 10 day interval (Figure 24). This is consistent with first experiment, in which the soil under both FGM and straw covers reached the permanent wilting point by 10 days (Figure 25). Treatments that received water every three days were different in above grass biomass between straw and FGM with straw having higher biomass compared to FGM, while treatments that received water every day did not have differences in biomass between different covers (Figure 26). Possible explanations for this are: 1) when the hydromulch is drying it becomes harder for the shoots to penetrate, limiting grass growth and 2) straw has better water holding capacity between watering events providing more moisture for plant growth when not watered every day. However, pots that received water every three days had water available to provide plant growth (Figure 27), regardless of cover type. This suggests that the limiting factor may been the difficulty of penetrating the drying FGM cover. This is consistent with the results of the soil box tests, in which grass growth appeared to be inhibited by the hydromulches even when the boxes were watered every day.

Conclusions

Based on the Experiment 1 and 2 we can conclude that straw maintains sufficient soil moisture for plant growth for a longer period than hydromulch by better inhibiting evaporation. Under certain field conditions, the extra days of sufficient moisture for plant growth may be critical. Hydromulch maintained moisture at sufficient levels for 1 day longer than bare soil, but straw maintained moisture at sufficient levels for 2 day longer than bare soil.

Even when water is not a limiting factor, hydromulch appears to inhibit grass growth possibly by creating a layer that is difficult for seedlings to penetrate, especially when the hydromulch is dry. In our field study we found that on site 2, where intervals between the second and the third storm and the third and fourth were 11 and 19 days, respectively, FGM ground cover had less above ground biomass than straw. In contrast, on site 4 where intervals between the first and the second storm and second and third storm were 3 and 8 days, respectively, and the subsequent storms occurred almost daily, both hydromluches (WFM and WCB) produced more biomass than straw.

TABLES AND FIGURES

Table 18: ANOVA, table for grass biomass production with two different covers and three different grass species.

Source	Pr > F	R^2	Coeff Var
BFM			
Tall fescue	0.0008	0.862	3.321
Centipedegrass	0.0912	0.534	4.808
Bermudagrass	0.07	0.565	1.381
FGM			
Tall fescue	0.2011	0.421	3.0973
Centipedegrass	0.0122	0.693	4.206
Bermudagrass	0.0385	0.605	5.279

Note: BFM=bonded fiber matrix. FGM=flexible growth media.

Table 19: Above ground biomass and cover percentages for bonded fiber matrix (BFM) at different rates and straw cover for three different types withing of grass. Means with same letter are not significantly different within row ($\alpha = 0.05$).

	Straw	BFM1	BFM2	BFM3
Tall fescue				
Biomass (kg ha^{-1})	984a	771a	497b	309c
Cover %	74a	62ab	48bc	38c
Centipedegrass				
Biomass (kg ha^{-1})	382b	488ab	670ab	751a
Cover (%)	48a	60a	63a	65a
Bermudagrass				
Biomass (kg ha^{-1})	1,393a	1,794a	1,487a	1,491a
Cover (%)	80a	89a	86a	89a

Note: BFM1= low application rate (1,120 kg ha^{-1}) of bonded fiber matrix. BFM2= recomended application rate (3,360 kg ha^{-1}) of bonded fiber matrix. BFM3= high application rate (5,040 kg ha^{-1}) of bonded fiber matrix.

Table 20: Above ground biomass and cover percentages for flexible growth media (FGM) hydromulch at different rates and straw cover for three different types of grass. Means with the same letter are not significantly different within row (α = 0.05).

	Straw	**FGM1**	**FGM2**	**FGM3**	**WFM**
Tall fescue					
Biomass (kg ha^{-1})	415a	213a	295a	400a	447a
Cover (%)	47a	46a	46a	51a	55a
Centipedegrass					
Biomass (kg ha^{-1})	319b	299b	598a	640a	409ab
Cover (%)	36b	48b	82a	78a	46b
Bermudagrass					
Biomass (kg ha^{-1})	444b	380b	817a	805a	409b
Cover (%)	66c	60c	87a	83ab	72bc

Note: FGM1= low application rate (1,120 kg ha^{-1}) of bonded fiber matrix. FGM2= recomended application rate (3,360 kg ha^{-1}) of bonded fiber matrix. FGM3= high application rate (5,040 kg ha^{-1}) of bonded fiber matrix.

Table 21: Surface crust measured. Means within a treatment with the same letter are not significantly different within row (α = 0.05).

Treatment	**Straw**	**1120 kg ha^{-1}**	**3360 kg ha^{-1}**	**5040 kg ha^{-1}**	**WFM**
Surface crust (kg m^{-2})					
BFM	245b	3,386a	3,347a	4,768a	N/A
FGM	20b	2,349a	4,458a	4,234a	2,034a

Note: BFM=bonded fiber matrix. FGM=flexible growth media.

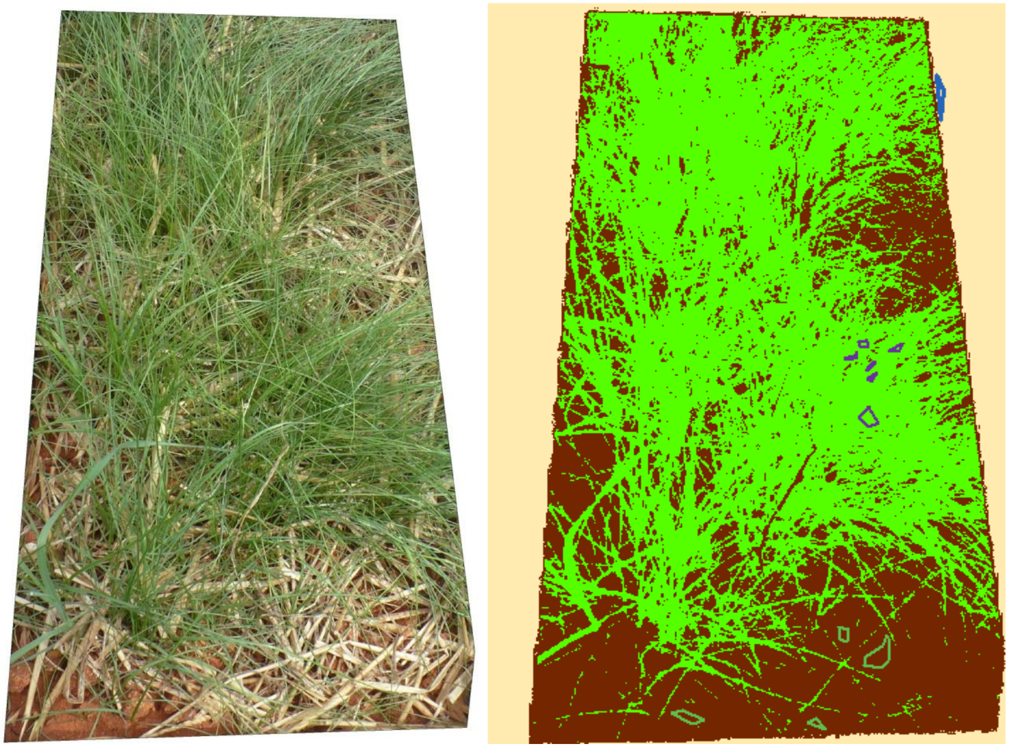

Figure 18: GIS photo used to estimate percent vegetative cover.

