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Field Evaluation of Hydromulches for Water Quality and Vegetation Establishment

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16. Abstract

Soil erosion and sediment pollution can be major 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 five construction sites in North Carolina to evaluate different mulch treatments on steep slopes for erosion control and vegetative establishment. Site 1 was located in the Coastal Plain region near Kinston, Site 2 was located in the mountain region near West Jefferson, and the remaining three were in the Piedmont near Raleigh. Of the five, two were 2:1 cut slopes and three were 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 4-5" (10-12 cm). At site 2, 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 3, 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 4 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 5. 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 2 and 4 had poor grass establishment with grass cover of <50%, while sites 3 and 5 had good grass establishment (67 and 85% cover, respectively). The reason for lower grass establishment under the hydromulches at some sites 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 may maintain sufficient soil moisture for plant growth for a longer period than hydromulch. Of the three grasses tested, tall fescue was inhibited by BFM but not FGM at recommend application rates or higher, while centipede and Bermuda grass had the same or higher growth as rates increased.

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Executive Summary

Controlling erosion through a combination of mulching and vegetation establishment is a critical part of construction site erosion and sediment control practices. The most common approach has been to apply grass seed, fertilizer, and lime followed by straw and tackifier to prevent erosion and create a good environment for seed germination and grass growth. The other two types of materials commonly used for this purpose are erosion control blankets and hydromulch. This project compared runoff quantity and quality as well as grass establishment among five different grades of hydromulch and straw with and without polyacrylamide (PAM). The hydromulches included a wood-cellulose blend, 100% wood, bonded fiber matrix, stabilized fiber matrix, and flexible growth medium. The tests were conducted on plots established on five NCDOT project sites and included three fill and two cut slopes.

Overall, there was no clear advantage of hydromulches over straw. At two sites, there were no differences in any runoff parameter due to high infiltration rates and/or low precipitation amounts. At two sites, the straw treatments resulted in better water quality compared to some of the hydromulches. At the fifth site, the straw cover had poorer runoff water quality compared to FGM, most likely due to low straw application rates. The wood/cellulose blend and 100% wood fiber products, much less expensive than the other hydromulches, performed poorly compared to all others. There was no clear advantage of any mulch material in grass growth or cover. However, the environmental conditions during the establishment period greatly affected stand establishment, with poorer stands during the winter than the summer and with drier conditions. Under greenhouse conditions, the BFM was found to inhibit tall fescue growth, but not centipede or Bermuda grass. A straw cover maintained soil moisture longer than the hydromulches, which may explain some of the field observations. Temporary irrigation after seeding, especially during dry periods, may prove to be worth the expense to ensure adequate establishment of vegetation on steep slopes.

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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).

LITERATURE REVIEW

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, with the smallest above–ground biomass in the BFM plots. Other studies found that BFM had less ground cover and biomass compared to straw (Babcock and McLaughlin, 2008; McLaughlin and Brown, 2006). Faucette et al. (2006) found that compost blankets provided an average of 2.75 times more vegetative cover than hydrosided after three months. 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.

STUDY METHODS

Description of Study Sites

This study was conducted on one borrow pit operation and four road construction slopes. The first site was at a borrow pit near Kinston and consisted of fill material that was stockpiled for later use and it had a 2.9:1 slope (Figure 1). The second site was located on the mountain region near West Jefferson, NC (Figure 2) and was a 2:1 cut slope (50% slope). The remaining three sites were all located in the Piedmont region near Raleigh, NC. The third site was a 2:1 fill slope located near Garner, NC, (Figure 3). The fourth site was a 2:1 cut slope in Apex, NC (Figure 4). The fifth site was a 2:1 fill slope in Holly Springs, NC (Figure 5). 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.

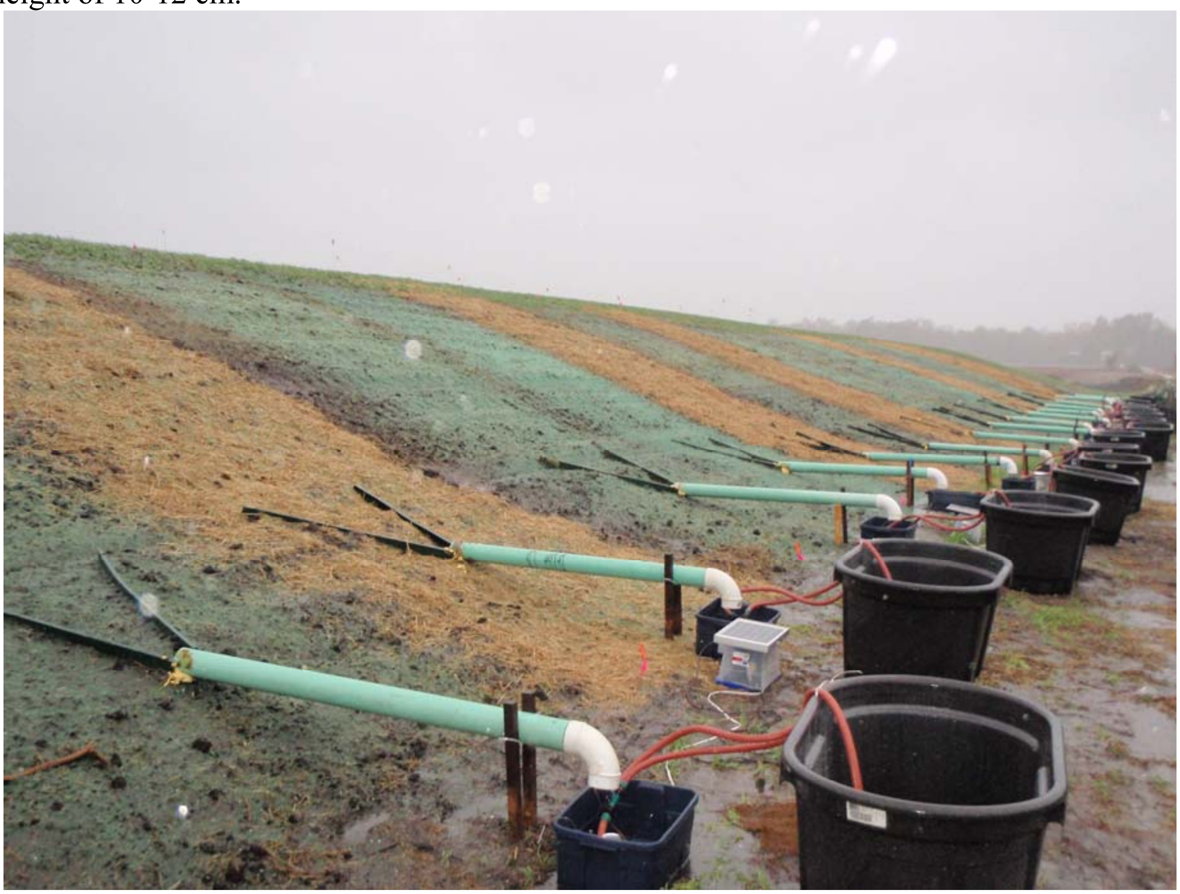

Figure 1. Runoff collection setup at site 1. Two 1.2 m pieces of edging used to direct water flow into a 10.2 cm diameter pipe, which then flowed into a 38 L container and pumped (split flow) into a larger 378.5 L container.

Figure 2. Site 2, West Jefferson, NC.

Figure 3: Site 3, Garner, NC.

Figure 4: Site 4, Apex, NC.

Figure 5: Straw cover and excessively applied tackifier at Site 5, Holly Springs, NC.

Plot Setup

Sites were active highway construction projects selected with the assistance of NC DOT staff throughout the state (Table 1). All sites were prepared by the contractors working on each project. Slopes were graded to a 2:1 slope and tracked by a bulldozer. The areas 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 2). Wheat straw was applied by hand or with a straw blower (site 4, Figure 9) and sprayed with tackifier according to NC DOT guidelines, one day prior to installation. At sites 4 and 5, the previously applied 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 1, 2, 4 and 5 were divided into 20 plots (3 m wide x 9 m long). Due to site restrictions, the area at site 3 was divided into 20 shorter plots (3 m wide x 6 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 five 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); 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 three sites (Table 3). Treatments were selected based on the results of tests of hydromulch performance test in a previous study (Whitley, 2011). Several of the paper-based hydromulches tested were eliminated as potential products due to poor coverage and grass germination in that study.

