Techniques for Establishing Vegetation for Erosion Control on Disturbed Slopes in Alabama

by

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Abstract

Soil erosion is a serious issue in the revegetation of disturbed slopes that occurs during highway and other construction. Although slope disturbance from highway construction is widespread, there is little information about proper fertilization or seeding methods for revegetation of those disturbed slopes. The study objectives were to evaluate: 1) the effect of incorporating lime and fertilizer on establishment of bermudagrass, 2) differences in bermudagrass establishment related to temporary covers, including wheat straw, erosion control blankets, and hydromulch, and 3) effects of cover treatments including polyacrylamide (PAM) on runoff volume and quality. Twenty-one (3m×8m) plots were used to compare six cover treatments to seeded no- cover control plots. Treatments used in the study were: 1NC – seeded no-cover; 1ECB - erosion control blanket; 1GM and 2GM - hydromulch with and without pre-incorporation of fertilizer; 1GMP and 2GMP – hydromulch plus PAM with and without pre-incorporation of fertilizer; and 1WS - wheat straw. At the end of the 13-month study, erosion control blanket had the highest runoff compared to the no-cover control but loose straw and hydromulch had the lowest runoff relative to the no cover control.

Observed average percent bermudagrass cover ranking at approximately 60 days after planting was (greatest to least cover): 1GM (66%), 2GMP (60%), 2GM (59%), 1GMP (49%), 1ECB (44%), 1WS (29%), and 1NC (20%). Adding polyacrylamide (PAM) to hydromulch did not significantly improve bermudagrass establishment. However, hydromulch treatments had more rapid bermudagrass establishment as compared to that measured in erosion control blanket, loose straw, or seeded control plots. When averaged over the first 90 days after planting, some differences in bermudagrass establishment became apparent. First, PAM application had no effect on bermudagrasss establishment. Second, within the hydromulch treatments, the incorporation of lime and fertilizer (versus surface application) did not affect bermudagrass establishment. Third, bermudagrass was established significantly quicker when a hydromulch was used as compared to an erosion control blanket, or loose straw. Filtered turbidity of runoff (relative to no cover control) indicated the following ranking (most effective to least effective): Loose straw, hydromulch, and erosion control blanket. The reduction in sediment loss from cover treatments compared to control plots ranged (most effective to least effective) from 22% to 98% for loose straw , 22% to 93% for hydromulch , 16% to 92% for erosion control blanket. Average annual sediment loss reductions compared to no cover control plots were 66% for loose straw, 58% for erosion control blanket, and 53% for hydromulch. Addition of PAM in the hydromulch treatment significantly reduced MTSS early in the year-long test in three of the first four storm events. Inclusion of PAM did not significantly reduce NTU at any sampling date. However, incorporation of lime and fertilizers into the soil before planting did not.

Addition of PAM to hydromulch treatments decreased the concentration of nitrate in runoff, but incorporating lime and fertilizer did not. Runoff from the no-cover control contained the highest phosphate the first 120 days after planting, followed by the erosion control blanket, hydromulch, and loose straw. However, these differences were not significantly different from each other. Incorporating lime and fertilizer or adding PAM did not significantly affect the concentration of phosphate in runoff.

Findings of this study emphasize the environmental importance of temporary covers on disturbed slopes during the first critical months of establishment, and indicate the need for

continued studies for more definite evaluation of each method under different soil growing conditions.

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I. INTRODUCTION

The impact of human activity on the landscape can deteriorate the environment by worsening soil erosion. The cost of environmental degradation and loss soil has been estimated at almost 44 billion dollars per year in the United States (Shepley et al., 2002). Dinel et al. (2000) revealed that since the beginning of civilization, cultivated areas, overgrazed pastures and deforestation have all caused soil erosion. Many catastrophic collapses have occurred, such as burial of whole cities and fields due to the accumulation and removal of sediment as gullies and sand dunes. Minimizing soil erosion requires an improvement in the way soil is used. As human populations have increased, so has soil erosion. Brady and Weil (1996) estimated that each year almost 4×10^9 tons of soil is lost directly as a consequence of agricultural and non-agricultural land activities in the United States. The worst scenario occurs when sediment is washed from disturbed areas and moves directly into a water body.

The United States Environmental Protection Agency (USEPA, 2000) states that the largest contributor to non-point source pollution in the United States is soil erosion from construction sites at a rate of 502,000 kg ha^{-1} yr^{-1} which can exceed twenty times that of agricultural losses (37,600 kg ha^{-1} yr^{-1}). Although US soil loss is of great concern, developing countries are even more prone to soil loss, as those countries focus on survival rather than resource conservation (Troeh et al., 2004). An accompanying risk to water quality from sediments following harvesting operations is the transport of attached nutrients. Further degradation of water quality resulting from turbid water can occur due to reduced light penetration into the water which decreases the ability of plants to fix energy (Grace, 2005).

Vegetation is the best protection against soil erosion, and is considered one of the best management programs to minimize soil loss from disturbed soil and steep slopes (Morgan and Rickson, 1995). Vegetative establishment is an important element for roadside and building construction sites, as it prevents erosion and maintains the integrity of the site. Successful vegetative establishment is obtained by a three-fold plan of choosing plants with rapid growth, properly selecting fertilizers, and preparing a quality seedbed. All these measures should follow regional specifications for vegetative cover management defined by authorities such as state departments of transportation (Tinsley et al., 2006).

The United States Environmental Protection Agency (USEPA) has determined that the highest hazard to the nation's water resource is contamination by sediment (Sojka et al., 2007). Sediment contamination decreases drainage capacity, increases risk of flooding, decreases diversity in aquatic population, clogs and damages industrial and commercial irrigation systems, and increases cost for wastewater treatments (Risse and Faucette, 2001). A number of amendments made to the Clean Water Act in 1987 make mandatory the control of storm water and sediment from constructions sites (USEPA, 2002). Foster et al. (1984) concluded that runoff and soil erosion were reduced by using surface applied organic amendments. Meyer (1985) stated that soil loss was almost stopped in mulched soils compared to unmulched soils. Lyle (1987) affirmed that mulch treatments performed better than hay and straw mats due to their ability to lessen soil movement generated by wind or water. Gorman et al. (2000b) stated that water infiltration was improved by using shredded bark, which dissipated raindrop energy and lessened soil surface crusting. Shredded barks also minimized overland flow and retain more water at the soil surface (Faucette et al., 2007). There has been only limited research conducted on the performance of mulch products, erosion control blankets, straw blankets, and the addition of a soil conditioner such as PAM for best managements practices (BMPs) for seeding.

Process of erosion

Soil can be eroded by water, wind, glaciers, animals, motor vehicles, and gravity. Soil erosion has been defined by the Soil and Water Conservation Society (2003) as the removal of clay, humus, rock and other particles via water, wind, and ice by gravity (Troeh et al., 2004). Biggelar et al. (2001) described three steps in the process of soil erosion by water: first, the separation of the fine component of soil from the soil mass, second is runoff with suspended solids, and third is accumulation in a new area. This accumulation process is more accurately described as sedimentation, apart from erosion. Soil erosion has a negative impact on uplands because of detachment and transport of soil from uphill slopes. Removed soil is deposited on lowlands and stream banks as sediment. Water induced erosion is categorized according to scale, with water induced erosion classed as sheet erosion, rill erosion, gully erosion, or stream bank erosion.

Sheet erosion is defined as the removal of a thin layer of soil from the soil surface by the impact of raindrops on soil particles (Walkers et al., 2007). Soil is transported down slope by moving water as sheet flow, and does not form channels or rills. Fields with significant sheet erosion are often abandoned after long periods of time due to resulting coarser textured soils with poor fertility (Grismer, 2007).

Rill erosion forms thin and shallow channels due to concentrated flow on the surface. Rill erosion is usually found in cultivated areas, and in soil without vegetative cover (Bradfort et al., 1987). Rills are typically small and can be eliminated by tillage. Also, they generally do not appear at the same place from year to year. Tillage can increase the severity of rill erosion. No till plus residue will decrease soil loss via rill erosion (US Environmental Protection Agency, 2004).

Ephemeral gullies are larger than rills. Unlike rills, they tend to reappear at the same places each year and are often located along the tillage marks between crop rows. Gully erosion is created by concentrated water flowing along a straight lined channel that deepens the ditch after every flow. Gully erosion occurs when the flow of water is concentrated, thus cutting v-shaped gullies. Gullies are large (1.5-5 m wide for a medium sized gully) and cannot be corrected by tillage. When a gully is covered by vegetation it is considered inactive. If no vegetation is present it is considered active (Troeh et al., 2004).

According to Bilbro and Fryream (1994) wind erosion is characterized by detachment, transportation, and deposition of soil particles. Wind erosion is separated into three distinct processes: suspension, saltation, and surface creep. Suspension is the process by which small soil particles (less than 0.05 mm diameter) are kept in the atmosphere and blown away as a congregate of dust or haze. Saltation describes the short downwind leaps of intermediate particles (0.05 to 0.5 mm) to a maximum of 1 cm height above the surface. Saltating particles detach other soil particles when hitting each other, which then increases the carrying capacity for fine soil particles. Surface creep results from the rolling of larger sized particles (greater than 1 mm) along the soil surface. Many factors affect the magnitude of soil loss from wind erosion including soil surface roughness, ground cover, soil type, wind speed, and plant shape (William et al., 2000).

Erosion control

The scale of soil erosion is determined by factors such as climate, geology, and soil biomass. Intensity and volume of rainfall, frequency of rainstorms, season, and wind are included as climatic factors. Soil structure, texture, slope gradient and direction are elements of soil geology. Type of vegetative cover, living organisms, and land use are characteristics of soil biomass. The rate of soil loss by erosion is related to soil management and land use. The mechanical detachment of soil particles by water is reduced when rainfall is intercepted by a vegetative cover (Wei et al., 2007).

Soil erosion by water can be controlled by minimizing runoff and by establishing a vegetative cover with the use of organic material. Foster et al. (1984) discovered that placing organic amendments on the soil surface decreased erosion, resulting in a significantly lower runoff flow than unmulched soil. Mulches had a higher performance than hay and straw mats due to improved soil contact, decreasing risk of wind or water erosion (Lyle, 1987). Addams et al. (1996) concluded that there was less than 2500 kg ha^{-1} of soil loss on mulched soil versus 50,700 kg ha^{-1} on uncovered soil from a 22 cm rainfall event. In other work, the soil surface was protected from crusting by shredded bark, which blocked and scattered the energy of the raindrops. Shredded bark also increased water infiltration and water holding capacity from overland runoff (Gorman et al., 2000).

In other work, synthetic blankets and mats did not always minimize the erosion underneath because of poor contact with uneven soil. Compost blankets filled soil irregularities, but wind more often blew them off the slopes in contrast to straw mulches (Meyer, 1972). Both crops and mulches help reduce soil erosion as they minimize the erosive impact of raindrops and reduce rainfall velocity. Crop residue also increases saturated hydraulic conductivity, which decreases runoff volume (Emmerich, 2003). Best Management Practices (BMPs) for erosion control include: 1) mulching to establish a plant cover, 2) permanent seeding on disturbed areas to establish a long-term vegetative cover, 3) improved soil stability via long-term vegetation, and 4) diversion of water from slopes, with transport to a stable outlet. Methods to achieve these BMPs can include grass swales, terraces, or shortened slopes (ASWCC, 2003a).

Short term BMPs for erosion control may include erosion control blankets or chemical stabilization using water-soluble anionic polyacrylamide (PAM) gels (ASWCC, 2003b). Furher et al. (2004) described how PAM reduced rill soil erosion in furrow irrigation and improved the water quality of the returned irrigation flow. The food mineral processing and municipal waste water treatment industries also use PAM. PAM increased soil infiltration, reducing soil erosion (Barvenik, 1994). Bologna et al. (1999) stated that anionic PAM is safe to use for the environment as a soil conditioner due to its chemical stability as a compound, in contrast to cation PAM.

Examples of Best Managements Practices (BMPs) Definitions from Storm Water Quality Handbooks (SWQH) (2003)

Hydromulching uses a mix of water and materials such as wood fiber, newsprint, and/or plant materials to provide temporary protection to the soil surface during seed establishment. Hydroseeding helps speed germination while reducing soil erosion, and is used as a substitute to sowing of dry seeds. It is especially useful on steep slopes or in other areas where planting equipment cannot easily reach. Hydromulching has some disadvantages, including the fact that the mulching equipment is bulky, requiring a ready supply of water to properly mix components.

Hydromulche mixtures typically include a soil stabilizer in a liquid slurry that is sprayed with a hydroseeder. The resulting temporary cover protects the soil surface by reducing raindrop impact. Hydromulch effects do not last the entire growing season, and require almost 24 hours of drying to be most efficient. Hydromulches solidify after application which decreases soil movement due to a binding effect. In addition, hydromulches promote seed growth by trapping moisture and increasing soil and seed stability.