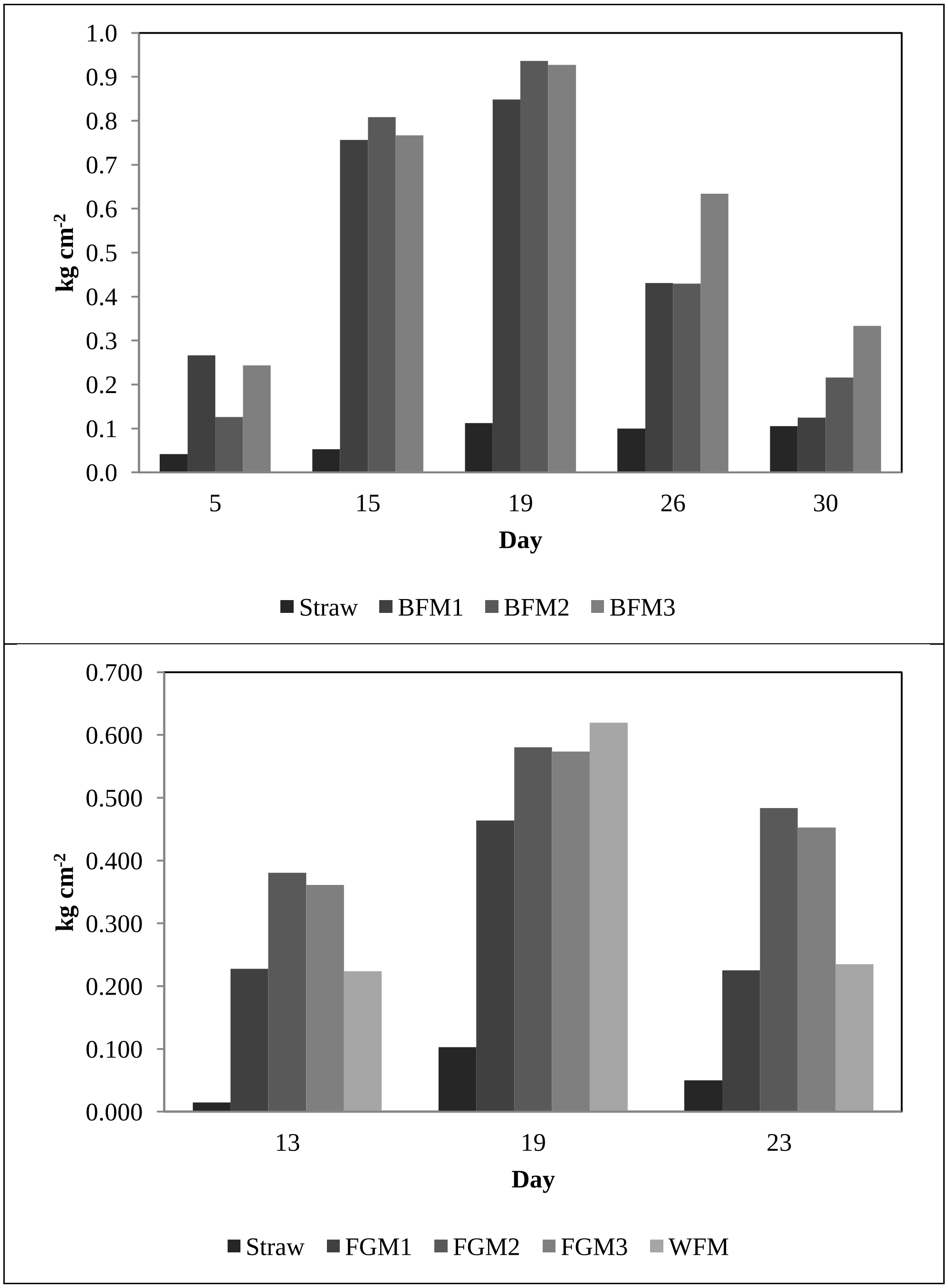

Figure 19: Crust strength under different covers (straw, BFM, FGM, and WFM). BFM=bonded fiber matrix. FGM=flexible growth media. WFM=wood fiber mulch. Application rates: 1=1,120 kg ha^{-1}; 2=3,360 kg ha^{-1}; 3=5,040 kg ha^{-1}.

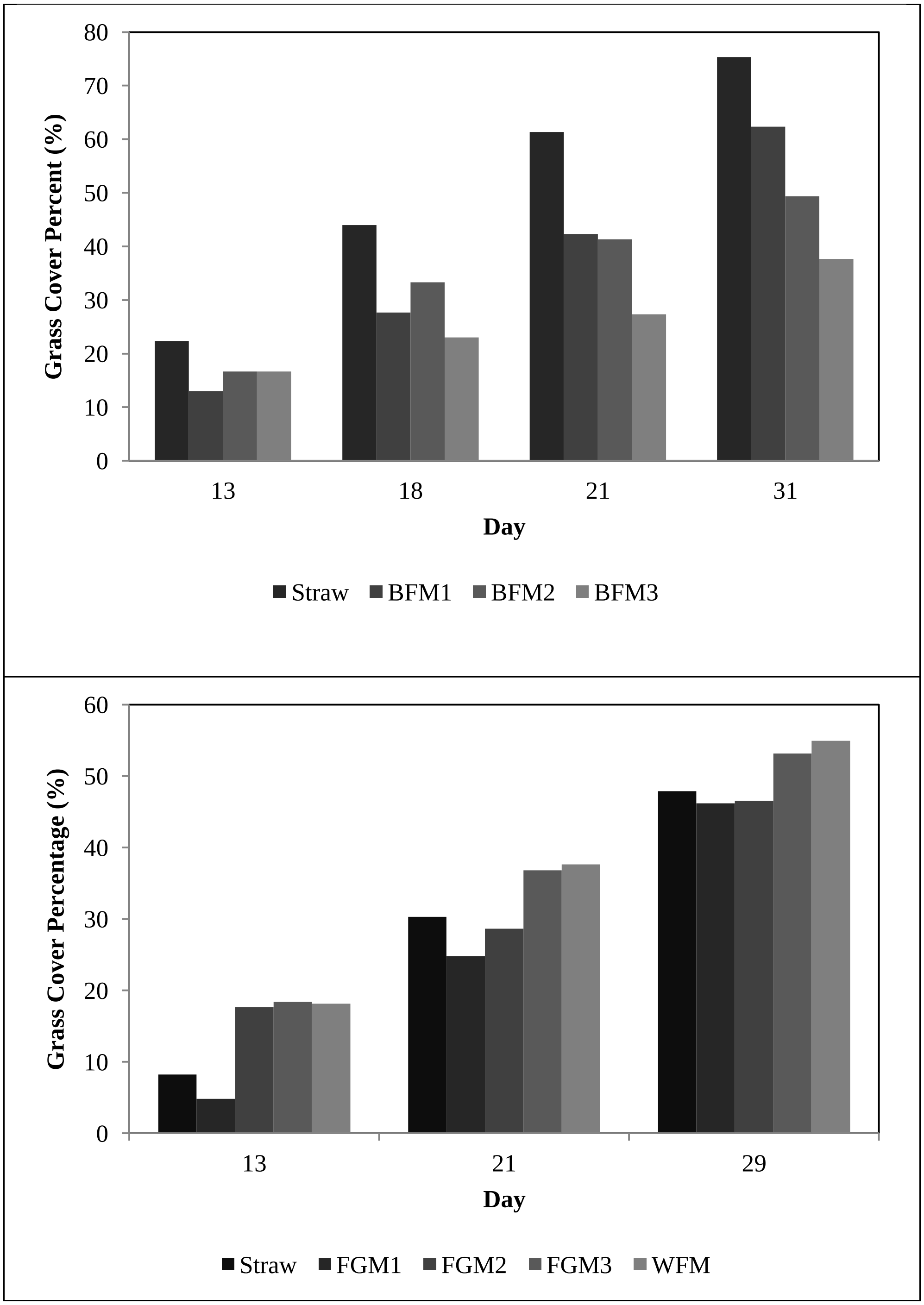

Figure 20: Tall fescue cover percent under different covers (straw, BFM, FGM, and WFM) over time. BFM=bonded fiber matrix. FGM=flexible growth media. WFM=wood fiber mulch. Application rates: 1=1,120 kg ha^{-1}; 2=3,360 kg ha^{-1}; 3=5,040 kg ha^{-1}.