Even though the nominal straw application recommended rate was 1-2 ton/acre (2,240 – 4,480 kg ha^{-1}), we noticed that the straw cover was lower on the third site (Garner, NC) compared to the other sites (Figure), providing less erosion protection. On site 5, after the straw was applied by hand, tackifier was excessively applied on straw plots (Figure 6). 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 previously indicated. 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 (liters per second) 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.

Table 1. Location, period of assessment, hydromulch materials tested, and runoff/storm events for each test site. A sixth site was fully set up in Asheboro between the Kinston and West Jefferson site test periods but a heavy rain (>6") caused the slope to fail.

Location (Region)	Assessment Period	Hydromulches Evaluated	Runoff/Storm Events
1. Kinston (Coastal Plain)	November 2009 – January 2010	WCM, WFM, BFM	5/5
2. West Jefferson (Mountain)	September – November 2010	BFM, FGM, SMM	8/10
3. Garner (Piedmont)	May - August 2011	BFM, FGM, SMM	8/10
4. Apex (Piedmont)	November 2011 – February 2012	WCM, WFM, FGM	8/11
5. Holly Springs (Piedmont)	June – August 2012	WCM, WCM, SMM	5/5

Table 2. North Carolina Department of Transportation seed, fertilizer, and lime specifications for eastern North Carolina.

Charlotte Area	Rate (kg ha-1)	Raleigh Area	Rate (kg ha-1)
Kentucky Bluegrass	22	Tall Fescue	56
Hard Fescue	84	Centipede	12
Rye Grain	28	Hulled Bermudagrass	28
10-20-20 Fertilizer	560	10-20-20 Fertilizer	560
Limestone	4479	Limestone	4479

Table 3. Summary of treatments at each site.

	Straw	Straw + PAM	FGM	SMM	BFM	WFM	WCB
Site 1	x	x	-	-	x	x	x
Site 2	x	x	x	x	x	-	-
Site 3	x	x	x	x	x	-	-
Site 4	x	x	x	-	-	x	x
Site 5	x	x	-	x	-	x	x

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

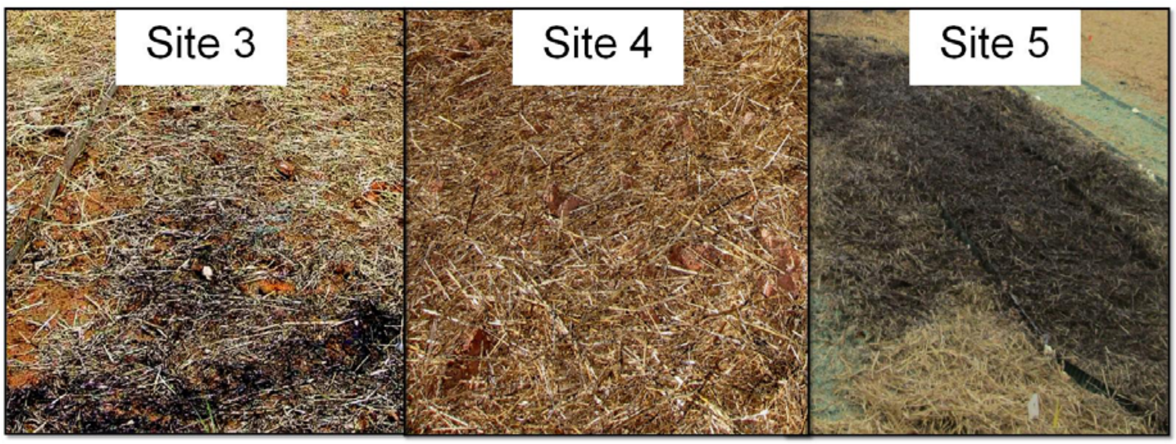

Figure 6: Straw cover at site 3, 4, and 5, Garner, NC.

Bulk Density and Soil Texture

At all 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 (Figure 7). On sites 1 and 2 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 was deposited into the larger tanks and mixed prior to collecting samples for analysis. On sites 3-5, 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 were calibrated for volume based on water depth. 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.

The amount of runoff was then corrected for the amount of water captured from the rain. For sites 1 and 2, 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 3-5 rain gauges were installed on the site to measure rainfall.

Turbidity was measured using an ANALITE NEP-160 portable turbidity meter (Figure 9). 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 10). Total sediment delivery was calculated by multiplying the runoff volume by the TSS concentration.


Figure 7: Example of plot set up (site 3).


Figure 8: Captured runoff.

Figure 9: ANALITE NEP-160 portable turbidity meter.

Figure 10: Vacuum filter device – TSS.

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 x 20 cm. Vegetation was clipped from randomly selected 20 x 20 cm squares (Figure 11). 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°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 69 days after seeding on January 11, 2010; site 2 was determined 60 days after seeding, on November 2, 2010, for site 3 80 days after seeding on July 29, 2011, for site 4 165 days after seeding on April 30, 2012 and for the site 5 one 55 days after seeding on August 15, 2012.

Vegetative cover on sites 1, 2 and 4 were 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 sites 3 and 5, photos were taken and vegetation analysis was done using geographic information systems software as follows. 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. 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 greater cover than was actually present.

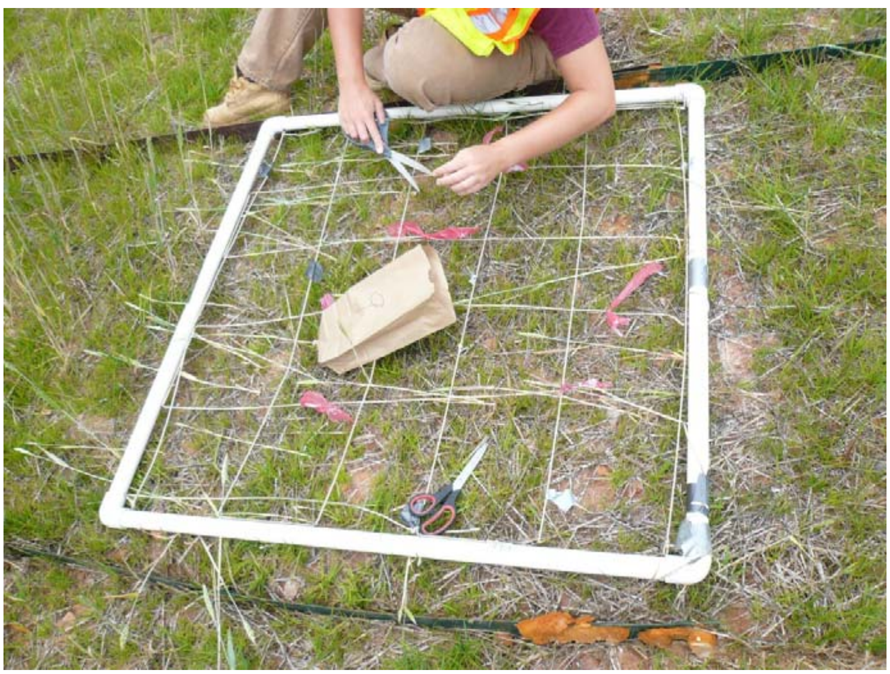

Figure 11: Biomass sampling

Nutrient Loss

Nutrient analyses were performed on runoff samples from site 3-5 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). The methods were as follows:
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 3 we excluded data from one FGM plot for storm 5. The 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. It is possible that there was contamination from wildlife such as a bird perched on the edge of the tub.

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.

RESULTS AND DISCUSSION

Runoff Volume

Sites 1 and 2 had no differences in runoff volume among all treatments (Table 4). Site 1 had a very sandy texture and apparently had high infiltration rates, since even during a large event (2.5”) very little runoff occurred. The rainfall pattern at Site 2 was relatively light and evenly distributed, so most of the rain was absorbed by the dry soil. Site 3 was unusual in our study in that the FGM had significantly less runoff than the two straw treatments, and the SMM had significantly less than the straw alone. We believe this was because of the relatively poor straw application which left too much bare soil exposed (Figure 6). At Sites 4 and 5 one or more hydromulches had significantly greater runoff than the straw mulch.

Table 4. Averaged mean runoff volumes for all five sites. Means with same letter are not significantly different within each site at (α = 0.05) using LSD test.