Straw mulches

One of the most commonly used mulches is straw. A uniform layer of straw is applied to the soil surface and then crimped into the soil with a studded roller. Sometimes stabilizing emulsion is applied in combination with temporary or permanent seeding to boost vegetation growth. Use of straw mulch can increase the risk of unwanted weed seed growth, is time consuming and costly when applied by hand, and does not always work on sandy soils.

Erosion control blankets

Erosion control blankets or mats consist of two subgroups: 1) Biodegradable rolled erosion control blanket, and 2) non-biodegradable. Biodegradable mats include those made from jute, excelsior (curled wood fiber), straw blanket, wood fiber blanket, coconut fiber blanket, and straw coconut. Non-biodegradable erosion control blankets are made of polypropylene, polyethylene, nylon or other synthetic fibers.

Vegetated cover studies on disturbed slopes

Land is disturbed by construction and development of buildings, roads, or highways. These construction sites often occur on steep slopes, and when left without vegetative cover for extended periods are exposed to soil erosion until vegetation is established (Green et al., 2000). Green et al. (2000) underlined the high cost of soil erosion on construction sites and the subsequent risks of water pollution. Expansions of urban areas create construction sites with large areas of bare soil that are susceptible to water and wind erosion. The best solution to erosion is rapid vegetation establishment. Orts et al. (2007) stated that building sites with ineffective erosion control practices increase sediment on streets and neighboring developments, adding suspended solids to rivers and lakes.

Comparing soil loss from different treatments throughout a 21.3 cm storm event, the bare soil had higher soil loss (18 tn ha^{-1}) than soil covered with mulch (0.9 tn ha^{-1}) (Addams, 1996). Meyer et al. (1972) concluded that less than 5 kg ha^{-1} of soil loss occurred when soil was covered with wood mulches, in comparison to 90 kg ha^{-1} soil loss from bare soil on a 20% slope on a highway construction site. Compost blankets had a significant advantage over wood mulches in preventing erosion on hillslopes, because of their capacity to sustain vegetation (Faucette et al., 2007). Mulch treatments can be harmful to the growing vegetation due to their capacity to immobilize nitrogen (Meyer et al., 1972). Granbery et al., (2001) found that healthy plant growth was sustained by a gradual release of nutrients by compost (fine particles) characterized by an optimum carbon to nitrogen ratio less than 20:1 for plant uptake.

A requirement of 70% to 75% straw soil cover by the Georgia Soil and Water Conservation commission was disputed by Adams (1996) who found that 90% soil cover was needed for significant water infiltration. Faucette (2004) concluded that almost 100% soil surface cover was obtained when compost blankets were used properly. Soil loss from synthetic blanket was generated by rills that formed underneath, reducing surface contact with the uneven soil surface (Addams, 1996).

Faucette et al. (2007) found that compost or humus made primarily of small particles adsorbed rainfall quickly, which increased infiltration and reduced runoff. Large particles reduced raindrop energy, preventing soil removal and reducing sediment transportations in overland runoff. Treatments made primarily with small particles contained more fertilizer nutrients and also improved soil structure (Faucette et al., 2007).

Many researchers have focused on the establishment of a vegetative cover on cultivated fields, but only a few on areas such as roadsides. One of the scientists who did examine mulches for grass establishment on fill slopes found that the best yield of grass seedlings was on plots protected by an excelsior mat (Dudeck et al., 1970). Mingguo et al. (2007) studied the effect of vegetation on runoff-sediment yield relationships and found that the runoff-sediment yield relationship could not be decreased by only establishing a vegetative cover in channels. In other work, soil loss was significantly reduced by grass growth (Pan et al., 2006).

Use of Polyacrylamide (PAM) to reduce erosion on disturbed slopes

During World War II, soil conditioners such as PAM were applied to stabilize road and landing strips (Entry et al., 2002). As early as 1950, soil stabilizers were used in agriculture (Weeks and Colter, 1952). Application of PAM improved soil physical characteristics by maintaining maximum soil aggregation at a 30-40 cm tilled soil depth (Entry et al., 2002). Since the 1990s, many studies were conducted on PAM, a synthetic, organic, water polymer with the capacity of reducing soil erosion, runoff, improving water infiltration, and promoting vegetation establishment (Davidson et al., 2009).

Sediment reduction was observed by Malik et al. (1991) when PAM was applied via infiltrating water and was totally adsorbed by dry top soil. PAM was sold for the first time in

1995 in the United States, and by 1999, almost 400,000 ha of soil received PAM treatment (Entry et al., 2002).

Lentz et al. (1994) found that water soluble anionic PAM significantly reduced erosion and improved water infiltration when applied at a rate of 1-10 g m^{-3} in furrow irrigation in the 1990s. PAM added to a mulch reduced runoff and soil losses in furrow irrigation (Lentz and Bjorneberg, 2003).

PAM can be added in two different forms, as a dry granular material or as a solution spray. Used in one of these forms, PAM has a positive effect on water infiltration in silty loam and sandy clay (Davidson et al., 2009). Vacher et al. (2003) found that PAM performance is linked to soil calcium, clay content, PAM molecular weight, and charge density. PAM adsorption by soil particles depends on soil properties including: clay type, soil texture, organic matter content, and the type of ions in soil solution (Seybold, 1994). Application of PAM has many advantages such as control of surface sealing, reduction of runoff and soil erosion, and helping to decrease of non point source pollution (Green and Scott, 2001).

In clay soil, PAM acts as a binding agent of the soil particles through an ionic attraction to the clay soil (Davidson et al., 2009). Soil loss was reduced when a PAM plus gypsum mixture was applied to 30 to 45% slopes (Vacher et al., 2003). Trout and Ajwa (2001) concluded that PAM application without gypsum did not increase the rate of water infiltration in sandy loam soils. In fact, application of PAM can have a negative impact on water infiltration when used in sandy loam soils due to the sealing of soil pores (Ajwa and Trout, 2006).

Chemistry of PAM

A broader range of chemical compounds with different chain length and function are described as PAM. The PAM polymer is represented by the chemical formula: $CH_2CHCONH_2$ (Davidson et al., 2009). The polymers have an average molecular weight ranging between 12 and 15 mg mol^{-1}. PAM products are available as flocculants for use as a thickening agent, in sugar and fruit juices processing, paper manufacture, water and wastewater treatment, and mining (Entry et al., 2002).

Large anionic PAM molecules are often used to control erosion and protect the environment against pollution. Two kinds of PAM are commercialized for erosion control purposes: granular and the liquid forms. The liquid form of PAM is generally applied with sprinklers or sprayed on the soil surface (Entry et al., 2002).

Effect of PAM on erosion control

Clay particles of soil react with PAM polymers to form cationic bridges, with divalent Ca^{2+} and Mg^{2+} as the main link between the polymers and soil particles. Strong adsorption of PAM molecules was observed as a consequence of the small hydration radius of divalent cations in soil solution (Davidson et al., 2009). In clay soils, PAM has a greater impact on erosion control because those soils have a high cation exchange capacity (CEC) which results in a stabilized soil structure via flocculation (Davidson et al., 2009). Soil with high level of sodium (Na) inhibits PAM flocculation capacity due to the larger hydrated radius of sodium (Figure 1), resulting in dispersion instead of flocculation. Lentz and Sojka (1996) found that soils with high sodium adsorption ratios had reduced water infiltration when treated with PAM. However, the addition of gypsum as a calcium supplement to sodium-affected soil did reduced soil loss

(Davidson et al., 2009). Orts et al. (2001) stated that calcium electrolytes are essential for performance of anionic PAM in erosion control and increased infiltration. The existence of calcium's double charge combined with its smaller hydrated radius gives calcium the ability to facilitate flocculation by acting as a bridge between anionic PAM and calcium ions (Figure 1) (Entry et al., 2002).

PAM has some limitations when used for erosion control. First, the relatively high viscosity of the PAM solution can make it hard to dissolve in water prior to spraying. Moreover, due to the fact that PAM is degraded by sunlight and mechanical breakdown over time, a onetime application of PAM is not sufficient as a permanent erosion control measure (Wallace et al., 1986). According to Caulfield et al. (2002), chemical degradation of PAM can be caused by acidic hydrolysis, whereas mechanical degradation of PAM is due to a reduction in viscosity.

PAM effect on infiltration in furrow irrigation

Sojka et al. (1998) found that PAM applied to a cultivated furrow slowed the irrigation stream because PAM-treated furrows had a higher infiltration rate. Low infiltration rates in untreated furrows occurred as soil aggregates were destroyed by wetting, sediment detachment and transport to the furrow stream (Entry et al., 2002). Entry and Sojka (2003) found that application of PAM in furrow irrigation reduced nitrate and phosphorus concentrations by 85 and 90%, respectively, compared to control treatments. Due to the ability of PAM to reduce nutrient concentration and soil loss from agricultural lands, PAM was considered as a recommended solution for controlling erosion and non point source pollution (Canady and Flanagan, 2004). PAM has two opposite impacts on water infiltration, as it can prevent or reduce soil sealing, but can increase viscosity within soil pores (Bjoneberg et al., 2003). PAM has the capacity to improve aggregate stability in fine to medium textured soils, while in contrast PAM may reduce infiltration in coarse, sandy soils. This is more likely to occur when PAM final concentrations in soil are higher than 20 kg ha^{-1} (Sojka et al., 1998). Shainberg et al. (1990) concluded that PAM applied at a rate of 20 kg ha^{-1} reduced soil loss in many situations.

Environmental impact of PAM

Several studies have been conducted to evaluate the effect of PAM on the environment, including Barvenic (1994), Bologna et al. (1999), and Seybold (1994). Those researchers concluded that PAM has the capacity to reduce soil loss from disturbed slopes and to minimize non point source pollution. Waters et al. (1999) studied PAM in Australia and found a drop in sediment loss, runoff volume, nutrient concentration and pesticide quantity when compared to BMPs commonly used by farmers. For safety reasons, it is imperative to use PAM with less than 0.05% of the acrylamide monomer in the solution, because it is a neurotoxin suspected of causing cancer in terrestrial mammals (Barvenic, 1994).

PAM underperformance can be attributed to physical, chemical, mechanical, and biological degradation when applied to soil surfaces. Ultraviolet and sun exposure on surface soil accelerated PAM degradation by 10% per year when applied for erosion control purposes (Kornecki et al., 2004). Biological degradation occurs when PAM incurs a biological hydrolysis of its amide group. In wastewater treatment, PAM molecules liquefy in water and then adsorb nutrients or microorganisms (Entry et al., 2002).

Sojka (1998) found that PAM can be unsafe when skin is exposed for a prolonged time, and can irritate mucus membranes. Moreover, PAM is very slippery when wet. A dry absorbent should be used to clean and to remove PAM applied on roadways prior to any attempt to wash down with water (Sojka, 1998).

Application of PAM for construction sites

PAM is one of many options for short term erosion control by construction companies (Green and Scott, 1999). For vegetation establishment on disturbed slopes, conventional mulch application has some disadvantages, such as cost and underperformance if rills are already formed (Meyer et al., 1972). Chaudari and Flanagan (1998) found that on steep slopes, PAM decreased runoff by more than 30%, while reducing sediment yield by more than 50%. Application of PAM also lowered on and off-site pollution, minimized slope reshaping, and improved growth of vegetation. Reduction in soil loss was estimated at 60-97% within a period of one month between applications for a three year PAM study on a construction site (Roa-Espinoza et al., 2000).

The cost of PAM application on steep slopes and construction sites at a rate of 80 kg ha^{-1} for the first PAM application costs is cheaper than a straw mulch application (Flanagan and Chaudari, 1999). PAM applied at rates of 1 to 5 kg ha^{-1} at prices ranging from $4.50 to $12 per kilogram of active ingredient is economically viable (Sojka, 1998). Soupir et al. (2004) stated that higher rates of PAM application on construction sites are more effective than those applied in furrow irrigation. PAM application as dry powder at a rate of 20 kg ha^{-1} on a 5% slope, and at a rate of 6.7 kg ha^{-1}on bare soil did not reduce soil loss or runoff, but straw application alone did (Soupira et al., 2004).

McLaughlin et al. (2006) concluded that runoff turbidity was not significantly reduced when PAM was applied at a rate higher than 11 kg ha^{-1} on slopes ranging between 20 and 50%. A combination of straw mulch and seed had a 61% lower average runoff turbidity on comparable slopes. A reduction of soil loss up to 93% compared to bare soil was observed by Roa-Espinosa et al. (2000) on a 10% slope of dry soil treated with PAM at a rate of 22.5 kg ha^{-1} mixed with mulch. The PAM treatment significantly reduced soil loss and runoff volume when applied at a rate of 20 kg ha^{-1} on smooth slopes between 6% and 9%. However, an application rate as much as 80 kg ha^{-1} was required on steep slopes varying between 32% and 45% (Flanagan et al., 2003). These studies have shown the importance of adding chemical stabilizers such as polyacrylamide to cover treatments for a quick vegetation establishment to reduce soil loss and runoff on disturbed slopes.