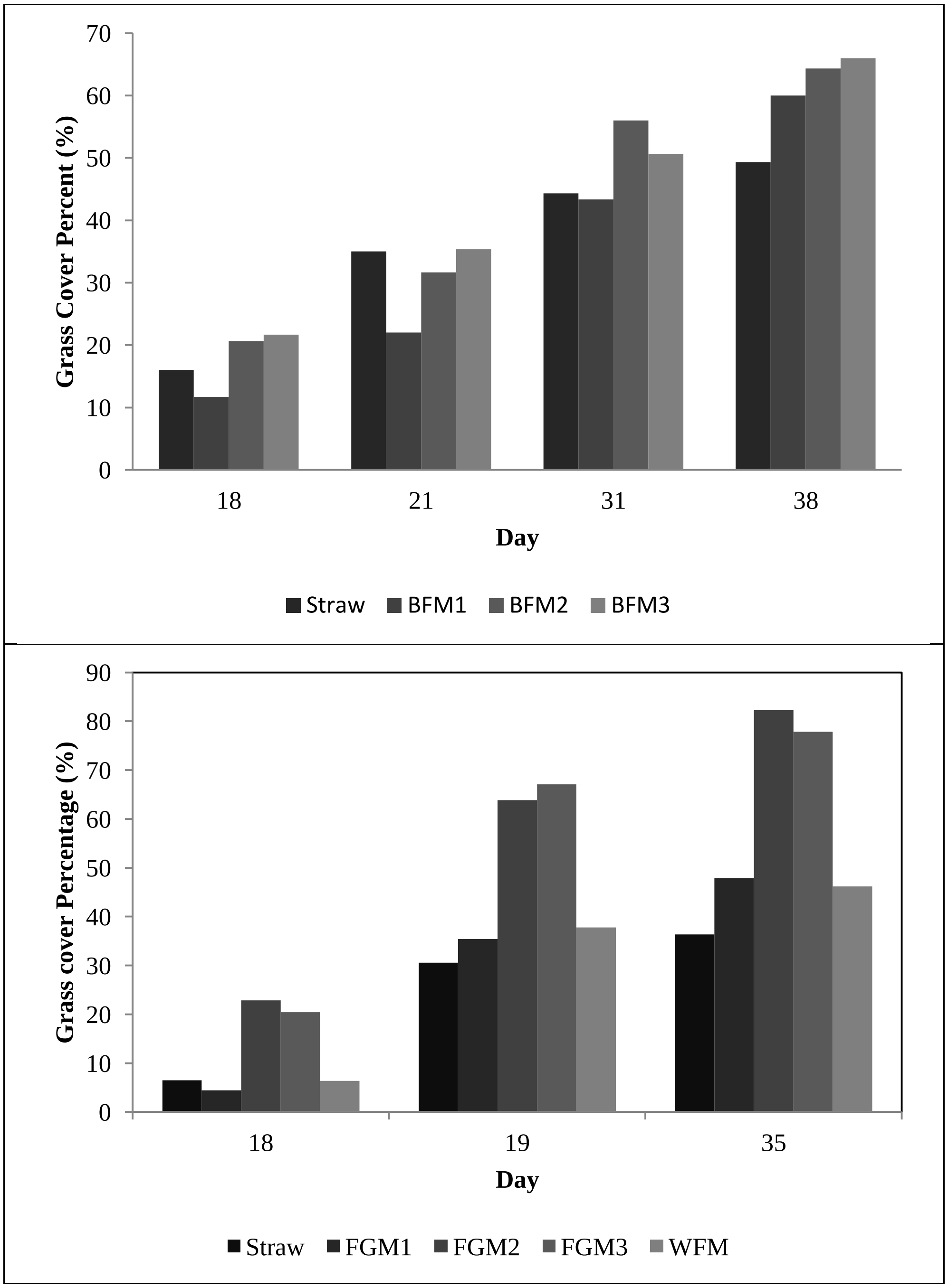

Figure 21: Centipedegrass cover percent under different covers (straw, BFM, FGM, and WFM) over time. BFM=bonded fiber matrix. FGM=flexible growth media. WFM=wood fiber mulch. Application rates: 1=1,120 kg ha^{-1}; 2=3,360 kg ha^{-1}; 3=5,040 kg ha^{-1}.

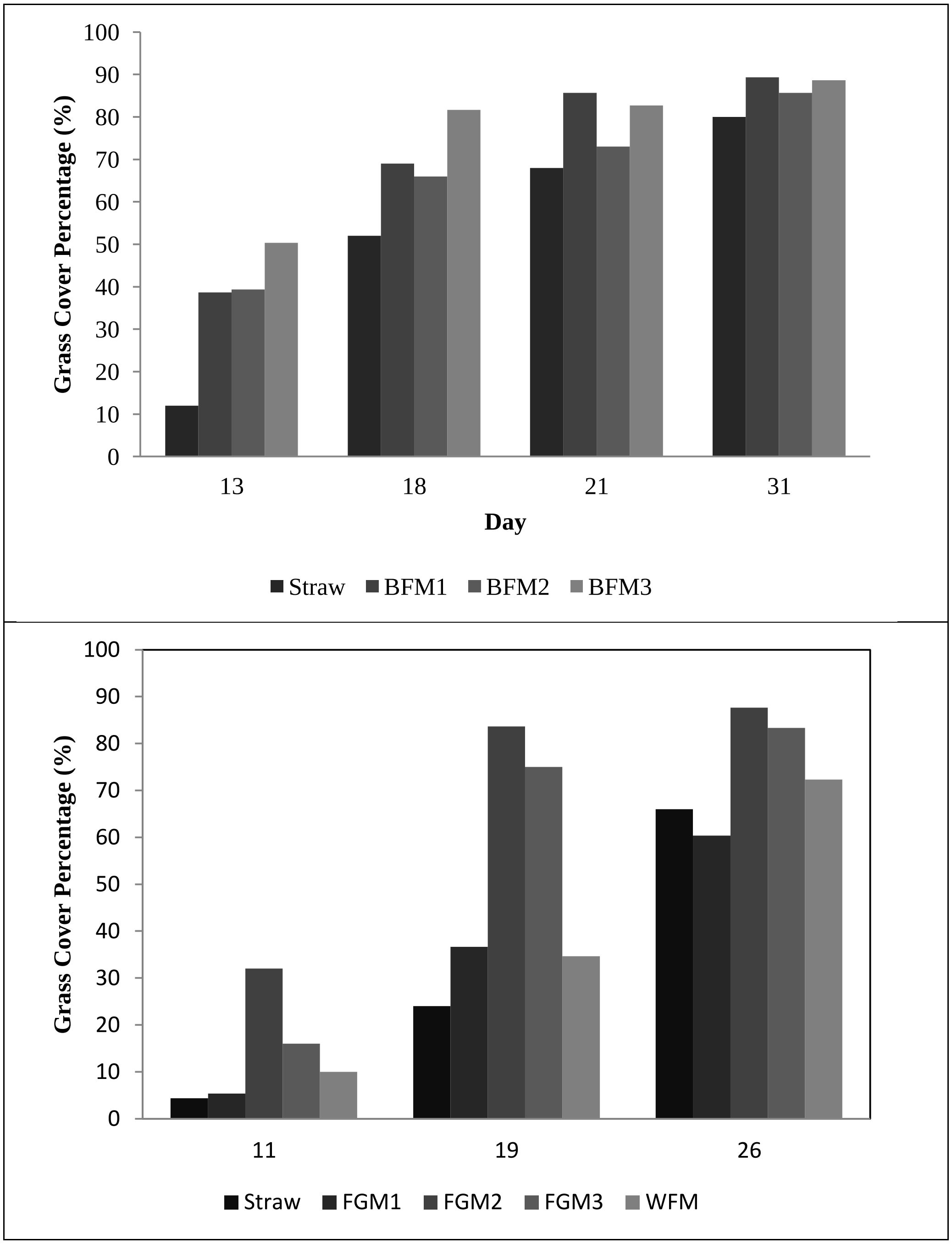

Figure 22: Bermudagrass cover percent under different covers (straw, BFM, FGM, and WFM) over time. BFM=bonded fiber matrix. FGM=flexible growth media. WFM=wood fiber mulch. Application rates: 1=1,120 kg ha^{-1}; 2=3,360 kg ha^{-1}; 3=5,040 kg ha^{-1}.