Treatment	Site 1, Kinston	Site 2, West Jefferson	Site 3, Garner	Site 4, Apex	Site 5, Holly Springs
			Runoff volumes (% of precipitation)		
Straw	12a	1.5a	23.6a	3.1c	12.9b
Straw+PAM	10a	0.9a	18.8ab	3.5bc	15.6ab
SMM	N/A	1.1a	15.3bc	N/A	20.2ab
BFM	14a	1.3a	16.6ab	N/A	N/A
FGM	N/A	0.9a	11.1c	7.9a	N/A
WFM	10a	N/A	N/A	9.0a	23.4ab
WCB	10a	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.

Turbidity

Because of the minimal runoff from Site 1 due to the sandy soil and low rainfall amounts at Site 2, the turbidity levels were exceptionally low at these sites (Table 5), and no differences were found among mulches. At Site 3, the FGM hydromulch had significantly lower turbidity compared to all other mulch treatments when averaged over all storm events. For individual events, the lowest turbidity recorded (7.9 NTU) was from the straw+PAM treatment for the second event. The poor straw cover on this site likely contributed to the higher turbidity from both straw treatments, as was demonstrated in our recent study (Whitley, 2011).

Runoff turbidity at Site 4 was significantly lower for the straw alone treatment compared to all three hydromulches tested there. Among the hydromulches, the FGM had significantly lower turbidity compared to the WCB. The lowest overall average turbidity was in runoff from the straw+PAM treatment. The addition of PAM to straw significantly reduced turbidity for 3 of the 8 runoff events. For Site 5, straw+PAM significantly reduced average turbidity compared to WFM and WCM, but no differences were found between it and either straw or SMM. This was the only site where the addition of PAM to straw significantly reduced turbidity for the first event, which is when differences would be most likely. There was a light, non-runoff producing rain approximately 5 days before the first runoff event, which may have dissolved and "activated" the granular PAM. Runoff during the last two of the five events at this site caused damage to the diversion barriers, which had not occurred at any other site. The 4th event was several days of rain which followed immediately after the 3rd event, in which rain occurred on each of 3 consecutive days. The 5th event was 2.5" over two days only three days after the 4th event. In July there were 10 days of rain, often on consecutive days.

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

Treatment	Site 1, Kinston	Site 2, West Jefferson	Site 3, Garner	Site 4, Apex	Site 5, Holly Springs
			Turbidity (NTU)		
Straw	40a	43a	1,247a	450c	410ab
Straw+PAM	23a	42a	1,122a	265d	365b
SMM	N/A	47a	777a	N/A	463ab
BFM	47a	55a	888a	N/A	N/A
FGM	N/A	50a	389b	592b	N/A
WFM	44a	N/A	N/A	938ab	1,765a
WCB	52a	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.

Total Suspended Solids

As with runoff volume and turbidity, neither Site 1 nor 2 had significant differences in TSS among the mulch treatments. At Site 3 the FGM hydromulch plots had the lowest TSS, significantly lower than straw, straw+PAM, and BFM, but not SMM. The high values in the straw treatments reflect the low straw application rate at this site. At Site 4, the straw+PAM treatment had significantly lower TSS than all three hydromulches tested at that site, but not compared to straw alone. Both straw treatments and SMM had significantly lower TSS than WCB at Site 5, with the WFM in between. The values from both WFM and WCB were about 4X higher than the straw+PAM treatment. TSS values for all sites are given in Table 6.

Table 6. Averaged mean TSS (mg L-1) for all five sites. Means with same letter are not significantly different within each site (α = 0.05) using LSD test.

Treatment	**Site 1, Kinston**	**Site 2, West Jefferson**	**Site 3, Garner**	**Site 4, Apex**	**Site 5, Holly Springs**
			Total suspended sediment (mg L^{-1})		
Straw	142a	355a	3,034a	801ab	1,520b
Straw+PAM	148a	225a	1,812a	373b	1,104b
SMM	N/A	346a	1,579ab	N/A	1,670b
BFM	135a	319a	2,297a	N/A	N/A
FGM	N/A	382a	655b	1,113a	N/A
WFM	178a	N/A	N/A	1,722a	4,127ab
WCB	202a	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.

Total Sediment Loss

The erosion rate was measured by calculating the total sediment loss (TSL), or a simple multiplication of the volume times the TSS. No differences in TSL were evident in the first two sites, as would be expected from the previously discussed results (Table 7). At Site 3, the SMM and FGM had significantly lower TSL than the straw alone, and FGM had significantly lower TSL than all but the SMM. FGM erosion was <10% of the straw alone losses, and the addition of PAM reduced erosion by 2/3 for the straw treatment. Again, poor soil cover due to low straw application rates resulted in high erosion rates. Evidence for this is a comparison to the erosion rates for the straw treatments at Sites 4 and 5, which about 100 fold lower. At Site 4, straw+PAM had significantly lower TSL compared to all three hydromulches tested, and straw alone had lower TSL than WFM. At Site 5, both straw treatments and SMM had significantly lower TSL than WCB, with WFM in between. There were no differences among straw, straw+PAM, or SMM.

Table 7. Averaged mean TSL (kg ha-1) for all five sites. Means with same letter are not significantly different within each site (α = 0.05) using LSD test.

Treatment	Site 1, Kinston	Site 2, West Jefferson	Site 3, Garner	Site 4, Apex	Site 5, Holly Springs
			Total sediment loss (kg ha^{-1})		
Straw	7.8a	13a	3,685a	51bc	36b
Straw+PAM	6.6a	8a	1,261ab	29c	29b
SMM	N/A	11a	959bc	N/A	35b
BFM	8.9a	12a	1,930ab	N/A	N/A
FGM	N/A	14a	333c	164ab	N/A
WFM	7.4a	N/A	N/A	237a	120ab
WCB	10.5a	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.

Vegetation Establishment

Vegetation establishment was estimated using both biomass production and estimated area coverage. Biomass was used to estimate overall vigor of the grass, while area coverage measured how well distributed the grass was for preventing erosion. Both measurements were clearly influenced by the time of year in which the stands were being established. Sites 1 and 2, both monitored late in the year, had relatively low biomass production but there were no differences among the mulch treatments (Table 8). Although the straw mulch produced somewhat higher grass cover compared to the hydromulches, the differences were not significant (Table 9). At Site 3, straw alone produced higher biomass compared to FGM, but there were no other significant differences among the five mulch treatments. Biomass production was 2-3 times higher than Sites 1 and 2 most likely due to the warm season conditions. No differences were found for grass cover at this site.

At Site 4, the straw alone mulch produced significantly higher biomass compared to the FGM and WCB hydromulches, and the straw+PAM treatment resulted in significantly greater biomass compared to FGM. Both straw treatments had significantly higher grass cover than all three hydromulches, which were not different between the three. Overall grass growth was again lower due to the November planting date. In spite of higher erosion rates, grass growth was greater on the hydromulch plots at Site 5 compared to the straw plots. Biomass production was significantly higher for both WFM and WCB compared to straw+PAM, and all three hydromulches had greater grass cover than both straw treatments. It is likely that the over-application of tackifier within the straw plots resulted in an inhibition of grass growth (Figure 12). We observed that in adjacent areas with "normal" tackifier applications had much better grass growth than in the plots.

Except for the last site where too much tackifier was applied, the straw mulch treatment usually resulted in better grass establishment. To help explain this effect, we conducted several experiments in the greenhouse (Appendix). In these tests, tall fescue was found to be inhibited by BFM but not FGM, while centipede and Bermuda grass were either not adversely affected or had improved growth compared to straw. However, when subjected to intervals of water stress (3 day watering cycle), grass growth was inhibited in the hydromulch treatments. To explore this further, pots with straw or hydromulch cover were allowed to dry after watering. The soil in the pots reached permanent wilting point on day 4 for bare soil, day 5 for FGM, and day 6 for straw. This suggests that hydromulch may allow soil to dry more quickly than straw and possibly inhibit growth through mechanical inhibition as it is drying between storm events.

Table 8. Averaged above biomass mean for all five sites. Means with same letter are not significantly different within each site ($\alpha = 0.05$) using LSD test.