Brofas et al. (2007) studied the effectiveness of hydroseeded cellulose, straw, and binding materials for revegetation of mine spoil in central Greece. They concluded that non native species such as *Lolium multiflorum* dominated in the first year, but after four years indigenous species went from 38.4 to 62.7% of cover. This shift in species occurred despite the use of the three mulching types and binding materials. Sutherland and Ziegler (2007) studied coir (coconut) fiber rolled erosion control systems in reducing sediment transport from hill slopes. They found that the random coir design had higher performance, with lowest sediment and rill initiation. Tinsley et al. (2006) studied the establishment success of native versus non-native herbaceous seed mixes on roadside re-vegetation. They observed an increase of 180% to 560% in plant density in two native-only seed mixes sixty days after the spring sowing, as compared to a native/non-native mix.

Szogi et al. (2007) studied erosion control practices integrated with PAM to lower nutrient runoff in furrow irrigation. They found that the sediment concentration in irrigation return flow required more offsite treatment in order to obtain desired water quality. Karim and Malik (2007) studied roadside revegetation by native plants, examining roadside microhabitats and species traits. They concluded that road building procedures create a gradient in the environment, soils, and roadside micro-topography. Native plants were naturally spread on side slopes and exhibited drought tolerance that made them very competitive in roadside re-vegetation.

SUMMARY

Previous studies indicate that successful vegetation establishment is essential for erosion control. Non-vegetation and temporary practices such as silt fences or straw bales, which are used as barriers to control sediment delivery, are ineffective themselves in removing sediment from runoff. Most studies that have been done on vegetative establishment of disturbed slopes were performed using artificial rainfall. These ‘worst-case’ scenarios, although valuable, do not adequately reflect the long-term needs (8-16 weeks) of field-applied mulches for vegetation establishment, especially when tested in container-sized or greenhouse-enclosed plots. When roadside work was performed that did not include artificial rainfall, treatments tested were experimental mulches derived from composted yard wastes. Although valuable, these materials are not widely used and available as commercial mulches. Also, research results may not transpose easily to larger sites or to different geographic areas. There is little research which examines the effectiveness of new mulches, straw blankets, or the inclusion of specialized chemical additives such as PAM for successful vegetation establishment, especially on slopes. Because there is little research examining their impact and effectiveness, our goal is to evaluate techniques necessary to install vegetative cover on disturbed sites.

OBJECTIVES

The overall goal of this study is to evaluate the effectiveness of hydromulch and other temporary cover treatments such as wheat straw and erosion control blankets to establish vegetative cover on disturbed slopes. The three specific objectives of this study are to evaluate: 1) the effect of incorporating lime and fertilizer on establishment of bermudagrass, 2) differences in bermudagrass establishment related to temporary covers, including wheat straw, erosion control blankets, and hydromulch with and without polyacrilamide, and 3) the effect of the above cover treatments on runoff volume, total suspended solids, turbidity, and nutrients in runoff.

II. METHOD AND MATERIALS

SITE DESCRIPTION

The study was located at the Alabama Agriculture Experiment Station's E.V. Smith (EVS) Research Center. The center was established in 1978 with an area of 1544 ha. Average rainfall for the area is 134.5 cm. Soils are typical of the Coastal Plain hill slopes, generally consisting of fine sandy loams and loamy sands (Figure 2). The primary soil series at the site are Cowart loamy sand and Malbis sandy loam.

Twenty-one plots, each 3 m wide × 8 m long, were constructed at two sites of 7 and 14 plots each with each plot separated longitudinally by a 1.5 m grassed alley (Figures 3 and 4). Prior to installation of the study treatments, upslope diversions and grassed swales were installed to divert upslope runoff. Appropriate silt fence sediment barriers were installed downslope of treatment plot areas. All twenty-one runoff plots were installed on a nominal 4:1 slope and fitted at the bottom with household rain gutters and downspouts draining into separate Coshocton wheel proportional water samplers (Bonta J., 2002). Fabricated Coshocton Wheels samplers were located at the bottom of the plots to collect and store 1/100th of runoff and sediment yield during rain events. Twenty liter (5 gallon) buckets were used at the Coshocton outlet to collect runoff volume samples. Collecting buckets were sampled after each of 13 rain events between July 12, 2008 and May 29, 2009.

Seven cover treatments including a seeded no cover control plot were applied on May 27, 2008 and replicated three times each (Table1). Each plot was seeded with *Cynodon dactylon* (common bermudagrass) on a prepared seedbed. Fertility recommendations for roadside establishment of bermudagrass were made by the Auburn University Soil Testing Laboratory

(Table 2). Nitrogen was applied as ammonium sulfate (21-0-0), P as triple phosphate (0-45-0), and K as potassium chloride (0-0-60), according to soil test recommendations (Table 2).

Three cover types were evaluated: 1) wheat straw, WS, 2) erosion control blanket, ECB, and 3) hydromulch, GM. All treatments with a “1” prefix: 1NC (no-cover), 1WS (wheat straw), 1ECB (Erosion control blanket), 1GM (hydromulch), and 1GMP (hydromulch + PAM) had recommended lime and fertilizer manually incorporated into the soil (10 cm depth) prior to planting. Treatments with a “2” prefix: 2GM (hydromulch) and 2 GMP (hydromulch + PAM) had fertilizer and lime surface applied at planting (Table 3). Hydromulches were applied using a TurfMaker® 430 hydro-seeder (Figure 5) at the hydromulch manufacturer’s recommended rate of 2240 kg ha^{-1} (2000 lb ac^{-1}). The erosion control blanket (treatment 1ECB) was installed according to manufacturer’s recommendations for stapling, trenching, and overlap. Similar to other incorporated treatments, the seeded no-cover treatment (1NC) had pelletized lime and fertilizer soil incorporated, followed by hand seeding and raking.

Relative cost of treatments and nutrients applied on the plots were estimated in \$/m^2 as follow: 1 \$/m^2 for lime, 0.90 \$/m^2 for nitrogen, 0.75 \$/m^2 for phosphorus, 0.20 \$/m^2 for potassium, 0.70 \$/m^2 for Erosion control blanket, 0.60 \$/m^2 for loose straw, 0.30 \$/m^2 for hydromulch (Table 4).

Runoff and sampling

Hydrologic data collection included the following: rainfall duration, rainfall volume, runoff volume, 1/100th runoff sample from the water sampler (Coshocton wheel) (Figure 6), total suspended solids (TSS) and load, turbidity (NTU), and a sub-sample from each 1/100th for nitrogen and phosphorus analyses. Runoff sampling after each rainfall runoff event began immediately after planting on May 27, 2008.

Twenty-one 15.2 cm Coshocton wheel samplers, one for each plot, were fabricated and laboratory tested to confirm that they would accommodate sustained runoff flows of up to 79.5 L min^{-1} (21 gpm) while providing 1/100th proportional sampling of inflow for a minimum threshold of 3 cm of rainfall (Bonta J.,2004). Bonta (2002) tested Coshocton wheels to assess their performance under unsteady flow, mimicking natural field conditions using a calibrated pressure sensor to record water depth in a well. Results obtained from the test showed that the Coshocton wheel collected the same proportional sample of the flow as obtained for steady-flow (Bonta, 2002).

Consequently, proportional runoff was automatically collected after each rainfall event (Figure 6). The Coshocton wheel successfully sampled rainfall events higher than 3.3 cm depth, the minimum depth required to launch the wheel plate (Figure 7).

Rainfall depth was measured by a manual rainfall gage (Productive Alternatives, Inc.) and an automatic rain gage reading to the nearest 0.25 mm (0.01 in). After each of 13 storms from July 12th 2008 to May 29th 2009, the volume of water in each sample bucket was recorded after having been well stirred and measured with four one liter capacity graduate cylinders then poured through filter bags (1 micron mesh size) (Ray Camp Company, GA). A subsample of runoff was collected and frozen until subsequent analysis for nutrient content. Another subsample was used to determine turbidity.

Modified total suspended solid

Modified Total suspended solids (MTSS) were determined using a modified total suspended solids method (TSS2540 D), as follows. After the volume of water in each bucket was recorded in the field, the entire collected sample was poured through a 1 micron filter bag (Ray Camp Company, GA) to separate sediment for subsequent determination of suspended solids. Filled bags were brought to the laboratory where filter bags containing the soil residue was dried at 103 to 105 degrees Celsius for 24 hours (Lenores et al., 1998). Filters bags were weighed until the variation between the last weight and the preceding one was less than 4%. The main modification to the standard method was the use of a filter bag in the field rather than a filter of similar mesh with a vacuum set up in the laboratory. This modification allowed collection of field data at the remote site.

Modified total suspended solids were measured directly in dry kg and then converted to kg ha^{-1}. MTSS event mean concentrations were determined for each storm by dividing MTSS mass, in kg, by total storm volume, in L. Resulting MTSS concentrations were verified for reasonableness by calculating the equivalent percent solids to verify that calculated suspensions were flowable (<10% solids). Only two treatments were found to have excessive solids contents, 1NC (on July 12 and July 14) and 1GM (on July 14). Estimated runoff volume was revised accordingly based on an assumed maximum flowable solid of 10%. Soil loss reduction was determined as one minus the ratio of soil loss from cover treatments (erosion control blanket, hydromulch, and wheat straw) over soil loss from the seeded no-cover control (Table 5).

Filtered turbidity

Filtered Turbidity in NTU (Nephelometric turbidity unit) was determined by a Hach (Loveland, Colorado) Portable Turbidity Meter, Model 2100P. In the field, samples from the 1/100th runoff were placed in 125 mL plastic bottles after being filtered through the 1 micron filter bag, and then moved to the lab where they were kept frozen to minimize biodegradation between sampling and analysis. After thawing, a repetitive sub-sample of 20mL was taken from the 125mL plastic bottle and placed in a sample cell inserted into the sampling compartment of the turbidity meter for replicate NTU reading (three times) until the lowest reading was displayed and recorded (Lenores et al., 1998). Because the maximum threshold of the instrument was 1000 NTU, filtered turbidities higher than 1000 NTU were determined by diluting sample two times or three times to obtain a readable value, and then back-correcting for the dilution. Per manufacturer's recommendations, the lowest replicated value was recorded (Hach Company, 2004).

Nutrient Analyses

A runoff sub-sample was collected in a 125 mL plastic bottle and kept frozen until analysis. Collected samples were filtered through a 0.45 micron filter and then analyzed for nitrate, ammonium, and phosphate. All nitrate, ammonium and phosphorus samples were measured via colorimetric development and analyses (Sims at al., 1995).

Statistical Analyses

SAS Institute (version 9.1) was used to analyze resulting data for means separation between treatments (LSD) on modified total suspended solid, runoff, turbidity, ammonium, phosphate, and nitrate. A significant difference between treatments was obtained at a P-value less than or equal to 0.10. Cover treatment effectiveness was determined by estimating runoff relative to the no cover control plots. Runoff coefficients and sediment loss reductions compared to the control were calculated using the formulas shown in Table 5. Statistical comparisons were conducted between treatments with mulches, treatments with and without incorporation of lime and fertilizer, and treatments with and without PAM. Statistical comparisons were also made within hydromulch treatments to isolate the impact of PAM and lime and fertilizer incorporation on runoff, modified TSS, filtered turbidity, and nutrient concentration.

Bermudagrass Establishment

For the first three months after planting, establishment data for bermudagrass was taken by randomly placing a 1m stick with 50 equally spaced marks at three locations within each plot and counting the number of times a bermudagrass plant touched a mark. Recorded touches were converted to percent and averaged for each plot. This method was used as it was a relatively easy method to quickly assess the growth of the target species within the first critical months of vegetation establishment.

III. RESULTS AND DISCUSSION

Runoff

Runoff volume was affected by mulch treatments, inclusion of PAM in the hydromulch, and by fertilizer incorporation. Mulches significantly affected runoff at 9 of 13 runoff events (Table 6), inclusion of PAM at 4 of 13 events (Table 7), and incorporation of fertilizer at 3 of 13 events (Table 8).

Runoff volume from all treatment plots responded proportionally to a variety of storm depths (Figure 8). A total of 13 storms with a total of 112.4 cm of precipitation (44.24 inches) occurred over the study period (Table 6). Despite vegetation growth, a relatively constant response ($R^2 = 0.82$) of runoff to rainfall was established during the study (Figure 9). High runoff volumes were observed when precipitation exceeded 10 cm despite the extent of cover (Figure 10).

Runoff volume was often reduced in hydromulch or loose straw treatments, with a significant reduction observed on 12 Jul, 28 Jul, 14 Aug, 27 Aug, 3 Dec, and 21 Jan, as compared to the seeded no-cover treatment (Table 6). Runoff volume from plots that received an erosion control blanket did not differ significantly from the seeded no cover control until several weeks after installation, with runoff volumes significantly lower compared to seeded no-cover on 14 Aug, 24 Oct, 3 Dec, 21 Jan, 12 May, and 29 May. Greatest runoff volume was from seeded no-cover, and typically followed the order: seeded no-cover > hydromulch ≈ blanket ≈ straw. Thus, there were no strong significant differences between cover treatments in runoff. No significant difference in total runoff due to treatment was observed on 14 Jul, 15 Dec, 8 March 8, and 1 Apr due to the growing vegetation and small rainfall for the two first events (Figure 8).