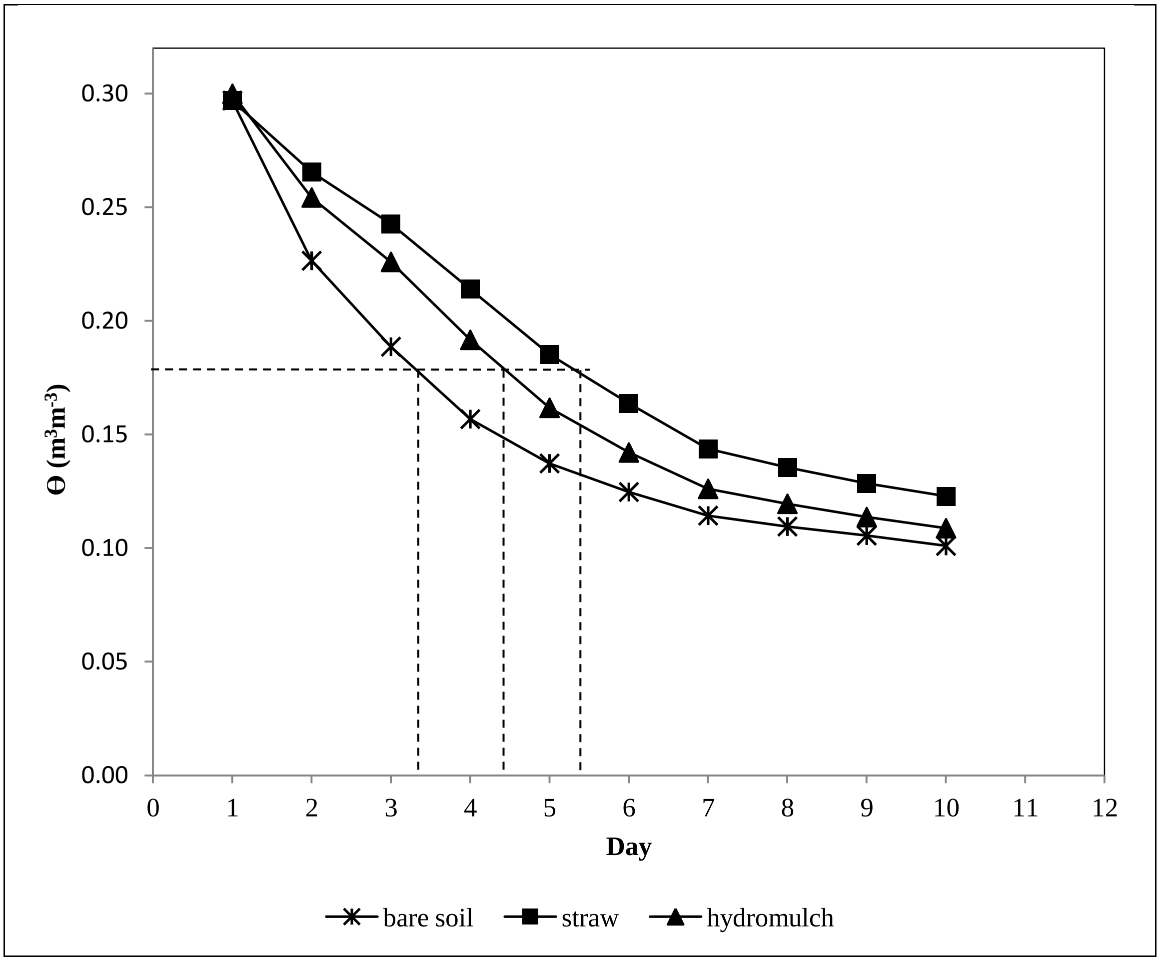

Figure 23: Volumetric water content for different ground covers: bare soil, straw mulch and hydromuulch (flexible growth media). Wilting point was 0.178 m m^{-3}= presented with dashed line.

Figure 24: Dead grass on straw cover (cover was removed for taking photo) when watered on a 10 day interval.