Treatment	Site 1, Kinston	Site 2, West Jefferson	Site 3, Garner	Site 4, Apex	Site 5, Holly Springs
			Biomass (kg ha^{-1})		
Straw	315a	429a	1,308a	472a	1,184ab
Straw+PAM	241a	454a	1,097ab	309ab	1,047b
SMM	N/A	314a	1,018ab	N/A	2,155ab
BFM	226a	364a	1,110ab	N/A	N/A
FGM	N/A	313a	875b	137c	N/A
WFM	310a	N/A	N/A	257ab	2,177a
WCB	322a	N/A	N/A	192bc	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 9. Averaged cover percentage mean for all four sites. Means with same letter are not significantly different within each site ($\alpha = 0.05$) using LSD test.

Treatment	Site 1, Kinston	Site 2, West Jefferson	Site 3, Garner	Site 4, Apex	Site 5, Holly Springs
			Cover (%)		
Straw	68a	49a	72a	56a	75b
Straw+PAM	66a	56a	68a	54a	67b
SMM	N/A	32a	65a	N/A	93a
BFM	53a	36a	70a	N/A	N/A
FGM	N/A	37a	59a	28b	N/A
WFM	55a	N/A	N/A	34b	94a
WCB	56a	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.

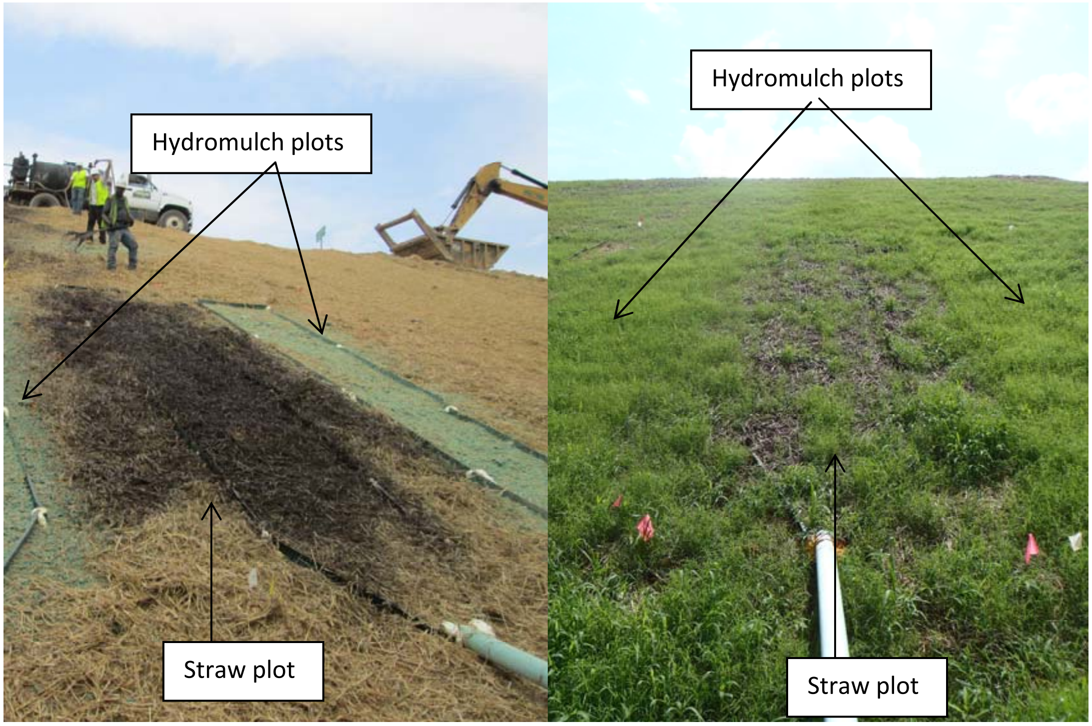

Figure 12: Difference between straw plot and hydromulch plots at the time of setup and when grass was established at Site 5.

Nutrients

The amount of N and P in runoff was determined for the first five storms at sites 3, 4, and 5. The straw cover treatments tended to have higher losses at Site 3, with almost 12% of the fertilizer N lost in runoff. At Sites 4 and 5, however, the losses were much lower and all mulch treatments tended to be similar. As has been discussed previously, the low straw application rate at Site 3 was likely the reason for the higher losses from those plots.

Table 10. Percentage of N and P fertilizer input that was lost due to runoff at site 3, 4 and 5 due to runoff.

Treatment	% N lost	% P lost
Site 3, 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 4, 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 5, 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.

Recommendations

The purpose of this project was to objectively determine if hydromulches of a wide variety of compositions had advantages over the standard straw mulch for erosion control and vegetation establishment. There have been a number of studies suggesting excellent erosion control, but these have typically been conducted in a rainfall simulator and often compared to a bare soil plot.

For erosion control, we did not find any clear, consistent advantage of hydromulch over straw mulch during the course of this study. The higher performance hydromulches (BFM, SMM, FGM) also did not consistently perform better than the lower cost hydromulches (WFM, WCM).

For vegetation establishment, we also found no advantage over the standard straw mulch application. The only time hydromulches improved grass growth compared to straw was when the tackifier was over-applied to the straw. There was some evidence of early grass growth inhibition by the hydromulches, possibly due to difficulties for the seedlings in penetrating the fiber layer during dry periods, or increased soil moisture losses.

We did not evaluate the other potential advantages or disadvantages of using hydromulch in place of straw. For instance, hydromulch may be more resistant to wind erosion and could be applied in areas prone to high winds or where close traffic may create wind gusts. Straw would also not be appropriate on steeper slopes than those tested (2:1). The need for water and loading and mixing is a disadvantage for hydromulch, especially in more remote areas. We also did not test the possible "one pass" approach to hydroseeding, in which seed, lime, fertilizer, and mulch are all mixed in the hydroseeder tank and applied together.

An alternative tackifier to asphalt emulsion should be found in order to make the straw mulch more environmentally attractive. The current alternative, using a low rate of hydromulch, has not been tested systematically and may be relatively ineffective. A wide variety of natural (e.g. guar) and synthetic materials (e.g. polyacrylamide) are sold as tackfiers, but their ability to hold straw together during wind and/or rain events has not been tested to our knowledge.

One of the major factors in the establishment of vegetation is soil moisture, as demonstrated in previous studies (e.g. Babcock and McLaughlin, 2011). Given the cost of seeding and mulching, approximately $2,000/acre, temporary irrigation using water trucks or hydroseeders might be worth considering. The current cost to rent a 4,000 gallon water truck is around $600/day, plus an estimated $100/day for a driver. The 4,000 gallons would provide 0.14" of irrigation per acre, which would be sufficient to maintain sufficient moisture to initiate and maintain grass growth during dry periods. It is likely that a truck and driver could irrigate 10-20 acres per day, which would likely cover most of the area being seeded at one time on a large project. At a 10-20 acre/day pace, this comes out to $35-70/acre to irrigate during prolonged dry periods, or this might be done several times during the first week to initiate germination and rooting. Fuel and water costs would add to this estimate, but this range provides a "ballpark" to use to determine the value of such a practice relative to current seed/mulch costs. A hydroseeder could also be used, but they typically have <2,000 gallon capacity and would therefore require more trips to cover the same area. If a water truck or hydroseeder was owned and present on the project, the costs would presumably be reduced.

Implementation and Technology Transfer Plan

1. This study determined that there is no clear advantage of using hydromulches over straw for either erosion prevention or grass establishment.
2. The Roadside Environmental Unit may want to establish criteria for areas where hydromulching has other advantages over straw, such a where straw would be susceptible to wind erosion, areas where asphalt emulsion tackifier would be unacceptable (e.g. adjacent to waterways), or on steep slopes.
3. Staff and contractors should be trained to properly evaluate and adjust the application of straw and tackifier to achieve successful erosion prevention and grass growth.
4. There should be an effort to find an environmentally sound tackifier for straw.

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Appendix

The following was excerpted from Chapter 3 of Gina Lee's thesis. These experiments were performed as follow-up to field experiments to help explain the results, primarily to test whether hydromulches have an adverse effect on grass germination and growth. It is included in this report as supplemental information.

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). 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

Tall Fescue

The vegetative cover at 18 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 A1). 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 A2). 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 A1). This material has a different mixture of proprietary components 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 A2). 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 A3.