The addition of PAM to hydromulch significantly reduced runoff volume on 28 Jul, 3 Dec, when treatments without PAM had significantly greater runoff volume (Table 7). The lack of a consistent effects due to PAM application may have been due to the fact that PAM does not always perform on sandy soils with low clay contents, and when applied only once (Ajwa and Trout, 2007).

The incorporation of lime and fertilizer by tillage significantly increased runoff on 28 July, 21 Jan (Table 7), and only on 14 Aug within hydromulch treatments (Table 8). All plots were similarly tilled, so tillage itself would not have directly caused these differences. Even if not significant, there was a trend for plots in which the fertilizer was incorporated to have greater runoff than measured in plots where fertilizer was not incorporated (9 of 13 dates). This result is opposite of what was been expected, and may be due to a disturbance of the soil surface with tilled treatments.

Runoff Coefficient (cm/cm)

Individual runoff coefficients were determined for each storm and treatment and represented graphically to identify possible changes associated with vegetation establishment (Figure 11). Runoff coefficient was calculated by dividing runoff from treatments by precipitation time. Higher runoff coefficients at the beginning and end of the study suggest changing of vegetation which was likely due to the absence of natural cover in the beginning and a poor stand at the end of the first year (Figure 11). The high runoff coefficient during the last event (May 12 and May 29, 2009) was caused principally by the large storm event of 17.8 cm, but also by widespread stand failure on plots. At the end of the first year, plots treated with loose straw or hydromulch had on average the lowest runoff coefficient (0.25) followed by erosion control blanket (0.26), and seeded no cover (0.36) (Table 9), similar to results obtained by Chaudari and Flanagan (1998). Seeded no-cover plots had 36% runoff coefficient at the end of the study. Loose straw and hydromulch had the highest runoff reduction (75%) compared to the control followed by erosion control blanket (74% reduction). Neither was significantly different from each other.

Modified total solids-concentration and load

Modified Total Suspended Sediment (MTSS), in kg ha^{-1} was determined for each storm and treatment. Results over the one year study indicate a substantial decrease in sediment yield especially during the first 90 days after planting (Figure 12). Application of any cover treatment significantly reduced MTSS as compared to the seeded no cover control, especially early in the study before vegetation establishment. Total suspended solids in all cover treatments were significantly lower on 12 Jul, 14 Jul, 21 Jul, and 14 Aug, the first four rainfall events after treatment application (Table 10). Differences due to mulch type were rarely apparent.

At the end of the study, seeded no cover plots had the highest MTSS when compared to total TSS collected from all hydromulch, erosion control blanket, and loose straw plots (Table 10) although there was no significant difference. Loose straw had the lowest non significant sediment yield in 10 of 13 collected events (Table 10). This finding is different from that of Lyle (1987), who showed that mulch treatments had higher performance than hay and straw mats.

Inclusion of PAM in the mulch treatment significantly reduced MTSS on14 Jul and 28 Jul (Table 11). Inclusion of PAM in the hydromulch treatment significantly reduced MTSS early in the year-long test in three of the first four storm events (Table 12). Treatments with PAM did not show reduction in MTSS after 27 Aug, likely due to PAM degradation by sunlight, ultraviolet, and washe off by repeated rainfall (Wallace et al., 2006).

The incorporation of lime and fertilizer in the mulch treatment and within the hydromulch treatments significantly increased MTSS on 14 Aug (Table 11, 12). Again, all plots were uniformly tilled so differences due to MTSS are not directly due to tillage (Table 12). This result was unexpected and remains unexplained pending further study.

Calculated soil loss reductions for each treatment and storm event are presented in Figure 13. Average soil loss reductions were used to determine the best erosion control management practices as compared to the no-cover control. Resulting soil loss reductions indicate decreased reduction over time compared to the seeded no cover plots as vegetation was established (Figure 13). Average reduction in sediment loss from cover treatments, as compared to the seeded no cover plots ranged from 92% to 27% for erosion control blanket, from 93% to 22% for hydromulch , and from 98% to 22% for loose straw (Table 13). Plots covered with loose straw had the highest average MTSS reduction of 66%, followed by erosion control blanket with 58% and finally plots treated with hydromulch at 53%. High sediment loss reduction in loose straw is likely a result of the high straw application used in this study as explained previously.

A linear relationship was obtained between average MTSS and precipitation ($R^2 = 0.14$) which indicates that precipitation was not the main factor influencing soil loss. Another linear relationship ($R^2 = 0.30$) was obtained between MTSS and runoff, with a similar relation ($R^2= 0.37$) between log MTSS (kg ha^{-1}) and filtered turbidity (NTU). Further study under controlled conditions would be needed to evaluate or verify these relationships.

Bermudagrass Establishment

Percent establishment of bermudagrass during the first 60 days after planting is presented in Table 12. On 6 Jun, almost 30 days after planting, the mulch treatment (with fertilizer and lime not incorporated) had the highest percent bermudagrass cover (49%), while the lowest was 1WS (6.7%). On 8 and 22 Jul, bermudagrass cover on the hydromulch (lime and fertilizer incorporated) treatment was 72% and 84%, respectively, the highest cover of any site. On 8 Jul, seeded no cover treatment had the lowest of cover (24%); and this effect continued until 22 Jul (Table 14).

When averaged over the first 90 days after planting, some differences in bermudagrass establishment became apparent (Table 14). First, PAM application had no effect on bermudagrasss establishment (Table 14 and 15). Second, within the hydromulch treatments, the incorporation of lime and fertilizer (versus surface application) did not affect Bermudagrass establishment. Third, bermudagrass was established significantly quicker when a hydromulch was used as compared to an erosion control blanket, or loose straw (Table 14 and 15).

Filtered turbidity (NTU)

Average turbidity measurements for each storm and treatment are presented in Figure 14. Similar to MTSS loads; highest turbidities were recorded during the first 90 days before vegetation was established.

During the study, the seeded no-cover treatment had the highest filtered turbidity, while plots with loose straw for reasons cited earlier, had the lowest filtered turbidity. Filtered turbidity values provided an indication of NTU differences between treatment runoff sampled during the study period. The addition of any cover (hydromulch, erosion control blanket, or straw) significantly reduced NTU (as compared to the seeded no cover control) on 4 of 13 samplings dates early in the study period (12 Jul, 28 Jul, 27 Aug, 21 Jan) (Table 16). In an additional 5 dates (14 Jul, 14 Aug, 24 Oct, 3 Dec, 29 May) application of loose straw significantly reduced NTU, as compared to seeded no-cover. The highest values of filtered turbidity (NTU) were recorded in the 90 days period after planting because the vegetation was not yet established. Lower overall average filtered turbidity in the loose straw treatment (Table 16) may not have occurred had such a heavy straw load been applied.

Inclusion of PAM did not significantly reduce NTU at any sampling date (Table 17, 18). There were only three dates (12 Jul, 14 Jul, and 3 Dec) when incorporation of lime and fertilizer significantly affected NTU (Table 17) and results were opposite of what was expected.

A weak linear relationship ($R^2 = 0.13$) was obtained between average filtered turbidity (NTU) and precipitation (cm). A stronger linear relationship ($R^2= 0.42$) was obtained between average filtered turbidity (NTU) and average MTSS (kg ha^{-1}), which is explained by the fact that filtered turbidity increases with increased modified total suspended solids.

Nutrient Analysis

Nitrate-N ($N0_3$-N) concentration was significantly greater in runoff from seeded no cover control plots compared to any cover, with significant differences observed on 12 Jul and 28 Jul (Table 19). There was no significant difference in phosphate (H_2P0_4-P) in runoff due to any treatment. The addition of PAM to the mulch treatment significantly reduced $N0_3$-N on 28 Jul but did not for H_2P0_4-P (Table 20). Within the hydromulch treatments, the inclusion of PAM did not significantly affect $N0_3$-N or H_2P0_4-P in runoff (Table 21). Tilling lime and the fertilizer into the soil did not affect nitrate or phosphate concentration in runoff.

IV. CONCLUSION

Large variability was observed in runoff, sediment yield, turbidity, and nutrient concentrations due to variable rainfall in outdoor plots, making evaluation between them challenging. In spite of large variability, differences were noted between treatments. Method of fertilizer incorporation (surface applied versus incorporated) and the use of PAM with hydromulch did not affect percent establishment of bermudagrass.

When averaged over the first 90 days after planting, some differences in bermudagrass establishment became apparent (Table 13). First, PAM application had no effect on bermudagrasss establishment (Table 12 and 13). Second, within the hydromulch treatments, the incorporation of lime and fertilizer (versus surface application) did not affect Bermudagrass establishment. Third, bermudagrass was established significantly quicker when a hydromulch was used as compared to an erosion control blanket, or loose straw (Table 12 and 13).

The average percent bermudagrass cover established from 26 Jun to 22 Jul revealed the following ranking: hydromulch (66 to 49%), erosion control blanket (44%), loose straw (29%), and seeded no cover (20%). The addition of PAM to hydromulch treatments, or tilling fertilizer and lime into the soil did not significantly enhance bermudagrass cover establishment.

During the study, loose straw treatments had the lowest runoff likely due to the heavy application of straw, followed by the hydromulch treatments, erosion control blanket, and then seeded no cover control plots. When treatments were compared to the control plots; the loose straw had the best performance in reducing runoff, followed by hydromulch. A significant difference in runoff was observed between the no-cover control and the cover treatments.

The addition of PAM to hydromulch treatments did alleviate soil loss especially at the beginning of the study, but the incorporation of lime and fertilizer into the soil did not reduce soil loss as expected. The reduction in sediment loss from cover treatments compared to the control plots ranged (most effective to least effective) from 22% to 98% for loose straw , 22% to 93% for hydromulch , 16% to 92% for erosion control blanket. Comparable average annual sediment loss reductions compared to no cover control plots were 68% for loose straw , 58% for erosion control blanket , and 53% for hydromulch. The addition of PAM to hydromulch decreased turbidity. However, incorporation of lime and fertilizers into the soil before planting did not. During the study period, loose straw treatments had the lowest turbidity, followed by the hydromulch, erosion control blanket, and no cover control.

Nitrate concentrations in runoff revealed that the seeded and fertilized no-cover control had higher concentrations in runoff, followed by the erosion control blanket, hydromulch, and loose straw. A significant difference was obtained between no cover, hydromulch, and loose straw treatments with regard to nitrate concentration on 12 Jul and 28 Jul. Adding PAM to the hydromulch or incorporating lime and fertilizer did decrease the concentration of nitrate in runoff but not significantly; and were however, these differences were not significantly different from each other.

Adding PAM to the hydromulch treatments reduced the concentration of phosphate in runoff on 14 Jul, but not significantly. Incorporating lime and fertilizer to the hydromulch treatments reduced the concentration of phosphate, but not significantly. Findings of this study emphasize the environmental importance of temporary covers on disturbed slopes during the first critical months of establishment, and indicate the need for continued studies for more definite evaluation of each method.

V. FUTURE RESEARCH

1. Due to the fact that this study did focus on parameters such as sediment yield, runoff, nutrients and on a brief period of vegetation growth, future studies should focus on a longer period of vegetation growth monitoring.

2. The effect of various soil properties such as texture, CEC, and structure on PAM should be investigated further.

3. Since PAM was only applied once at the beginning of study, future studies should consider more than one application so that degradation would be minimized.

4. Coshocton wheel used for water proportional sampling collected only one percent of the total runoff in this study, future study should consider a higher percentage which would increase the number of events collectable.

5. PAM application combined with other BMP's appears from this study to be economically viable for erosion control, but needs further literature and field study.

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BIBLIOGRAPHY

Addams, J.E. 1996. Influence of mulches on runoff, erosion, and soil moisture depletion. SSSAJ 30: 110-114.

Ajdwa, H.A., T.J.Trout. 2006. Polyacrylamide and water quality effects on infiltration in sandy loam soils. SSSAJ 70: 643-650.

ASWCC. 2003a. Alabama handbook for erosion control, sediment control, and stormwater managment on construction site and urban areas: Montgomery:alabama.Volume 1:754.

ASWCC. 2003b. Alabama handbook for erosion control, sediment control and stormwater managment on construction sites and urban areas: Alabama Handbook. Volume 2: 754.

Barret, M.E., J.E. Kearney, T.G. McCoy, and J.F. Malina. 1995. An evaluation of temporary sediment controls. The University of Texas at Austin.Water Ressources Technical Report 95-6.

Barvenic, F.W. 1994. Polyacrylamide characteristics related to soil application. SSSAJ 158: 235-243.

Biggelar, D., C.R.Lal, K.Wiebe, and V.Breneman. 2001. Impact of Soil Erosion on Crop Yields in North America. Adv. Agron. 72: 1-52.

Bilbro, J.D., and D.W. Fryrear. 1994. Wind erosion losses as related to plant silhouete and soil cover. Agron. J. 19: 550-563.

Bjorneberg, D.L., F.L.Santos, N.S. Catanheira,O.C. Martins, J.L. Reis, J.K. Aase, and R.E. Sojka. 2003. Using polyacrylamide with sprinkler irrigation to improve infiltration. JSWC 58(5). 283-289.