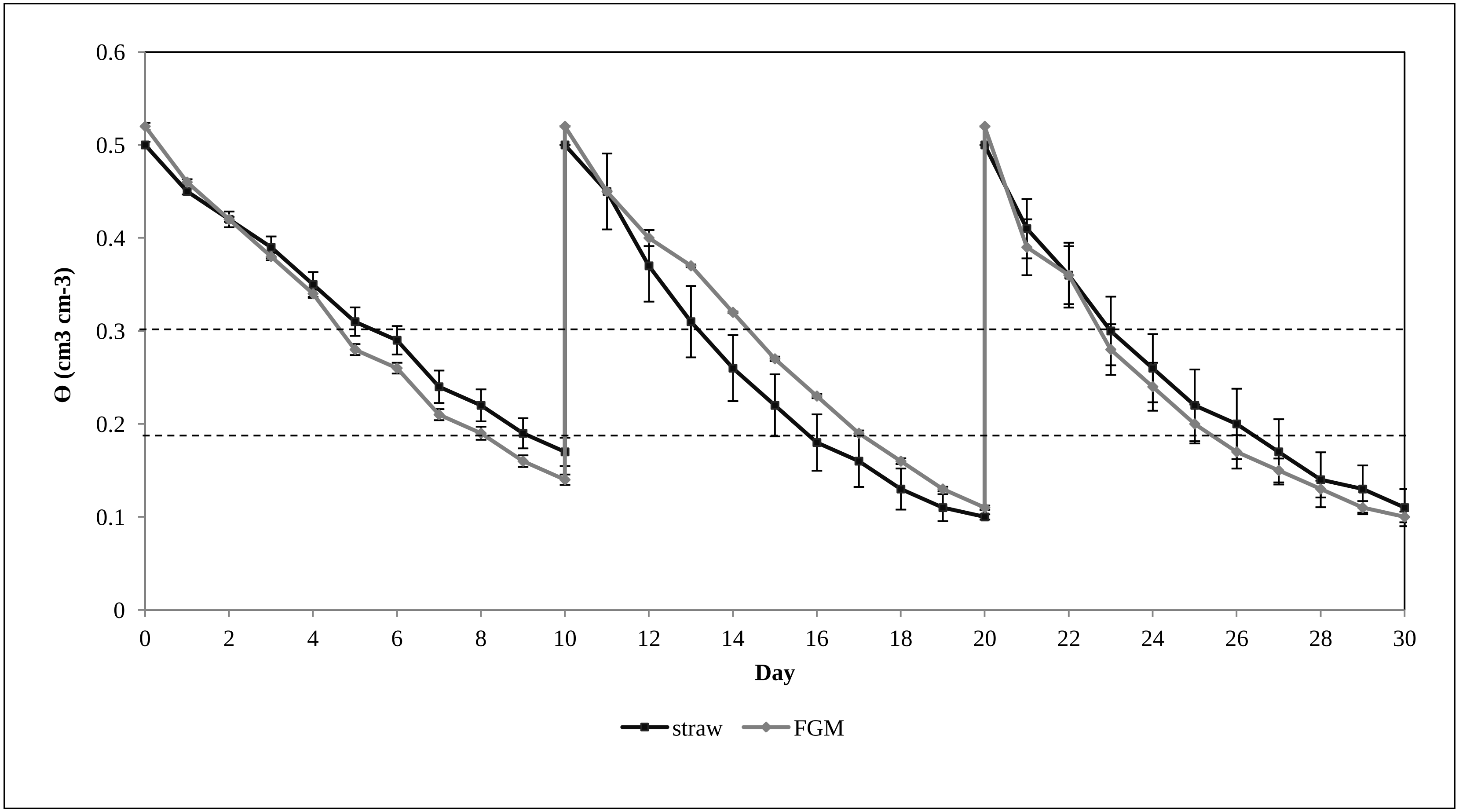

Figure 25: Volumetric water content of soil in pots for the ten-day watering interval for straw or FGM over 30 days in green house. FGM=flexible growth media.

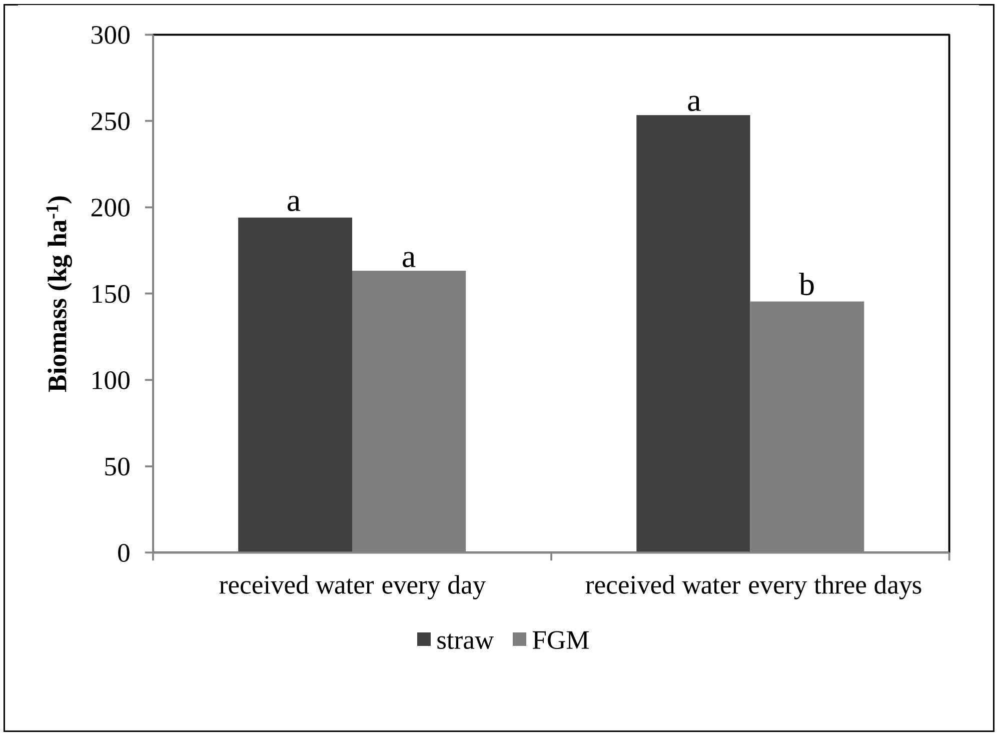

Figure 26: Above ground biomass for the one- and three-day watering intervals for the straw and FGM cover. FGM=flexible growth media. Means with same letter are not significantly different within each treatment ($\alpha = 0.05$) using LSD test.

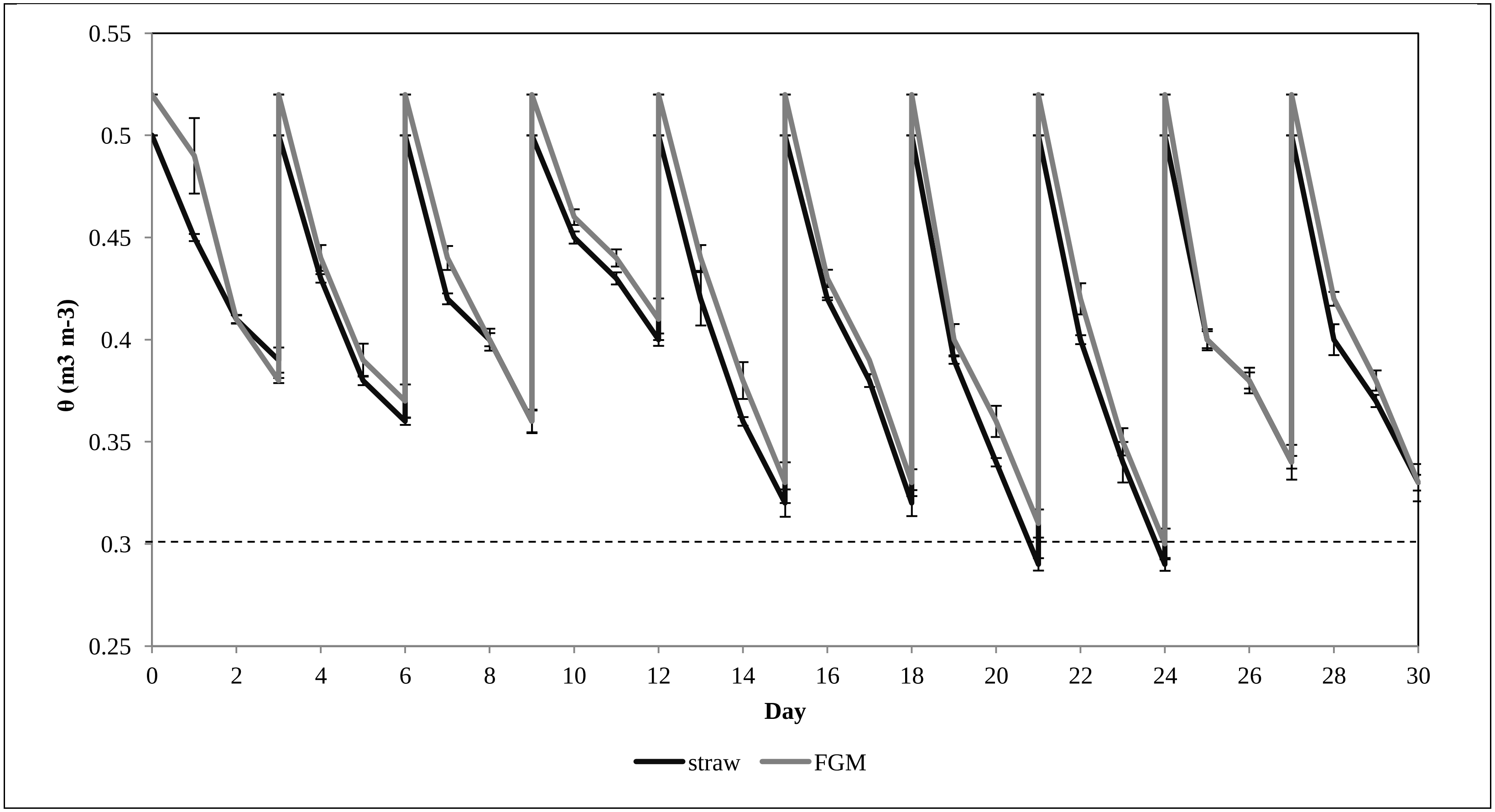

Figure 27: Volumetric water content of soil in pots for the three-day watering interval for straw or FGM over 30 days in greenhouse. FGM=flexible growth media.