Centipedegrass and Bermudagrass

Change in cover percentage over time for centipedegrass and bermudagras are given in Figures A4 and A5. 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) Θ=Vw/Vs , sample calculation: Θ=Vw/Vs= 214.45 cm^3/800cm^3= 0.263 $cm^3 cm^{-3}$, 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 (Θ=w* ρ_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^{o}C 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 A6). 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 A7). 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 A8). 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 A9). 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 A10), 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 A1. 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 A2. Above ground biomass and cover percentages for bonded fiber matrix (BFM) at different rates and straw cover for three different types 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 A3. 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 ($\alpha = 0.05$).

	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 A4. Surface crust measured. Means within a treatment with the same letter are not significantly different within row ($\alpha = 0.05$).

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.

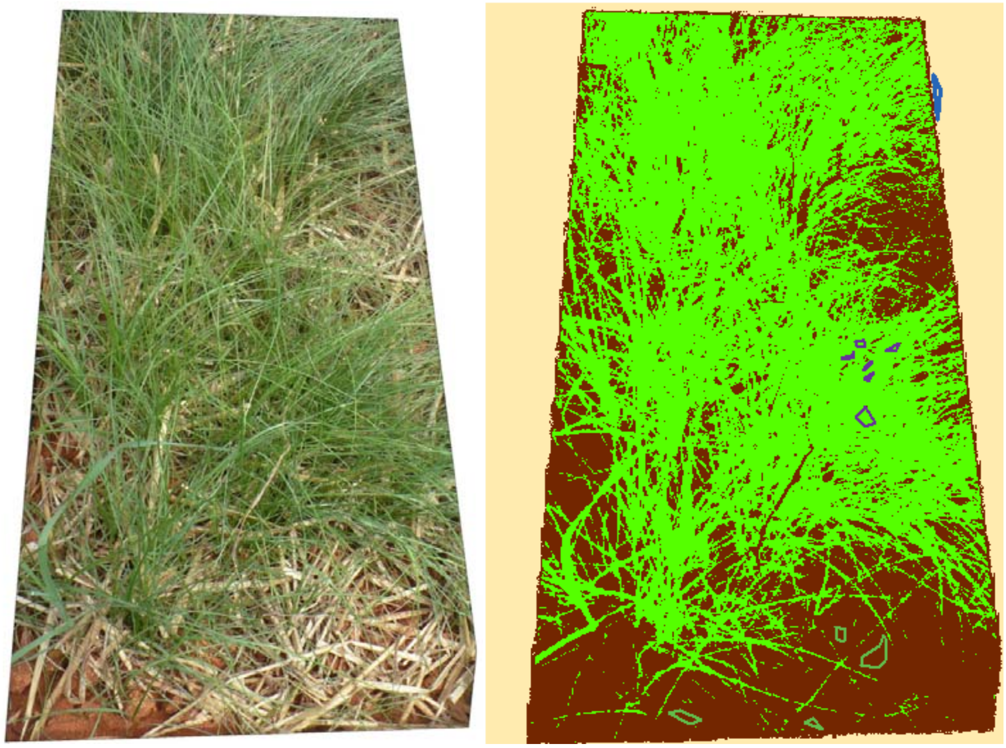


Figure A1: GIS photo used to estimate percent vegetative cover.

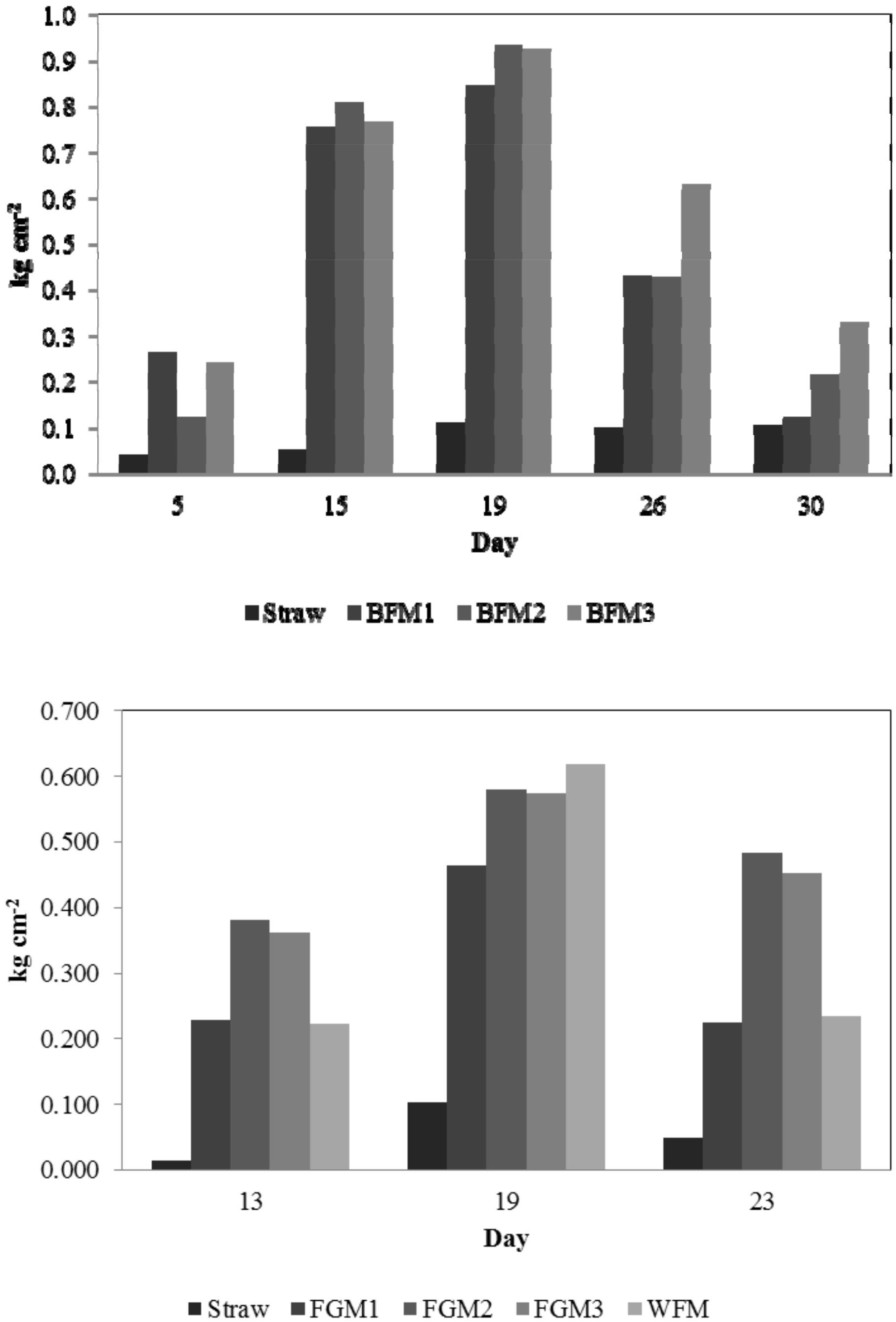
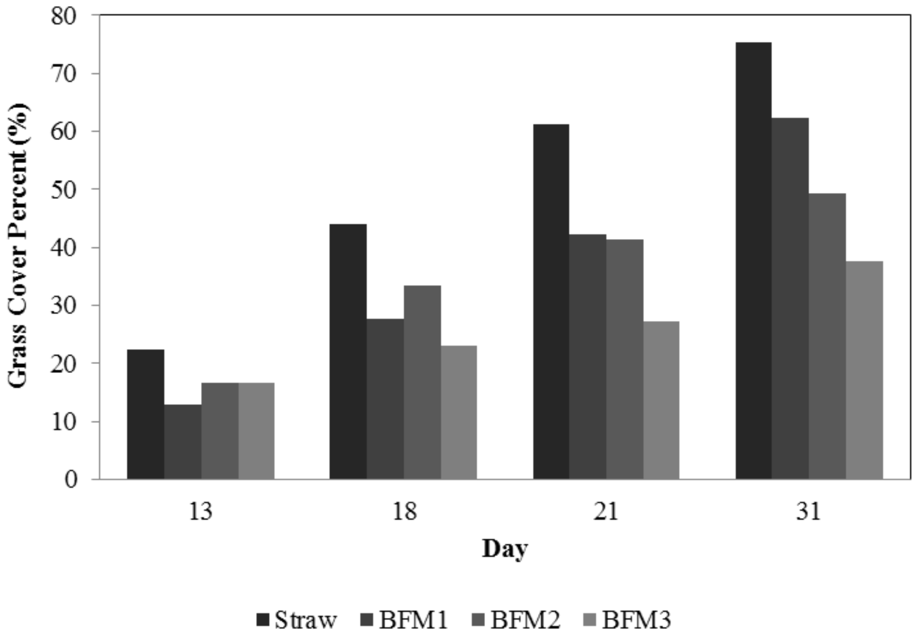


Figure A2: Crust strength under different covers (straw, BFM, FGM, and WFM). BFM=bonded fiber matrix. FGM=flexible growth media. WFM=wood fiber mulch. Application rates: 1=1,120 kg ha^{-1}; 2=3,360 kg ha^{-1}; 3=5,040 kg ha^{-1}.