Bologna, L.S., F.F. Andrawes, F.W. Barvenik, R.D. Lentz, and R.E. Sojka. 1999. Analysis of residual acrylamide in field crops. SSSAJ 37: 240-244.

Bonta, J. 2002. Modification and performance of the coshocton wheel with the modified drop-box Weir. J. Soil Water Consv. 379: 364-373.

Bonta, J.V. 2004. Drop-box weir for measuring flow rates under extreme flow conditions. J. Soil Water Consv. 63(4):134A.

Bradfort, J.M., Ferris, J.E., Remley, P.A. 1987. Interril soil erosion processes: I. Effect of surface sealing on infiltration, runoff and soil splash detachment. SSSAJ 51: 1566-1571.

Brady, N.C.,and R.R. Weil. 1996. The Nature and properties of Soils, 11th edition. Upper Saddle River, NJ, Prentice Hall.

Brofas, G., C.Varelides, G.Mantakas, K.Tsagari, and M.Stefanakis. 2007. Effectiveness of cellulose, straw, and binding material for mining spoils revegetation by hydro-seeding, in central Greece. Ecological Engineering 31: 375-382.

Canady, N.A., and D.C. Flanagan. 2004. Use of polyacrylamide to reduce runoff, soil loss and nutrients loss under lagoon effluent sprinkler irrigation. ASAE/CSAE 4: 12.

Caulfield, M.J., X. Hao,G.G. Qiao, D.H. Solomon. 2002. Degradation on polyacrylamides. Part I. Linear polyacrylamide. Polym. 44: 1331-1337.

Chaudari, K., D.C. Flanagan. 1998. Polyacrylamide effect on sediment yield, runoff, and seedling emergence on a steep slope. Technical papers. ASAE. St. joseph, MI.

Cramberry, D., W.Kelly, D. Langston, K. Rucker, J. Diaz-Perez. 2001. Testing compost value on pepper plants. JCOR 42: 10.

Davidson, R.A., C.F. Davidson, A. Roa-Espinosa. 2009. Linear anionic polyacrylamide as an effective post-fire soil treatment:Understanding the chemistry and physical science. JSWC 64: 243-252.

Dinel, H., T. Pare, M. Schnitzer, N. Pelzer. 2000. Direct land application of cement kiln dust and lime-sanitized biosolids: extractability of trade metals and organic matter quality. Geoderma 96: 307-320.

Dudeck, A.E., N.P. Swanson, and A.R. Dedrick, 1970. Mulches for grass establishmenton fill slopes. Agron. J. 62: 810-812.

Emmerich, W.E. 2003. Season and erosion pavement influence on saturated soil hydraulic conductivity. SSSAJ 168: 637-645.

Entry, J.A., R.E. Sojka, M. Watwood, and C. Ross. 2002. Polyacrylamide preparations for protection of water quality threatened by agricultural runoff contaminants. Env. Pol. 120: 191-200.

Entry, J.A., and R.E. Sojka. 2003. The efficacy of polyacrylamide to reduce nutrient movement from an irrigated field. ASAE 46(1): 75-83.

Faucette, L.B. 2004. Environmental benefits and impacts of compost systems and industry standard BMPs used for erosion control in construction activities. PhD dissertation, Institute of Ecology, University of Georgia.

Faucette, L.B., J.Governo, C.F. Jordan, B.G. Lockaby, H.F. Carino, and R. Governo. 2007. Erosion control and storm water quality from straw with PAM, mulch, and compost blankets of varying particles sizes. JSWC 62(6): 404-413.

Faucette, L.B., K.A.Sefton, A.M.Sadeghi, and R.A. Rowland. 2008. Sediment and phosphorus removal from simulated storm runoff with compost filter socks and silt fence. JSWC 63(4): 257-261.

Flanagan, D.C., and K. Chaudari. 1999. Erosion control with polyacrylamide on steep slopes. Toronto,Canada. Technical papers. ASAE. St. joseph, MI.

Flanagan, D.C., L.D. Norton, J.R. Peterson, K. Chaudhari. 2003. Using polyacrylamide to control erosion in agricultural and disturbed soils in rainfed areas. JSWC 58(5): 301-311.

Foster, G.R., R.A.Young, M.J.M. Romkens, and C.A. Onstad. "Processes of soil erosion by water in soil erosion and crop productivity. ASA. 137-162.

Furher, G.J., J.L. Morace, H.M. Johnson, J.F. Rinella, J.C. Ebbert, S.S. Embrey, I.R. Waite, K.D. Carpenter, D.R. Wise, and C.A. Hugues. 2004. Water quality in the Yakima river bassin. Washington: U.S. Geological Survey Circular 1237.

Gorman, J.M., J.C. Sencindiver, D.J. Horvath, R.N. Singh, and R.F. Keefer. 2000b. Erodibility of fly ash used as topsoil subsitute in mineland reclamation. J. Env. Qual. 29: 805-811.

Gorman, J.M., Sencindiver, D.J., Horvath, R.N. Singh, and R.F. Keefer. 2000. Erodibility of fly ash used as a topsoil subsitute in mine land reclamation. J. Env. Qual. 29: 805-811.

Grace, J. M. III. 2005. Forest operations and water quality in the south. ASAE 48(2): 871-880.

Granberry, D.,W. Kelly, D. Langston, K. Rucker, and J. Diaz-Perez. 2001. Testing compost value on pepper plants. JCOR 42: 12.

Green, S., D.E. Scott, L.O. Norton, and J.G. Graveel. 2000. PAM molecular weight and charge effects on infiltration under simulated rainfall. Soil Sci. Soc. Am. J. 64: 1786-1791.

Green, V.S., and D.E. Scott. 2001. Polyacrylamide: A review of the use, effectiveness, and cost of a soil erosion control amendment. Soil Conservation. 384-389.

Grismer, M.E. 2007. Soil Restoration and erosion Control: Quantitaive Assessment and direction. ASABE 51: 1619-1926.

Hach Company. 2004. Portable turbid meter Model 2100P. Instrument and procedure manual. Loveland, Colorado. Cat. No. 464500-88. 78 pp.

Harrel, M.S., and G.L. Miller. 2005. Composted yard waste affects soil displacement and roadside vegetation. J. Am. Soc. Hort. Sci. 40: 2157-2163.

Holt G., M. Harmel, D. Potter, and K. Pelletier. 2005. Comparison of cotton-based hydro-mulches and conventional wood and paper hydro-mulches-study 1. J. Cotton sci.: 9(3).

Karim, M.N., and A.U. Malik. 2007. Roadside revegetation by native plants: I roadside microhabitats, floristic zonation and species traits. Thunder Bay, Canada:P7B5E1. Department of Biology, Lakehead University.

Kornecki, T.S., B.C.Grigg, J.L. Fouss, and L.M. Southwick. 2004. Effectiveness of sugarcane residue and polyacrylamide in reducing soil erosion from quarter-drains under souther louisiana weather conditions. ASAE/CSAE 042082:12.

Lenores S.C., A.E. Greenberg, and A.D. Eaton. 1998. Standard methods for the examination of water and waste water. 1015 fifteenth Street, NW Washington, DC 20005-2605: American Public Association, American Water Works Association, Water Environment Association.

Lentz, R.D. and R.E. Sojka. 1994. Field results using poyacrylamide to manage furrow erosion and infiltration. Soil Sci.158: 274-282.

Lentz, R.D., and D.L. Bjorneberg. 2003. Polyacrylamide and straw residue effect on irrigation furrow erosion and infiltration. JWSC 58: 1339-1351.

Lentz, R.D., and R.E. Sojka. 1996. Five years summary research using PAM in furrow irrigation. in:Sojka,R.E., R.D.Lentz (Eds.), Managing irrigation-induced erosion and infiltration with polyacrylamide. University of Idaho Misc. Publ.101-96: 20-27.

Lepore, B.J., A.M. Thompson, A. Peterson. 2009. Impact of polyacrylamide delivery method with lime and gypsum for soil and nutrient stabilization. JSWC 64(3): 223-231.

Lyle, E.S. 1987. Surface mine reclamation manual. New York: Elsevier.

Malik, M., A. Nadler, J. Letey. 1991. Mobility of polyacrylamide and polysaccaharide polymer through soil materials. Soil Techno.4: 255-263.

McLaughlin, R.A., T.T. Brown. 2006. Evaluation of erosion control products with and without added polyacrylamide. JAWRA 42(3): 675-684.

Meyer, L.D. 1985. Interrill erosion rates and sediments caracteristics. ASAE 29: 948-955.

Meyer, L.D., C.B. Johnson, and G.R. Foster. 1972. Stone and woodchip mulches for erosion control on construction sites. JSWC 27: 264-267.

Mingguo, Z., C. Qiangguo, and C. Hao. 2007. Effect of vegetation on Runoff-Sediment Yield relationship at different spatial Scales in hilly areas of the loess plateau, North China. Ecological Society of China 27: 3572-3581.

Morgan, R.P.C., and R.J. Rickson. 1995. Slope stabilization and erosion control: A bioengineering approach. Chapman et Hall, London.

Orts, W.J., R.E. Sojka, G.M. Glenn, and R.A. Gross. 2000. Biopolymer additives for the reduction of soil erosion losses during irrigation. Ind. Crops Prod. 11(1):19-29.

Orts, W.J., A. Roa-Espinosa, R.E. Sojka, G.M. Glenn, S.H. Inam, K. Erlacher, and J.S. Pedersen. 2007. Use of synthetic polymers for soil stabilization in agricultural, construction, and military applications. JMCE 19: 58-66.

Pan, C.Z., Z.P. Shangguan, and T.W. Lei. 2006. Influence of grass on runoff and sediment yield on sloped loess surfaces under simulated rainfall. J. Hydro. 331: 178-185.

Risse, S., and B. Faucette. 2001. Compost utilization for erosion control. University of Georgia Cooperative Extension Service Bulletin CES 1200.

Roa-Espinosa, A.,G.D. Bubenzer, and E.S. Miyashila. 2000. Sediment and runoff control on construction sites using four application methods of polyacrylamide mix. Chicago: EPA/625/R-00/01.

Seybold, C.A. 1994. Polyacrylamide review:Soil conditioning and environmental fate. CSSSPA 25(11,12): 2171-2185.

Shainberg, I., D. Warrigton, and P. Rengasamy. 1990. Effects of soil conditioner and gypsum application on rain infiltration and erosion. J.Soil Sci. 149: 301-307.

Shepley, B., Smith, R., and G.L. Jackson. 2002. Market and analysis of erosion control mats. US Department of Agriculture, Forest Service, Forest Products Laboratory. 9pp.

Sims, G.K., T.R. Ellsworth, and R.L. Mulvaney. 1995. Microscale determinaiton of inorganic nitrogen in water and soil Extracts. Commun. Soil Sci. Plant Anal. 26: 303-316.

Storm Water Quality Handbook. 2003. Project planning and design guide. Storm water quality handbooks. California: Department of transportation.

Sojka, R.E., D.L Bjoneberg, J.A. Entry, R.D. Lentz, and W.J. Orts. 2007. Polyacrylamide in agriculture and environmental land managment. Adv. Agron. 92: 75-162.

Sojka, R.E., R.D. Lemtz, and D.T.Westermann. 1998. Water and erosion managment with multiple application of polyacrylamide in furrow irrigation. SSSAJ 62(6): 1672-1680.

Soupir, M.L., S. Mostaghimi, A. Maters, K.A. Flahive, D.H. Vaughan, A. Mendez, and P.W. McMellan. 2004. Effectiveness of polyacrylamide in improving runoff water quality from construction sites. JAWRA 40(1): 53-66.

Sutherland, R.A., and A.D. Ziegler. 2007. Effectiveness of coir-based rolled Erosion control systems in reducing sediment transport from hillslopes. Applied Geography 27: 150-164.

Szogi, A.A., B.G. Leib, C.A. Redulla, R.G. Stevens, G.R. Mathiew, and D.A. Strausz. 2007. Erosion practices integrated with polyacrilamide for nutrient reduction in rill irrigation runoff. Agri. water Mngt 91:43-50.W

Tinsley, J.M., M.T., Simmons, S.Windhager. 2006. The establishment success of native versus non-native herbaceous seed mixes on a revegetated roadside in Central Texas. Ecological Engineering 26: 231-240.

Troeh, R.F., J.A. Hobbs, R.L. Donahue. 2004. Soil and Water Conservation for Productivity and Environmental Protection 4th edition. 672pp.

Trout, T.J., and H. Ajwa. 2001. Polyacrylamide effects on infiltration in San Joaquin Valley sandy loam soils. ASAE. Sacramento, California. Paper 01-2259.

USDA. 2009. WebSoil Survey. nrcs.gov.

USEPA. 2000. Bosque Watershed doesn't waste manure. Non Point Source News Notes 63: 21-22.

USEPA. 2002. Methods for measuring toxicity and bioaccumulation of sediment associated with contaminants with freshwater invertebrates. 2nd ed. EPA/600/R-99/064.