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APPENDIX

Appendix 1: Hydromulch Descriptions

Hydromulch Type	Definition/Composition
Stabilized Mulch Matrix (SMM)	SMM Stabilized Mulch Matrix is the pre-blended combination of Thermally Refined® wood fibers, proprietary cross linked tackifiers and activators anchor the fiber matrix to the soil surface. Max Slope: 2:1 Max Slope Length (m): 15 Erosion Control Effectiveness (%): 90 Functional longevity (months): 3-6
Bonded Fiber matrix (BFM)	The combination of Thermally Refined® wood fibers and multi-dimensional tackifiers. Proprietary cross-linked, hydro-colloidal tackifiers and activators anchor the fiber mulch matrix to the soil surface. Max Slope: 1:1 Max Slope Length (m): 30 Erosion Control Effectiveness (%): 95 Functional longevity (months): 6-12
Flexible Growth Medium (FGM)	Is consist of Revolutionary Micro-Pore particles, 100% recycled Thermally Refined® wood fibers, 100% biodegradable interlocking man-made fibers help, 100% non-toxic biopolymers and water absorbents Max Slope: 1:1 Max Slope Length (m): 23 Erosion Control Effectiveness (%): 99 Functional longevity (months): 12-18
Enviroblend Wood/Paper Fiber Mulch (WC)	Consist of: Thermally Refined® Wood Fibers (60%), cellulose Fiber (27%) ,proprietary emulsifying agents (TriFlo) ~ 1% and moisture content ~ 12% Max Slope: 3:1 Max Slope Length (m): 7 Erosion Control Effectiveness (%): 35 Functional longevity (months): 3
Conwed Wood Fiber Mulch (W)	Consist of: Thermally Refined® Wood Fibers (~ 87%), proprietary emulsifying agents (TriFlo) ~ 1% and moisture content ~ 12% Max Slope: 2:1 Max Slope Length (m): 8.5 Erosion Control Effectiveness (%): 45 Functional longevity (months): 3

Source: http://www.profileevs.com/proofpoints/hydraulic-mulch-important-differences-between-cellulose-and-wood-fiber-mulches-and-their

Appendix 2: ANOVA Table and Contrasts Between Treatments

Source	df	Pr > F	R^2	Coeff Var
Runoff volumes (% of precipitation)				
Site 1, West Jefferson, NC				
Block	3	0.1202		
Treatment	4	0.4914	0.47	474.25
Site 2, Garner, NC				
Block	3	0.0033		
Treatment	4	0.0084	0.796	8.247
Site 3, Apex, NC				
Block	3	0.0025		
Treatment	4	0.0206	0.783	27.111
Site 4, Holly Springs				
Block	3	0.0313		
Treatment	4	0.1148	0.670	13.32
Turbidity (NTU)				
Site 1, West Jefferson, NC				
Block	3	0.0037		
Treatment	4	0.4883	0.693	5.979
Site 2, Garner, NC				
Block	3	0.3042		
Treatment	4	0.0180	0.65	6.459
Site 3, Apex, NC				
Block	3	0.0133		
Treatment	4	0.0003	0.849	4.858
Site 4, Holly Springs				
Block	3	0.0821		
Treatment	4	0.0245	0.720	8.899
Total Suspended Sediment (mg L^{-1})				
Site 1, West Jefferson, NC				
Block	3	0.1408		
Treatment	4	0.2871	0.505	3.194
Site 2, Garner, NC				
Block	3	0.2031		
Treatment	4	0.0356	0.625	8.158
Site 3, Apex, NC				
Block	3	0.0442		
Treatment	4	0.0165	0.712	8.954
Site 4, Holly Springs				
Block	3	0.3936		
Treatment	4	0.088	0.557	9.582

Appendix 2 (continued)

Total Sediment Load (kg ha^{-1})				
Site 1, West Jefferson, NC				
Block	3	0.8258		
Treatment	4	0.7436	0.192	21.849
Site 2, Garner, NC				
Block	3	0.2032		
Treatment	4	0.0149	0.673	11.386
Site 3, Apex, NC				
Block	3	0.0039		
Treatment	4	0.0326	0.7611	19.881
Site 4, Holly Springs				
Block	3	0.1216		
Treatment	4	0.0776	0.652	8.995
Biomass (kg ha^{-1})				
Site 1, West Jefferson, NC				
Block	3	0.0892		
Treatment	4	0.6499	0.472	7.302
Site 2, Garner, NC				
Block	3	0.1054		
Treatment	4	0.3065	0.520	3.600
Site 3, Apex, NC				
Block	3	0.0254		
Treatment	4	0.0106	0.742	7.346
Site 4, Holly Springs				
Block	3	0.2993		
Treatment	4	0.0532	0.610	5.496
Cover (%)				
Site 1, West Jefferson, NC				
Block	3	0.0019		
Treatment	4	0.1515	0.750	8.684
Site 2, Garner, NC				
Block	3	0.4196		
Treatment	4	0.4276	0.374	3.414
Site 3, Apex, NC				
Block	3	0.0091		
Treatment	4	<0.0001	0.905	3.600
Site 4, Holly Springs				
Block	3	0.4483		
Treatment	4	0.0032	0.756	2.589

Appendix 3: Runoff Volumes, Turbidity and Total Suspended Sediment for all Sampling/Storm Events

Sampling/Storm event	Treatment	Runoff volume (L)	Turbidity (NTU)	TSS (mg L^{-1})
Site 1, West Jefferson, NC				
1	Straw	8.9a	51a	576.2a
1	Straw+PAM	5.6a	57a	612.2a
1	FGM	11.7a	53a	619.5a
1	SMM	10.2a	56a	483.9a
1	BFM	12.9a	78a	487.3a
2	Straw	2.4a	31a	185.3a
2	Straw+PAM	1.7a	30a	191.3a
2	FGM	1.4a	44a	195.2a
2	SMM	1.6a	39a	243.0a
2	BFM	1.7a	38a	200.7a
3	Straw	5.4a	44a	304.0a
3	Straw+PAM	4.0a	34a	323.4a
3	FGM	1.9a	51a	307.9a
3	SMM	4.5a	33a	274.2a
3	BFM	3.3a	45a	256.4a
Site 2, Garner, NC				
1	Straw	78a	2,226a	5,393.8a
1	Straw+PAM	78a	2,124a	4,389.6a
1	FGM	59a	465b	1,553.1b
1	SMM	52a	586b	2,930.7a
1	BFM	82a	1,313a	4,285.5a
2	Straw	4.1a	986.3a	2,611.8a
2	Straw+PAM	1.2ab	7.9ab	121.9a
2	FGM	0.1c	0.1b	0.2b
2	SMM	2.3ab	77.3a	128.9a
2	BFM	0.3bc	6.0ab	10.2ab
3	Straw	159.0a	1,634a	3,232.5a
3	Straw+PAM	130.3a	1,360a	1,923.7a
3	FGM	58.7b	761b	960.1b
3	SMM	87.1ab	757b	1,709.6ab
3	BFM	97.1ab	603b	1937.2a
4	Straw	5.3a	833a	1,670.9a
4	Straw+PAM	0.6b	537a	817.0a
4	FGM	0.2b	1b	1.2b
4	SMM	0.3b	63ab	87.6ab
4	BFM	0.7b	922a	1,012.0a

Appendix 3 (continued)