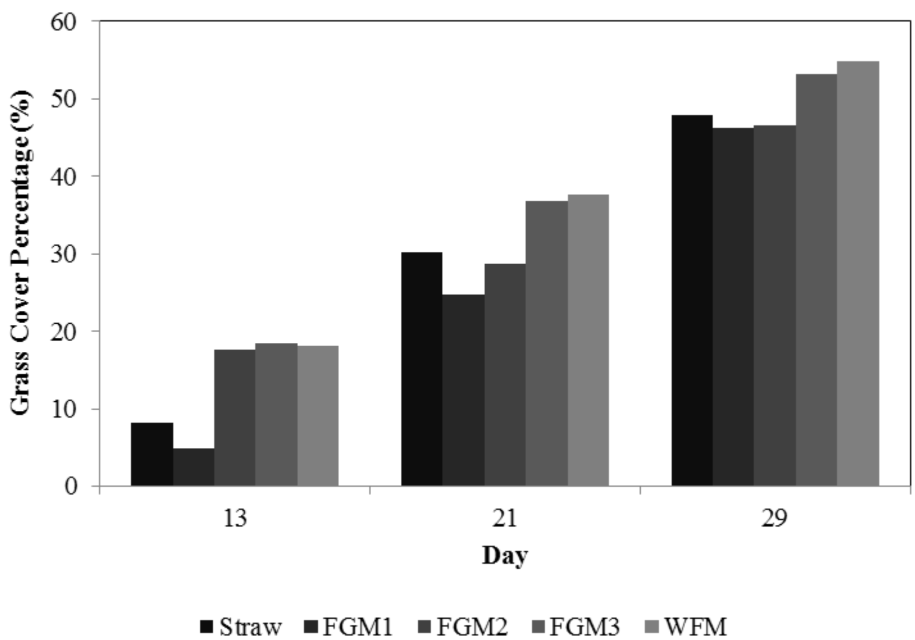
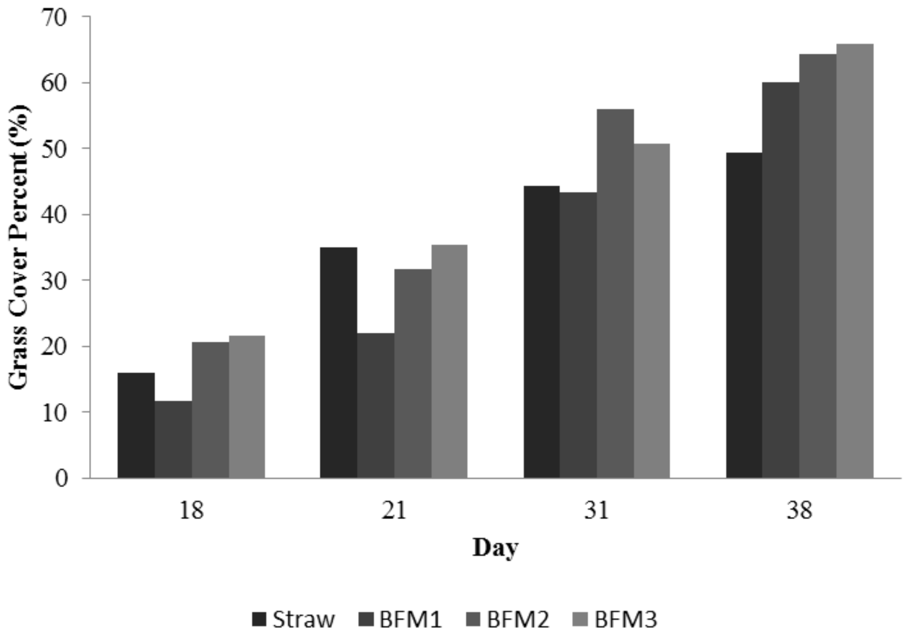


Figure A3: Tall fescue cover percent under different covers (straw, BFM, FGM, and WFM) over time. BFM=bonded fiber matrix. FGM=flexible growth media. WFM=wood fiber mulch. Application rates: 1=1,120 kg ha^{-1}; 2=3,360 kg ha^{-1}; 3=5,040 kg ha^{-1}.



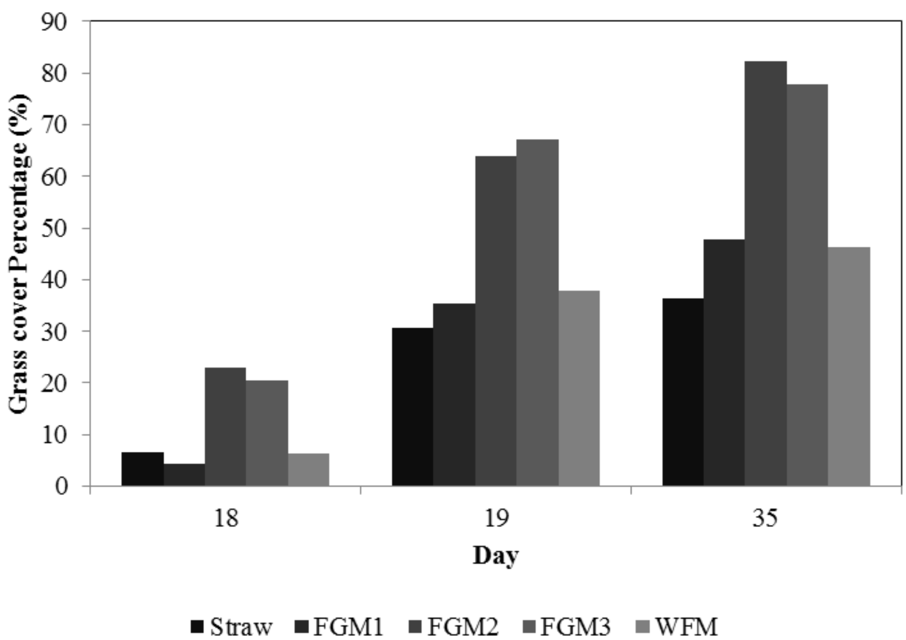


Figure A4: Centipedegrass cover percent under different covers (straw, BFM, FGM, and WFM) over time. BFM=bonded fiber matrix. FGM=flexible growth media. WFM=wood fiber mulch. Application rates: 1=1,120 kg ha^{-1}; 2=3,360 kg ha^{-1}; 3=5,040 kg ha^{-1}.