USEPA. 2004. The use of best managment (BMPs) in urban watersheds. Office of Research and Development (Office of Research and Development EPA 600/R-04/184). 184 pp.

Vacher, C.A., R.J. Loch, and S.R. Raine. 2003. Effect of addition of polyacrylamide on infiltration and erosion on disturbed lands. Australian J. Soil Res. 41:1509-1520.

Walkers, J.D., M.T. Walter, J.Y. Parlange, C.W. Rose, T. Meerveld, and H.J. Gao. 2007. Reduced raindrop-impact driven soil erosion by infiltration. J. Hydro. 342:331-335.

Wallace, A., G.A. Wallace, and A.M. Abouzamzam. 1986. Effects of excess of levels of a polymer as a soil conditioner on yields mineral nutrition of plants. Soil Sci. 141: 377-380.

Waters, D., R. Drysdale, and S. Kimber. 1999. Reducing off-site movement of sediment and nutrients in a cotton production system. Brisbane-Qld: NPIRD Nutrient Conference.

Weeks, L.E., and W.G. colter. 1952. Effect of synthetic soil conditioners on erosion control. Soil Sci. 73, 473-484.

Wei, L., B. Zhang, M. Wang. 2007. The effect of antecedent soil moisture on runoff and soil erosion in alley cropping systems. Institute of Soil Science, Chinese Academy of Science. Nanjying 210008.

William, J.D., D.E. Wilkins, C.L. Jr. Douglas, W.R. Rickman. 2000. Soil and Tillage Research. Oregon Agric. Exp. Sta. Spec. Rep. 55:71-78.

Table 1: Description of the cover and fertilizer treatments.

Cover treatment	**Description**
1NC	Seeded no-cover (control) with incorporation of lime and fertilizer by tillage.
1ECB	Erosion control blanket with incorporation of lime and fertilizer by tillage. Two 2 m widths of product were used for each plot, trenched and stapled per manufacturer's recommendations.
1GM	Hydromulch product with incorporation of lime and fertilizer by tillage. Hydromulch was applied using a hydroseeder (Figure 5) at 2240 kg/ha, per manufacturer's recommendations,
1GMP	Hydromulch and PAM with incorporation of lime and fertilizer by tillage. Polyacrylamide powder was applied in solution with the hydromulch based on soil tests and at rates recommended by the supplier (17 kg/ha).
1WS	Wheat straw was applied at 3360 kg/ha following incorporation of lime and fertilizer by tillage and hand seeding.
2GM	Hydromulch without incorporation of fertilizer by tillage.
2GMP	Hydromulch and PAM without incorporation of fertilizer by tillage. Polyacrylamide powder was applied in solution with the hydromulch based on soil tests and at rates recommended by the supplier.

Table 2: Soil test recommendations for study plots, E.V. Smith Research Station.

Fertility, lime and cover treatments applied for common bermudagrass[1]														
Plot #	14	13	12	11	10	9	8	7	6	5	4	3	2	1
P_2O_5 (kg/ha)	90	100	78	78	100	100	90	90	90	90	90	90	100	90
K_2O (kg/ha)	0	56	0	0	100	100	180	224	202	157	179	168	134	78
Lime (T/ha)	0	1.5	1.0	1.0	1.0	0	1.0	2.5	2.5	1.5	1.5	1.5	1.5	1.5
Cover[2]	2 GM	2 GMP	1 WS	1 GMP	1 GM	1 ECB	1 NC	1 ECB	2 GMP	2 GM	1 NC	1 WS	1 GMP	1 GM

[1] Recommendations from Auburn University soil testing laboratory for bermudagrass for roadside establishment. N was applied as ammonium sulfate (21-0-0), P as triple phosphate (0-45-0), and K as potassium chloride (0-0-60).

[2] Cover treatment names:

1GM: Hydromulch product with incorporation of lime and fertilizer by tillage

2 GM: Hydromulch without incorporation of fertilizer by tillage.

1GMP: Hydromulch and PAM with incorporation of lime and fertilizer by tillage.

2GMP: Hydromulch and PAM without incorporation of fertilizer by tillage

1WS: Wheat straw with incorporation of lime and fertilizer by tillage and hand seeding.

1ECB: Erosion control blanket with incorporation of lime and fertilizer by tillage

1NC: Seeded no-cover (control) with incorporation of lime and fertilizer by tillage

Table 3: Summary of plot treatments for 2008 at E.V. Smith

Lime, fertilizer, & seed treatments	**NC**	**WS**	**WSP**	**ECB**	**GM**	**Hydro-mulch + PAM**
Lime, fertilizer& seed. Soil incorporated	1NC	1WS	NA	1ECB	1GM	1GMP
Lime, fertilizer, & seed. Not soil incorporated	NA	NA	NA	NA	2GM	2GMP

1GM: Hydromulch product with incorporation of lime and fertilizer by tillage

2GM: Hydromulch without incorporation of fertilizer by tillage.

1GMP: Hydromulch and PAM with incorporation of lime and fertilizer by tillage.

2GMP: Hydromulch and PAM without incorporation of fertilizer by tillage

1WS: Wheat straw with incorporation of lime and fertilizer by tillage and hand seeding.

1ECB: Erosion control blanket with incorporation of lime and fertilizer by tillage

1NC: Seeded no-cover (control) with incorporation of lime and fertilizer by tillage

Table 4: Cost of the products used in the cover treatment.

Cover Treatment	**Cost of Product ($/m^2)**	**Equipment**
Hydromulch	0.30	TurfMaker 350 hydroseeder
ECB	0.70	NA (installed by hand)
Straw	0.60	NA (applied by hand)
Lime	1.00	NA (applied by hand)
Potash	0.20	NA (applied by hand)
Phosphorus	0.75	NA (applied by hand)
Nitrogen	0.90	NA (applied by hand)

Hydromulch: 1GM, 2GM, 1GMP, and 2GMP

For the 21 plots the following amounts of lime and fertilizer were used:

Lime = 7 (18 kg bags) at $4.00 per bag = 126 kg at $28

Potash = 30% of 23 kg bag at $16.00 = 7 kg at $5

Phosphorus = 74% of 23 kg bag at 24.50 = 17 kg at $18

Nitrogen = 42 kg = 1.84 bags times $11.50= 42 kg at $21

†Price estimated by Earl Norton and Bill Bryce (Department of Agronomy and Soils, Auburn University). Does not include equipment, labor, or other application costs.

Table 5: Formulas for the calculation of runoff and sediment reduction.

	Runoff	**Sediment**
Parameter	Runoff coefficient, RC[2]	Sediment loss reduction[1], SLR
Formula	$RC = (RO_{TRT}/PR)\times 0.0043$	$SLR = 1-(TSS_{TRT}/TSS_{NC})$

[1] Sediment loss reduction compared to the seeded no cover control, where TSS = total suspended solid (kg ha^{-1}), TRT = cover treatment, and NC = no cover seeded control

[2] Runoff coefficient compared to the seeded no cover control, where RO = runoff (L),

PR: Precipitation (cm) and RC is dimensionless.

Table 6: Comparison between treatments for runoff (L).

Runoff (L)					
Cover treatment					
Date (2008-2009)	**No-cover (N=3)**	**Blanket (ECB) (N=3)**	**Hydromulch (N=12)**	**Loose straw (N=3)**	**Rainfall (cm)**
12 July	390^{a}	380^{a}	236^{b}	235^{b}	4
14 July	316^{a}	253^{a}	303^{a}	370^{a}	3
28 July	397^{a}	223^{ab}	58^{b}	75^{b}	4
14 Aug	360^{a}	177^{b}	168^{b}	139^{b}	5
27 Aug	1550^{a}	1206^{ab}	958^{b}	908^{b}	15
24 Oct	540^{a}	263^{b}	330^{ab}	385^{ab}	10
3 Dec	493^{a}	368^{b}	321^{bc}	275^{c}	7
15 Dec	288^{a}	173^{a}	284^{a}	178^{a}	4
21 Jan	243^{a}	184^{b}	215^{b}	180^{b}	4
8 March	988^{a}	750^{a}	540^{a}	962^{a}	14
1 Apr	1363^{a}	933^{a}	893^{a}	1197^{a}	15
12 May	1125^{a}	872^{b}	1062^{ab}	1000^{ab}	13
29 May	1832^{a}	1407^{ab}	1700^{ab}	1242^{b}	18

† Means with the same letter are not significantly different at alpha=0.10.

†Hydromulch: 1GM, 2GM, 1GMP, 2GMP.

Table 7: The impact of PAM, lime and fertilizer application and method of incorporation on runoff (L).

Runoff (L)	**Lime and fertilizer placement**		**Polyacrylamide (PAM)**	
Date (2008-2009)	**Incorporated (N= 12)**	**not incorporated (N=6)**	**No (N=12)**	**Yes (N=6)**
12-Jul	271 ^{a}	245 ^{a}	270 ^{a}	247 ^{a}
14-Jul	300 ^{a}	322 ^{a}	282 ^{a}	359 ^{a}
28-Jul	169 ^{a}	15 ^{b}	145 ^{a}	63 ^{a}
14-Aug	179 ^{a}	136 ^{a}	162 ^{a}	194 ^{a}
27-Aug	1004 ^{a}	964 ^{a}	1039 ^{a}	894 ^{a}
24-Oct	432 ^{a}	372 ^{a}	392 ^{a}	453 ^{a}
3-Dec	295 ^{b}	360 ^{a}	334 ^{a}	282 ^{b}
15-Dec	252 ^{a}	240 ^{a}	190 ^{b}	364 ^{a}
21-Jan	221 ^{a}	171 ^{b}	187 ^{a}	238 ^{a}
8-Mar	703 ^{a}	531 ^{a}	687 ^{a}	561 ^{a}
1-Apr	1020 ^{a}	824 ^{a}	1028 ^{a}	807 ^{a}
12-May	1015 ^{a}	1028 ^{a}	983 ^{a}	1093 ^{a}
29-May	1542 ^{a}	1639 ^{a}	1484 ^{a}	1757 ^{a}

† Means with the same letter are not significantly different at $\alpha = 0.10$.

Table 8: The impact of PAM, lime and fertilizer application and method of incorporation on runoff (L) within the hydromulch treatments.

Runoff (L)	**Lime and fertilizer placement**		**Polyacrylamide (PAM)**	
Date (2008-2009)	**Incorporated (N= 6)**	**not incorporated (N=6)**	**No (N=6)**	**Yes (N=6)**
12-Jul	230^{a}	245^{a}	228^{a}	247^{a}
14-Jul	289^{a}	322^{a}	252^{a}	359^{a}
28-Jul	102^{a}	15^{b}	54^{a}	63^{a}
14-Aug	200^{a}	136^{a}	166^{a}	194^{a}
27-Aug	952^{a}	964^{a}	1022^{a}	894^{a}
24-Oct	463^{a}	372^{a}	382^{a}	453^{a}
3-Dec	268^{b}	360^{a}	346^{a}	282^{a}
15-Dec	328^{a}	240^{a}	204^{a}	364^{a}
21-Jan	259^{a}	171^{b}	193^{a}	238^{a}
8-Mar	549^{a}	531^{a}	518^{a}	561^{a}
1-Apr	974^{a}	824^{a}	990^{a}	807^{a}
12-May	1095^{a}	1028^{a}	1031^{a}	1093^{a}
29-May	1761^{a}	1639^{a}	1643^{a}	1757^{a}

† Means with the same letter are not significantly different at $\alpha = 0.10$.

Table 9: Runoff coefficient for each storm and treatment during the study.

Date (2008-2009)	**No-cover (N=3)**	**Blanket (ECB) (N=3)**	**Hydromulch (N=12)**	**Loose straw (N=3)**
12 Jul	0.42	0.41	0.26	0.25
14-Jul	0.41	0.38	0.47	0.55
28-Jul	0.45	0.25	0.05	0.08
14-Aug	0.30	0.15	0.15	0.11
27-Aug	0.46	0.36	0.30	0.27
10-Oct	0.24	0.12	0.15	0.17
3-Dec	0.29	0.22	0.19	0.16
15-Dec	0.32	0.19	0.24	0.20
21-Jan	0.27	0.21	0.21	0.20
8-Mar	0.29	0.22	0.17	0.29
1-Apr	0.39	0.26	0.24	0.34
12-May	0.38	0.30	0.36	0.34
29-May	0.44	0.34	0.41	0.30
Average	0.36	0.26	0.25	0.25

† Runoff coefficient was calculated using runoff volume statistically compared in Table 6 based on formulas presented in Table 5.

Table 10: Effect of cover treatments on MTSS (kg ha^{-1}).