5	Straw	13.7a	1383a	1,295.9a
5	Straw+PAM	8.2ab	1234a	921.2a
5	FGM	6.2b	361b	436.6a
5	SMM	8.7ab	751ab	701.9a
5	BFM	7.9ab	628ab	896.3a
6 and 7	No runoff			
8	Straw	10.9a	1,205ab	2,333.4a
8	Straw+PAM	5.7ab	1,321ab	1,263.0a
8	FGM	3.9b	486b	399.1a
8	SMM	5.1ab	1,782a	1,469.4a
8	BFM	6.2ab	1,682a	3,338.9a
9	Straw	40.0a	1,042a	4,2826.6a
9	Straw+PAM	28.3ab	832a	2,804.6ab
9	FGM	13.9c	335a	567.0b
9	SMM	19.2bc	636a	1,691.7ab
9	BFM	24.2abc	882a	3,629.0ab
10	Straw	156.7a	474a	942.9a
10	Straw+PAM	128.8a	428a	768.2ab
10	FGM	63.2b	238a	277.3b
10	SMM	157.2a	432a	833.6ab
10	BFM	129.4a	369a	759.2ab
Site 3, Apex, NC				
1	Straw	16.6a	246a	310.7a
1	Straw+PAM	6.9a	19a	25.6a
1	FGM	10.8a	41a	30.1a
1	WFM	69.0a	421a	444.9a
1	WCB	46.4a	510a	818.3a
2	Straw	0.1bc	421a	291.4a
2	Straw+PAM	0.1c	5b	0.7b
2	FGM	0.4ab	601a	584.6a
2	WFM	0.8a	1,140a	2,075.6a
2	WCB	0.8a	1,368a	2,049.0a
3	No runoff			
4	Straw	7.2a	1,533a	3,090.2ab
4	Straw+PAM	9.2a	852c	1,538.2b
4	FGM	12.9a	1,208bc	3,481.3ab
4	WFM	17.7a	1,737ab	4,861.0a
4	WCB	18.7a	2,151a	4,416.0a
5	Straw	15.8a	699bc	1,176.0ab
5	Straw+PAM	15.7a	371c	300.2b

Appendix 3 (continued)

5	FGM	34.2a	989ab	1,562.4a
5	WFM	36.2a	1,063ab	1,583.8a
5	WCB	12.7a	1,853a	2,599.0a
6 and 7	No runoff			
8	Straw	3.2ab	556a	820.6a
8	Straw+PAM	1.1b	10b	12.7b
8	FGM	8.3a	1,022a	1,498.2a
8	WFM	7.3a	1,230a	1,929.5a
8	WCB	7.6a	1,581a	1,986.2a
9	Straw	0.3b	5b	0.7b
9	Straw+PAM	1.1b	15b	5.9b
9	FGM	17.2a	189a	339.0a
9	WFM	15.6a	893a	417.5a
9	WCB	13.6a	453a	684.6a
10	Straw	7.4b	73b	114.0d
10	Straw+PAM	9.9b	110b	144.9cd
10	FGM	19.0a	194ab	245.1ab
10	WFM	13.8a	304a	183.9bc
10	WCB	18.0a	191ab	317.4a
11	Straw	0.2c	10c	1.0c
11	Straw+PAM	0.5bc	15bc	8.1bc
11	FGM	1.2ab	76ab	175.3ab
11	WFM	2.6a	745a	1,770.1a
11	WCB	2.1a	652a	1,922.0a
Site 4, Holly Springs				
1	Straw	10.4a	416a	1,776.1ab
1	Straw+PAM	8.1a	168b	1,019.4b
1	SMM	10.0a	176ab	1,155.3b
1	WFM	10.0a	308ab	1,205.0b
1	WCB	14.9a	606a	2,704.8a
2	Straw	6.7a	423b	1,254.9ab
2	Straw+PAM	11.1a	332b	778.4b
2	SMM	5.2a	478b	1,016.8ab
2	WFM	7.1a	1,858a	3,144.8a
2	WCB	14.3a	1,978a	4,212.9a
3	Straw	22.7b	351b	441.4c
3	Straw+PAM	34.1ab	347b	299.2c
3	SMM	27.6b	510b	553.4bc
3	WFM	42.0ab	1,386a	2,107.0a
3	WCB	75.9a	814ab	1,410.6ab

Appendix 3 (continued)

4	Straw	N/A	368b	652.0b
4	Straw+PAM	N/A	325b	568.4b
4	SMM	N/A	391b	763.0b
4	WFM	N/A	2,333a	3,679.0a
4	WCB	N/A	1,098ab	2,507.4a
5	Straw	N/A	1,176b	2,526.7a
5	Straw+PAM	N/A	1,212ab	2,370.8a
5	SMM	N/A	2,465ab	3,356.2a
5	WFM	N/A	3,245ab	8,720.2a
5	WCB	N/A	4,760a	8,507.0a

Note: Means with same letter are not significantly different ($\alpha = 0.05$) using LSD test. PAM=Polyacrylamide. WFM=wood fiber mulch. WCB=70:30 wood fiber/cellulose blend.

Appendix 4: N, P and Total Organic C lost on site 2, 3 and 4 for five storm events

Storm event	Trt	NH4	NO3	TKN	PO4	TP	TOC
		mg L^{-1}					
Site 2, Garner, NC							
1	Straw	9.7	3.7	24.1	0.7	5.0	20.3
1	Straw+PAM	5.2	3.5	14.9	0.6	2.9	18.0
1	FGM	4.1	3.0	9.4	0.3	1.0	19.6
1	SMM	6.1	4.6	15.0	0.4	2.0	22.0
1	BFM	5.0	1.0	24.2	0.5	2.9	22.4
2	Straw	4.7	9.4	12.1	0.3	2.0	20.4
2	Straw+PAM	2.9	7.0	9.4	0.1	1.2	16.7
2	FGM	0.8	2.6	3.3	0.1	0.3	11.0
2	SMM	3.0	11.0	6.4	0.2	0.6	24.2
2	BFM	3.9	4.0	7.3	0.2	0.6	16.4
3	Straw	0.8	8.7	11.5	0.1	2.5	22.9
3	Straw+PAM	0.4	4.6	8.2	0.2	1.7	22.1
3	FGM	1.0	2.7	5.4	0.2	0.9	23.6
3	SMM	0.2	1.6	6.0	0.2	1.3	29.6
3	BFM	1.0	3.4	10.0	0.1	1.6	25.8
4	Straw	0.7	0.5	6.0	0.2	1.4	19.6
4	Straw+PAM	0.7	0.5	4.4	0.1	0.8	15.7
4	FGM	0.7	0.3	3.5	0.1	0.5	11.9
4	SMM	0.7	0.4	3.7	0.1	0.6	16.4
4	BFM	0.7	0.4	4.1	0.1	0.8	15.3
5	Straw	0.6	0.3	6.6	0.5	1.7	23.0
5	Straw+PAM	0.4	0.3	6.8	0.2	1.3	19.5
5	FGM	0.2	0.3	3.5	0.1	0.4	14.2
5	SMM	0.4	0.3	5.6	0.2	1.0	20.1
5	BFM	2.1	0.27	6.0	0.1	0.9	19.3
Site 3, Apex							
1	Straw	1.95	0.26	3.48	0.07	0.23	10.48
1	Straw+PAM	2.36	0.44	4.33	0.08	0.18	7.73
1	FMG	2.33	0.23	3.93	0.21	0.32	13.70
1	WFM	1.90	0.51	3.55	0.06	0.24	12.13
1	WCB	2.35	0.54	4.38	0.06	0.54	8.95
2	Straw	0.95	0.35	3.40	0.05	0.28	8.53
2	Straw+PAM	0.66	0.33	1.78	0.10	0.19	8.38
2	FMG	1.68	0.42	3.60	0.06	0.44	13.88
2	WFM	1.41	0.54	3.85	0.08	1.08	16.65
2	WCB	1.65	0.59	4.68	0.04	0.94	13.35