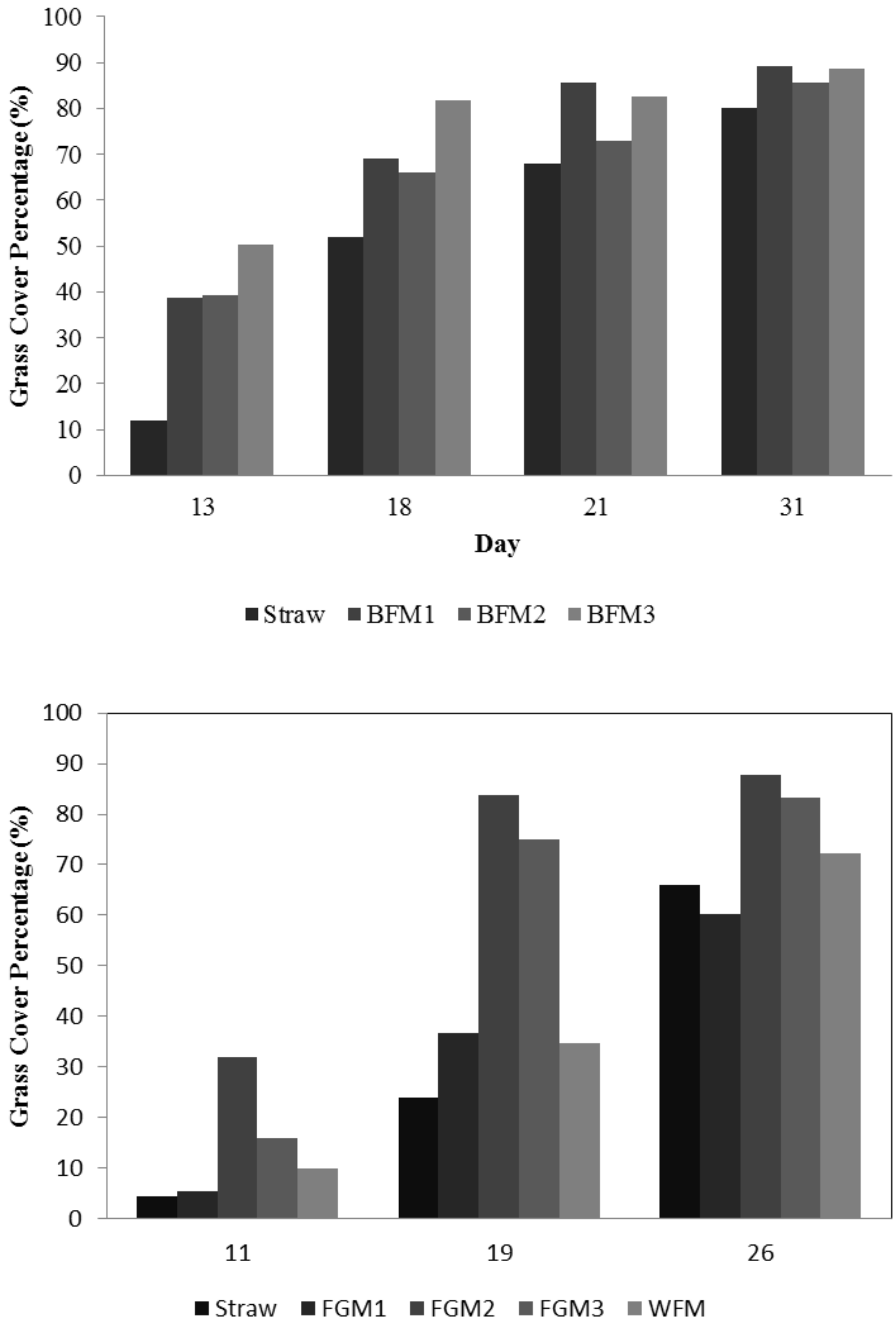


Figure A5: Bermudagrass cover percent under different covers (straw, BFM, FGM, and WFM) over time. BFM=bonded fiber matrix. FGM=flexible growth media. WFM=wood fiber mulch. Application rates: 1=1,120 kg ha^{-1}; 2=3,360 kg ha^{-1}; 3=5,040 kg ha^{-1}.

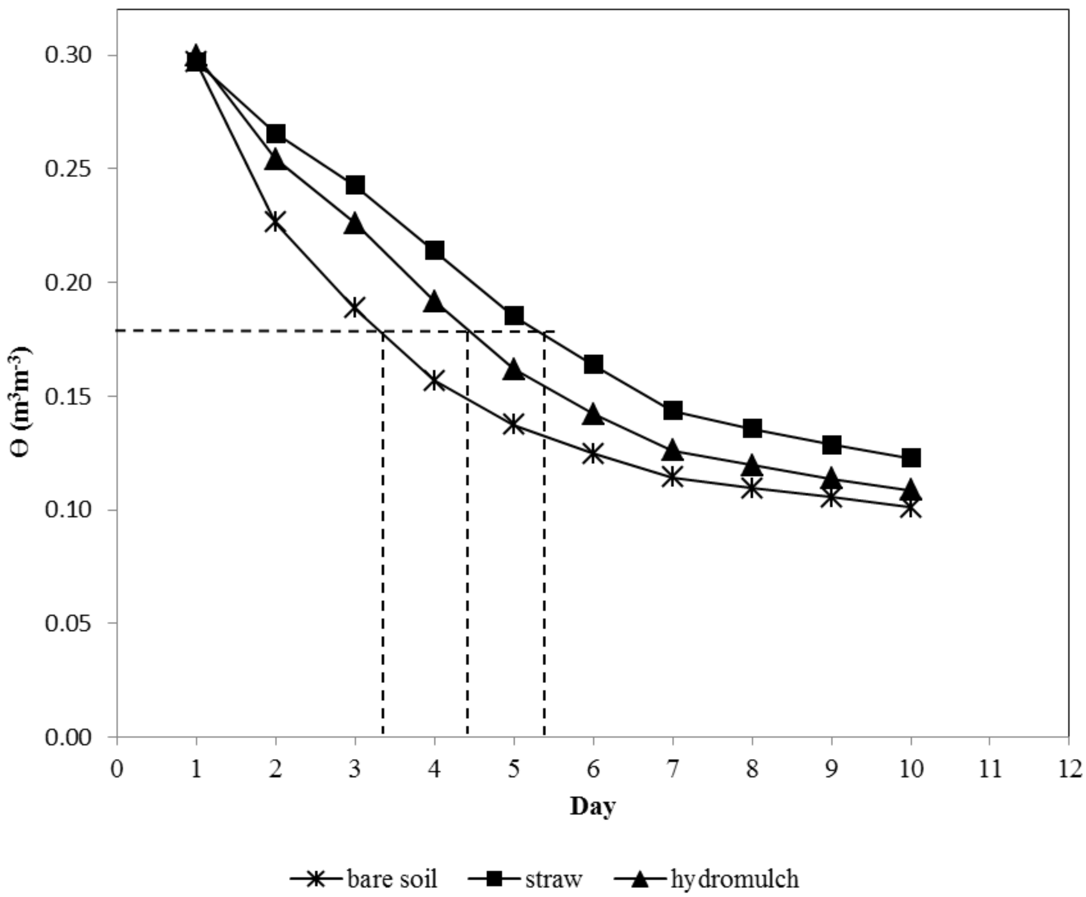


Figure A6: Volumetric water content for different ground covers: bare soil, straw mulch and hydromuulch (flexible growth media). Wilting point was 0.178 m m^{-3}= presented with dashed line.

Figure A7: Dead grass on straw cover (cover was removed for taking photo) when watered on a 10 day interval.