MTSS (kg ha^{-1})				
Cover treatment				
Date (2008-2009)	**No cover (N=3)**	**Blanket (ECB) (N=3)**	**Hydromulch (N=12)**	**Loose straw (N=3)**
12 July	16166 ^{a}	1249 ^{b}	1075 ^{b}	384 ^{b}
14 July	13899^{a}	2350 ^{b}	2253 ^{b}	484 ^{b}
28 July	2450 ^{a}	194 ^{b}	157 ^{b}	88 ^{b}
14 Aug	5861^{a}	826 ^{b}	682 ^{b}	162 ^{b}
27 Aug	507 ^{a}	221 ^{a}	214 ^{a}	108 ^{a}
24 Oct	64 ^{a}	22 ^{a}	56 ^{a}	39 ^{a}
3 Dec	32 ^{a}	10 ^{b}	18 ^{ab}	5 ^{b}
15 Dec	99 ^{a}	58 ^{a}	70 ^{a}	39 ^{a}
21 Jan	19 ^{a}	11 ^{b}	12 ^{b}	7 ^{b}
8 March	201 ^{a}	96 ^{a}	60 ^{a}	114 ^{a}
1 Apr	111 ^{a}	78 ^{a}	86 ^{a}	86 ^{a}
12 May	376 ^{a}	181 ^{b}	189 ^{b}	162 ^{b}
29 May	274 ^{a}	200 ^{a}	209 ^{a}	138 ^{a}

† Means with the same letter are not significantly different at $\alpha = 0.10$.

† Hydromulch: 1GM, 2GM, 1GMP, 2GMP.

Table 11: The impact of PAM, and effect of lime and fertilizer incorporation on MTSS ($kg\ ha^{-1}$).

MTSS ($kg\ ha^{-1}$)	**Lime and fertilizer placement**		**Polyacrylamide (PAM)**	
Date (2008-2009)	**Incorporated (N= 12)**	**not incorporated (N=6)**	**No (N=12)**	**Yes (N=6)**
12-Jul	944^{a}	1080^{a}	983^{a}	1002^{a}
14-Jul	1171^{a}	3581^{a}	2585^{a}	752^{b}
28-Jul	169^{a}	116^{a}	173^{a}	109^{b}
14-Aug	854^{a}	151^{b}	231^{a}	289^{b}
27-Aug	245^{a}	102^{a}	785^{a}	129^{a}
24-Oct	54^{a}	50^{a}	35^{a}	87^{a}
3-Dec	17^{a}	11^{a}	11^{a}	20^{a}
15-Dec	62^{a}	65^{a}	65^{a}	55^{a}
21-Jan	10^{a}	11^{a}	9^{b}	14^{a}
8-Mar	106^{a}	57^{a}	102^{a}	65^{a}
1-Apr	92^{a}	83^{a}	88^{a}	92^{a}
12-May	193^{a}	164^{a}	184^{a}	182^{a}
29-May	211^{a}	200^{a}	210^{a}	204^{a}

† Means with the same letter are not significantly different at $\alpha = 0.10$.

Table 12: The impact of PAM, and effect of lime and fertilizer incorporation on MTSS (kg ha^{-1}) within the hydromulch treatments.

MTSS (kg ha^{-1})	**Lime and fertilizer placement**		**Polyacrylamide (PAM)**	
Date (2008-2009)	**Incorporated (N= 6)**	**not incorporated (N=6)**	**No (N=6)**	**Yes (N=6)**
12-Jul	1071 ^{a}	1080 ^{a}	1149 ^{a}	1002 ^{a}
14-Jul	925 ^{b}	3581 ^{a}	3753 ^{a}	752 ^{b}
28-Jul	197 ^{a}	116 ^{a}	205 ^{a}	109 ^{b}
14-Aug	1214 ^{a}	151 ^{b}	1075 ^{a}	289 ^{b}
27-Aug	325 ^{a}	102 ^{a}	298 ^{a}	129 ^{a}
24-Oct	77 ^{a}	50 ^{a}	40 ^{a}	87 ^{a}
3-Dec	25 ^{a}	11 ^{a}	16 ^{a}	20 ^{a}
15-Dec	75 ^{a}	65 ^{a}	85 ^{a}	55 ^{a}
21-Jan	12 ^{a}	11 ^{a}	9 ^{b}	14 ^{a}
8-Mar	63 ^{a}	57 ^{a}	54 ^{a}	65 ^{a}
1-Apr	90 ^{a}	83 ^{a}	81 ^{a}	92 ^{a}
12-May	215 ^{a}	164 ^{a}	197 ^{a}	182 ^{a}
29-May	218 ^{a}	200 ^{a}	213 ^{a}	204 ^{a}

† Means with the same letter are not significantly different at $\alpha = 0.10$.

Table 13: Soil loss reduction compared to seeded no cover control for each treatment and storm event during the study.

Date (2008-2009)	**Blanket (ECB)**	**Hydromulch**	**Loose straw**
12-Jul	0.92	0.93	0.98
14-Jul	0.83	0.84	0.97
28-Jul	0.92	0.94	0.96
14-Aug	0.86	0.88	0.97
27-Aug	0.56	0.58	0.79
10-Oct	0.61	0.12	0.30
3-Dec	0.70	0.44	0.83
15-Dec	0.41	0.30	0.60
21-Jan	0.41	0.40	0.66
8-Mar	0.16	0.47	0.43
1-Apr	0.30	0.10	0.22
12-May	0.52	0.00	0.57
29-May	0.27	0.24	0.31
Average	0.58	0.53	0.66

† Soil loss reduction was calculated using TSS data statistically compared in Table 9 based on formulas presented in Table 5.

Table 14: Percent establishment of common bermudagrass as affected by temporary cover treatment and sampling date, E.V. Smith, 2008

Mulch	**Lime and fertilizer incorporated**	**Polyacrylamide (PAM)**	**Percent Establishment**		
			June 26	**July8**	**July22**
1GMP	Y	Y	34.0	44.9	68.0
2GMP	N	Y	49.0	62.7	67.3
1GM	Y	N	42.3	72.0	84.0
2GM	N	N	33.7	69.3	73.3
1ECB	Y	N	17.3	55.6	59.3
1WS	Y	N	6.7	47.1	33.3
1NC	Y	N	7.0	23.6	30.0

1GM: Hydromulch product with incorporation of lime and fertilizer by tillage.

2 GM: Hydromulch without incorporation of fertilizer by tillage.

1GMP: Hydromulch and PAM with incorporation of lime and fertilizer by tillage.

2GMP: Hydromulch and PAM without incorporation of fertilizer by tillage.

1WS: Wheat straw with incorporation of lime and fertilizer by tillage and hand seeding.

1ECB: Erosion control blanket with incorporation of lime and fertilizer by tillage.

1NC: Seeded no-cover (control) with incorporation of lime and fertilizer by tillage.

Table 15: Contrast to compare percent establishment of common bermudagrass for selected treatments.

Cover treatment	**Pr > F**		
	June 26	**July8**	**July22**
PAM versus No PAM (Hydromulch treatments)	0.61	0.27	0.24
Incorporated of lime and fertilizer versus surface application (Hydromulch treatments)	0.64	0.61	0.52
Hydromulch versus erosion control blanket	0.0008	0.37	0.005
Hydromulch versus loose straw	0.01	0.69	0.0019

† Pr values < 0.1 indicate significant difference between treatments.

† Hydromulch: 1GM, 2GM, 1GMP, 2GMP.

Table 16: Comparisons between treatments for filtered turbidity (NTU).

Filtered turbidity (NTU)				
Cover treatment				
Date (2008-2009)	**No cover (N=3)**	**Blanket (ECB) (N=3)**	**Hydromulch (N=12)**	**Loose straw (N=3)**
12 July	3000^{a}	715^{b}	622^{b}	512^{b}
14 July	1336^{a}	701^{ab}	352^{b}	442^{b}
28 July	1315^{a}	184^{b}	276^{b}	49^{b}
14 Aug	403^{a}	303^{ab}	250^{bc}	155^{c}
27 Aug	43^{a}	22^{b}	29^{b}	20^{b}
24 Oct	31^{ab}	38^{a}	24^{bc}	19^{c}
3 Dec	20^{a}	13^{a}	13^{b}	12^{b}
15 Dec	24^{a}	18^{ab}	11^{b}	15^{ab}
21 Jan	23^{a}	13^{b}	14^{b}	12^{b}
8 March	15^{a}	17^{a}	13^{a}	13^{a}
1 Apr	30^{a}	24^{a}	13^{a}	11^{a}
12 May	49^{a}	18^{a}	49^{a}	20^{a}
29 May	38^{a}	22^{ab}	20^{b}	17^{b}
Average	487	161	130	100

† Means with the same letter are not significantly different at $\alpha = 0.10$.

† Hydromulch: 1GM, 2GM, 1GMP, 2GMP.

Table 17: The impact of PAM, and effect of lime and fertilizer incorporation on filtered turbidity (NTU).

Filtered turbidity (NTU)	**Lime and fertilizer placement**		**Polyacrylamide (PAM)**	
Date (2008-2009)	**Incorporated (N= 12)**	**not incorporated (N=6)**	**No (N=12)**	**Yes (N=6)**
12-Jul	648 ^{a}	562 ^{b}	644 ^{a}	569 ^{a}
14-Jul	538 ^{a}	200 ^{b}	476 ^{a}	324 ^{a}
28-Jul	233 ^{a}	203 ^{a}	210 ^{a}	248 ^{a}
14-Aug	224 ^{a}	280 ^{a}	197 ^{a}	335 ^{b}
27-Aug	27 ^{a}	24 ^{a}	27 ^{a}	25 ^{a}
24-Oct	27 ^{a}	24 ^{a}	27 ^{a}	23 ^{a}
3-Dec	13 ^{a}	11 ^{b}	12 ^{a}	14 ^{a}
15-Dec	13 ^{a}	11 ^{a}	13 ^{a}	12 ^{a}
21-Jan	13 ^{a}	16 ^{a}	14 ^{a}	14 ^{a}
8-Mar	15 ^{a}	12 ^{a}	14 ^{a}	14 ^{a}
1-Apr	13 ^{a}	17 ^{a}	16 ^{a}	11 ^{a}
12-May	33 ^{a}	50 ^{a}	44 ^{a}	28 ^{a}
29-May	19 ^{a}	22 ^{a}	17 ^{a}	25 ^{a}

† Means with the same letter are not significantly different at $\alpha = 0.10$.

Table 18: The impact of PAM, and effect of lime and fertilizer incorporation on filtered Turbidity (NTU) within the hydromulch treatments.

Filtered turbidity (NTU)	**Lime and fertilizer placement**		**Polyacrylamide (PAM)**	
Date (2008-2009)	**Incorporated (N= 6)**	**not incorporated (N=6)**	**No (N=6)**	**Yes (N=6)**
12-Jul	682^{a}	562 ^{a}	675 ^{a}	569 ^{a}
14-Jul	503 ^{a}	200 ^{b}	379 ^{a}	324 ^{a}
28-Jul	349 ^{a}	203 ^{a}	304 ^{a}	248 ^{a}
14-Aug	220 ^{a}	280 ^{a}	165 ^{b}	335 ^{a}
27-Aug	33 ^{a}	24 ^{a}	32 ^{a}	25 ^{a}
24-Oct	25 ^{a}	24 ^{a}	25 ^{a}	23 ^{a}
3-Dec	32 ^{a}	38 ^{b}	29 ^{a}	40 ^{a}
15-Dec	15 ^{a}	11 ^{a}	12 ^{a}	14 ^{a}
21-Jan	10 ^{a}	11 ^{a}	10 ^{a}	11 ^{a}
8-Mar	15 ^{a}	12 ^{a}	14 ^{a}	14 ^{a}
1-Apr	13 ^{a}	16 ^{a}	15 ^{a}	14 ^{a}
12-May	15 ^{a}	12 ^{a}	13 ^{a}	14 ^{a}
29-May	9 ^{a}	17 ^{a}	15 ^{a}	11 ^{a}

† Means with the same letter are not significantly different at $\alpha = 0.10$.

Table 19: Effect of cover treatment on NO_3-N, H_2P0_4- P in runoff, in µg/L.

NO_3-N (µg L^{-1})				
Cover treatment (N=21)				
Date (2008-2009)	**No cover (N=3)**	**Blanket (ECB) (N=3)**	**Hydromulch (N=12)**	**Loose straw (N=3)**
12 July	1.60^{a}	0.93^{b}	0.1^{b}	0.03^{b}
14 July	0.49^{a}	0.15^{a}	1.15^{a}	0.15^{a}
28 July	1.22^{a}	0.52^{ab}	0.09^{b}	0.47^{ab}
14 Aug	1.00^{a}	0.92^{a}	0.16^{a}	0.42^{a}
H_2PO_4-P (µg L^{-1})				
Cover treatment (N=21)				
Date (2008-2009)	**No cover (N=3)**	**Blanket (ECB) (N=3)**	**Hydromulch (N=12)**	**Loose straw (N=3)**
12 July	0.24^{a}	0.23^{a}	0.09^{a}	0.42^{a}
14 July	1.1^{a}	0.66^{a}	0.87^{a}	0.58^{a}
28 July	0.06^{a}	0.02^{a}	0.57^{a}	0.47^{a}
14 Aug	0.81^{a}	0.11^{a}	0.96^{a}	1.18^{a}

† Means with the same letter are not significantly different at $\alpha = 0.10$.