Appendix 4 (continued)

3	Straw	1.15	0.25	3.25	0.09	0.91	5.58
3	Straw+PAM	1.39	0.25	3.23	0.14	0.67	5.33
3	FMG	0.72	0.19	3.05	0.16	0.88	10.63
3	WFM	0.39	0.20	2.83	0.01	0.86	9.60
3	WCB	0.73	0.23	3.40	0.03	1.00	7.48
4	Straw	0.60	0.13	2.07	0.37	0.98	6.35
4	Straw+PAM	0.40	0.16	3.08	0.11	0.51	5.05
4	FMG	0.30	0.10	1.85	0.19	0.76	10.45
4	WFM	0.18	0.10	1.78	0.05	0.58	9.98
4	WCB	0.34	0.12	2.20	0.06	0.89	6.58
5	Straw	0.80	0.22	2.23	0.51	0.48	11.45
5	Straw+PAM	0.11	0.10	1.68	0.04	0.60	9.15
5	FMG	0.10	0.10	1.95	0.54	0.79	11.53
5	WFM	0.10	0.10	2.08	0.17	0.92	12.50
5	WCB	0.16	0.10	2.43	0.21	1.09	8.70
Site 3, Holly Springs							
1	Straw	7.03	0.38	16.70	1.30	4.53	25.48
1	Straw+PAM	5.30	0.45	9.55	1.23	2.40	20.33
1	SMM	7.80	0.75	16.78	1.45	3.80	36.93
1	WFM	4.93	1.31	11.83	0.43	1.83	23.95
1	WCB	4.73	0.39	12.23	1.21	4.00	19.97
2	Straw	6.93	3.45	11.40	0.71	2.97	22.95
2	Straw+PAM	7.35	3.98	11.25	0.42	1.35	24.28
2	SMM	7.08	2.55	12.15	1.27	3.32	30.35
2	WFM	7.18	3.55	13.98	0.25	3.23	22.83
2	WCB	8.17	4.03	17.63	0.86	5.07	30.03
3	Straw	6.08	3.03	11.85	0.72	1.53	23.90
3	Straw+PAM	5.78	2.05	10.83	0.56	1.24	25.68
3	SMM	5.10	1.01	11.13	1.44	2.43	26.58
3	WFM	5.20	1.53	11.10	0.52	1.48	23.15
3	WCB	4.00	1.63	10.57	0.90	1.97	24.47
4	Straw	3.73	1.45	7.38	0.54	1.24	14.95
4	Straw+PAM	2.73	0.89	6.55	0.59	1.19	14.43
4	SMM	3.28	1.12	6.78	0.89	1.48	15.88
4	WFM	3.00	0.70	8.33	0.59	1.58	13.98
4	WCB	2.52	0.95	7.90	0.52	1.39	15.53
5	Straw	1.90	0.36	4.23	0.46	0.91	9.03
5	Straw+PAM	1.90	0.41	4.35	0.34	0.83	8.08
5	SMM	1.45	0.19	4.13	0.69	1.23	7.25
5	WFM	1.31	0.18	5.15	0.49	1.35	7.10
5	WCB	1.24	0.18	5.20	0.30	1.14	7.80

Note: PAM=Polyacrylamide. WFM=wood fiber mulch. WCB=70:30 wood fiber/cellulose blend.

Appendix 5: Material Data (Tackifier) Safety Sheet

MATERIAL SAFETY DATA SHEET

Product:	**HFMS-1**		
Manufacturer:	SEACO, Inc. 2700 William Tuller Drive Columbia, S.C. 29205	Emergency Telephone Numbers:	803-799-5335 800-729-5335
Synonyms:	medium setting grade asphalt emulsion		

Section II - Hazardous Ingredients/Identity Information

Hazardous Components
(Specific Chemical Identity):

	Common Name	CAS Number	OSHA PEL	ACGIH TLV	Concentrations (%) Recommended (Optional)
Asphalt		8052-42-4	ND	5 MG/M3 (asphalt fumes)	57 - 69
Emulsifiers		Proprietary	ND	ND	0 - 4
Water		7732-18-5	ND	ND	Balance

TLV for asphalt relates to the fume given off when asphalt is heated.
Additives are not considered hazardous as contained in this product.

Section III - Physical/Chemical Characteristics

Boiling Point	212F (100C)	Specific Gravity (water=1)	0.9 - 1.1
Vapor Pressure (mm Hg)	same as water	Melting Point	NA
Vapor Density (Air=1)	ND	Evaporation Rate	ND
Solubility in Water	Soluble		
Appearance and Odor	Brown, viscous liquid with characteristic asphalt odor		

Section IV - Fire and Explosion Data

Flash Point: Greater than 212F for the product with water vapor in the atmosphere.
In normal use in an open environment, the product will not support combustion.
In a closed environment, with water driven off, will burn like oil.

		Flammable Limits			
Autoignition Temperature	ND	LEL	ND	UEL	ND
Extinguishing Media	Foam, carbon dioxide, dry chemical, water sponge				
Special Firefighting Procedures	None				
Unusual Fire and Explosion Hazards	None				

Section V - Reactivity Data

Stability	Unstable		Conditions to Avoid
	Stable	X	Conditions to avoid
Incompatibility (Materials to Avoid)		Strong oxidizers and acids	
Hazardous Decomposition or Byproducts		ND	
Hazardous Polymerization	May occur		Conditions to Avoid
	Will not occur	X	Conditions to Avoid

ND=no data available NA=not applicable

Section VI - Health Hazard Data

Routes of Entry	Inhalation?	Skin?	Ingestion?	Eyes?
		X	X	X

Health Hazards (Acute and Chronic) ND
Signs and Symptoms of Exposure Prolonged or repeated contact may cause skin irritation
Medical Conditions Generally Aggravated by Exposure ND

Emergency and First Aid Procedures

EYES	Gently flush with large amounts of water. **Call a physician immediately**.
SKIN	Remove asphalt with waterless hand cleaner and wash with soap and warm water. If irritation occurs, consult a physician.
INHALATION	Remove victim from exposure. **Call a physician immediately**.
INGESTION	If large amounts are swallowed, do not induce vomiting. **Call a physician immediately.**

Section VII - Precautions for safe handling and use

Steps to be taken in case material is released or spilled
Recover free product. Add adsorbent (sand, earth, sawdust, etc.) to spill. Hot product will solidify when cooled.
Keep petroleum products out of sewers and watercourses by diking or impounding.
Advise authorities if product has entered or may enter sewers or watercourses.

Waste Disposal Method
Assure conformity with local and federal governmental regulations for disposal.
Recovered material may be blended with aggregate and used for patching or other maintenance use.

Precautions to be taken in handling and storing
Do not handle or store near heat, sparks, flame or strong acids or oxidizers.

Section VIII - Control Measures

Respiratory protection (Specify type) Not required under normal conditions and adequate ventilation

Ventilation	Local Exhaust	NA	Special	NA
	Mechanical (General)	NA	Other	NA

Protective Gloves	Insulated gloves for hot asphalt. Cloth gloves acceptable for cold asphalt.
Eye Protection	Safety glasses with side shields.
Other protective clothing or equipment	Standard work clothing with long sleeve shirts.
Work/Hygienic Practices	Practice safe working habits

ND=no data available NA=not applicable

INFORMATION SUPPLIED BY: EMERGENCY PHONE NO.
Tim Owings 800-729-5335 or 803-799-5335
revised format 1/18/2011

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Appendix 6: Normal Precipitation for September and October in North Carolina based on 1971-2000 Normals