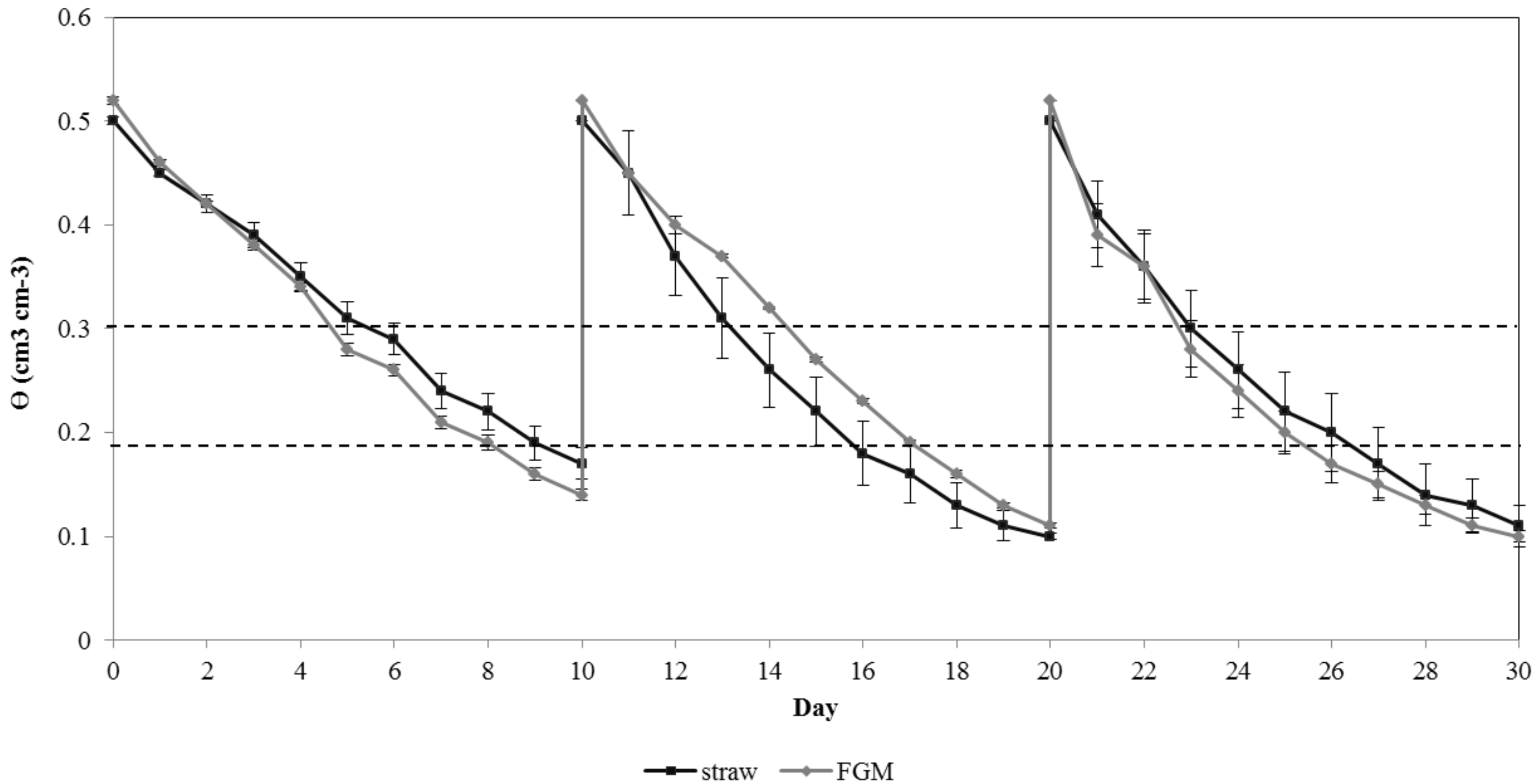


Figure A8: Volumetric water content of soil in pots for the ten-day watering interval for straw or FGM over 30 days in green house. FGM=flexible growth media.

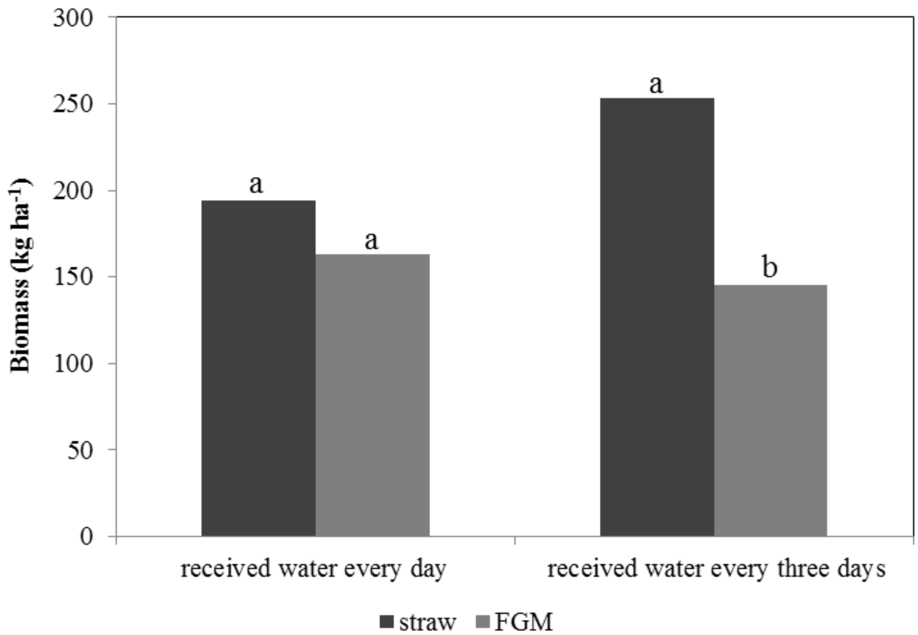


Figure A9: Above ground biomass for the one- and three-day watering intervals for the straw and FGM cover. FGM=flexible growth media. Means with same letter are not significantly different within each treatment (α = 0.05) using LSD test.

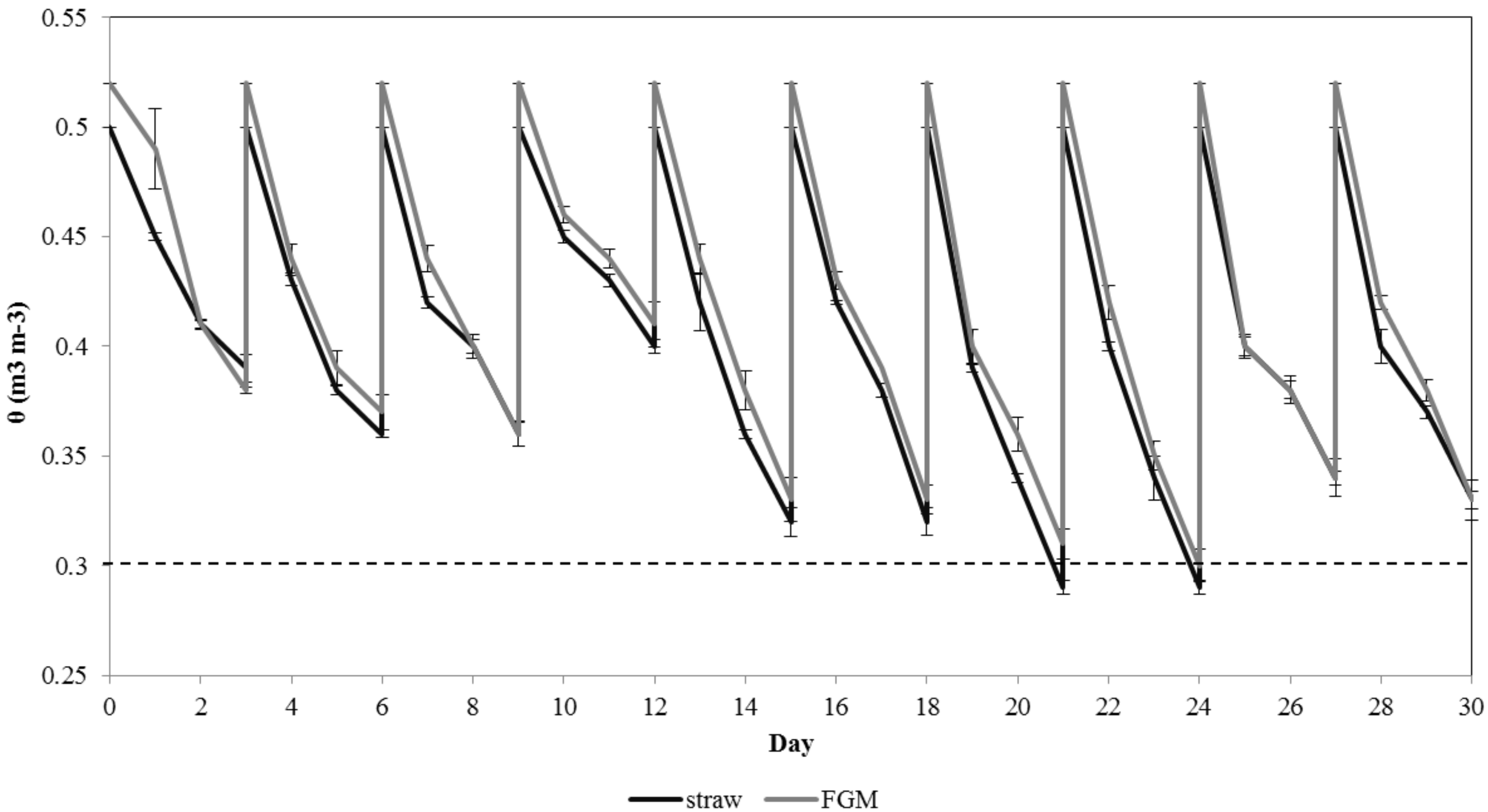


Figure A10: Volumetric water content of soil in pots for the three-day watering interval for straw or FGM over 30 days in greenhouse. FGM=flexible growth media.


Figure A11: Example of plot failure at planned site 2 (Asheboro, N.C.). The site was abandoned after this first event.