† Hydromulch: 1GM, 2GM, 1GMP, 2GMP.

Table 20: The impact of PAM, lime and fertilizer incorporation on NO_3-N and H_2P0_4- P in µg L^{-1}.

Nitrate (µg L^{-1})						
Date	**PAM**	**NO_3^-N (µg L^{-1})**	**N**	**Lime and Fertilizer Placement**	**NO_3^-N (µg L^{-1})**	**N**
12-July	No	0.54^{a}	12	Incorporated	0.23^{a}	12
	Yes	0.22^{a}	6	Not incorporated	0.29^{a}	6
14-July	No	1.08^{a}	12	Incorporated	0.64^{a}	12
	Yes	0.29^{a}	6	Not incorporated	1.18^{a}	6
28-July	No	0.33^{a}	12	Incorporated	0.25^{a}	12
	Yes	0.02^{b}	6	Not incorporated	0.18^{a}	6
14-Aug	No	0.46^{a}	12	Incorporated	0.47^{a}	12
	Yes	0.08^{a}	6	Not incorporated	0.05^{a}	6
Phosphate (µg L^{-1})						
Date	**PAM**	**$H_2P0_4^-$ P (µg L^{-1})**	**N**	**Lime and Fertilizer Placement**	**$H_2P0_4^-$ P (µg L^{-1})**	**N**
12-July	No	0.17^{a}	12	Incorporated	0.21^{a}	12
	Yes	0.15^{a}	6	Not incorporated	0.09^{a}	6
14-July	No	0.78^{a}	12	Incorporated	0.71^{a}	12
	Yes	0.80^{a}	6	Not incorporated	0.93^{a}	6
28-July	No	0.33^{a}	12	Incorporated	0.23^{a}	12
	Yes	0.72^{a}	6	Not incorporated	0.92^{a}	6
14-Aug	No	0.55^{a}	12	Incorporated	0.54^{a}	12
	Yes	1.48^{a}	6	Not incorporated	1.48^{a}	6

† Means with the same letter are not significantly different at $\alpha = 0.10$.

Table 21: The impact of PAM, lime and fertilizer incorporation on NO_3-N and H_2P0_4- P in µg L^{-1} within the hydromulch treatments.

Nitrate (µg L^{-1})						
Date	**PAM**	**NO_3^-N (µg L^{-1})**	**N**	**Lime and Fertilizer Placement**	**NO_3^-N (µg L^{-1})**	**N**
12-July	No	0.08^{a}	6	Incorporated	0.01^{b}	6
	Yes	0.22^{a}	6	Not incorporated	0.29^{a}	6
14-July	No	2.02^{a}	6	Incorporated	1.13^{a}	6
	Yes	0.29^{a}	6	Not incorporated	1.18^{a}	6
28-July	No	0.18^{a}	6	Incorporated	0.01^{a}	6
	Yes	0.02^{b}	6	Not incorporated	0.18^{a}	6
14-Aug	No	0.24^{a}	6	Incorporated	0.27^{a}	6
	Yes	0.08^{a}	6	Not incorporated	0.05^{a}	6
Phosphate (µg L^{-1})						
Date	**PAM**	**$H_2P0_4^-$ P (µg L^{-1})**	**N**	**Lime and Fertilizer Placement**	**$H_2P0_4^-$ P (µg L^{-1})**	**N**
12-July	No	0.02^{a}	6	Incorporated	0.08^{a}	6
	Yes	0.15^{a}	6	Not incorporated	0.09^{a}	6
14-July	No	0.94^{a}	6	Incorporated	0.81^{a}	6
	Yes	0.80^{a}	6	Not incorporated	0.93^{a}	6
28-July	No	0.42^{a}	6	Incorporated	0.22^{a}	6
	Yes	0.72^{a}	6	Not incorporated	0.92^{a}	6
14-Aug	No	0.45^{a}	6	Incorporated	0.44^{a}	6
	Yes	1.48^{a}	6	Not incorporated	1.48^{a}	6

† Means with the same letter are not significantly different at $\alpha = 0.10$.

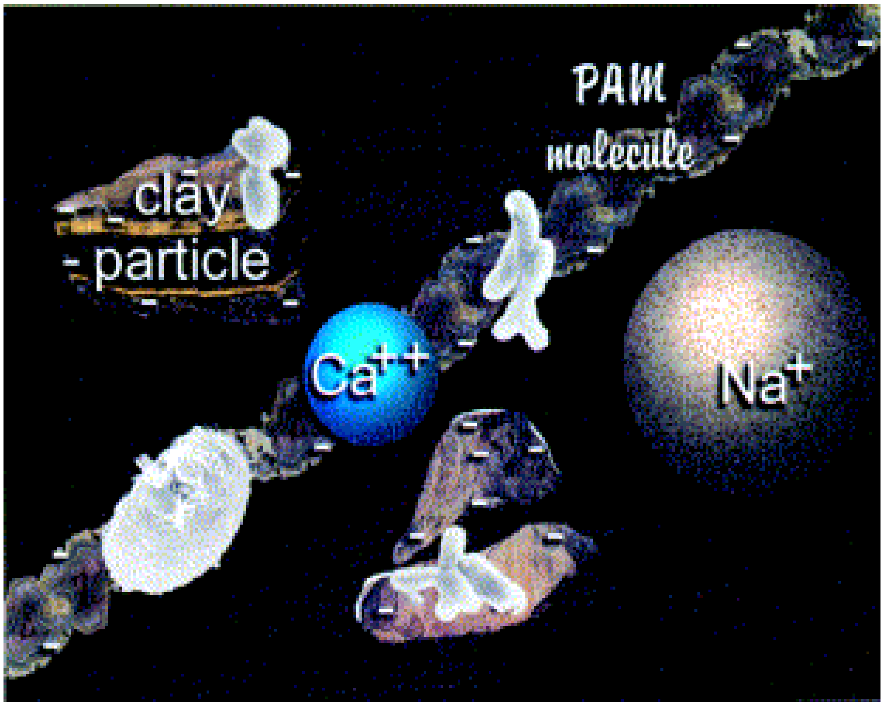

Figure 1: Diagram conception of a polyacrylamide PAM molecule sticking to soil particles, a calcium ion with comparatively smaller hydrated radius, a sodium ion with a comparatively large hydrated radius. Ca^{2+} contained in the water bridges the anionic surfaces of soil particles and PAM molecules which enable flocculation.

Source: Entry et al. (2002).

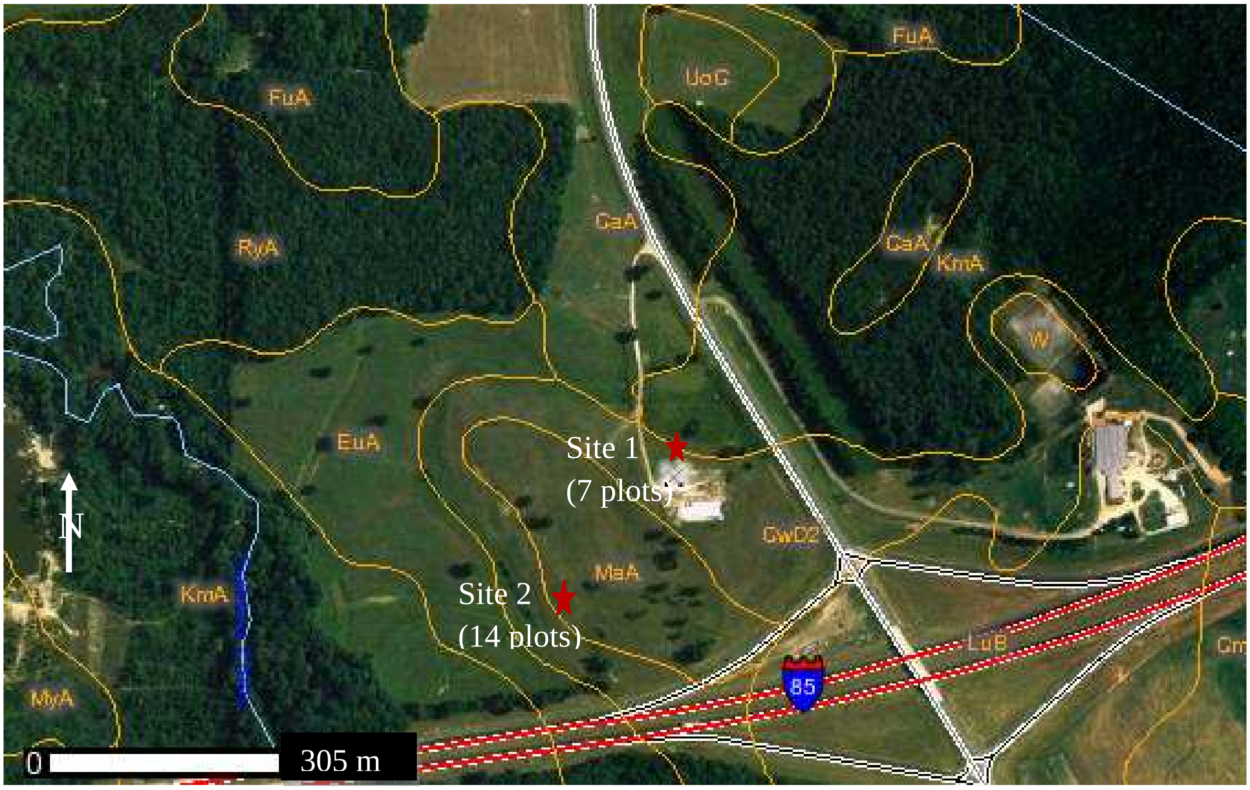

Figure 2: Aerial view and Soil Map of E.V. Smith, Macon County, Alabama (USDA, 2009). CwD2: Cowarts loamy sand; KmA: Kinston-Mooreville complex loamy sand, frequently flooded; MaA: Malbis fine sandy loam.

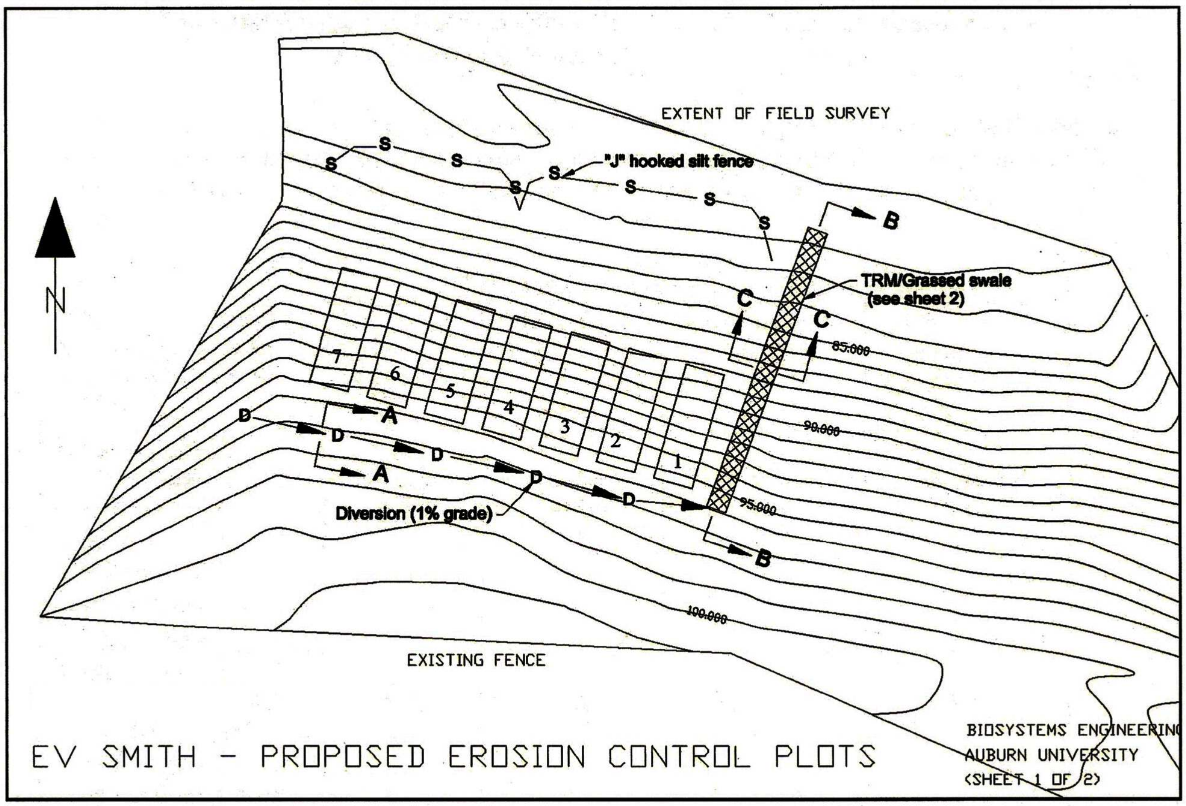

Figure 3: Experimental site showing plot layout area with erosion and sediment control, Site 1. Drawn by Mark Dougherty. Contour elevations are in feet. B: Swale; D: diversion; S: silt fence.

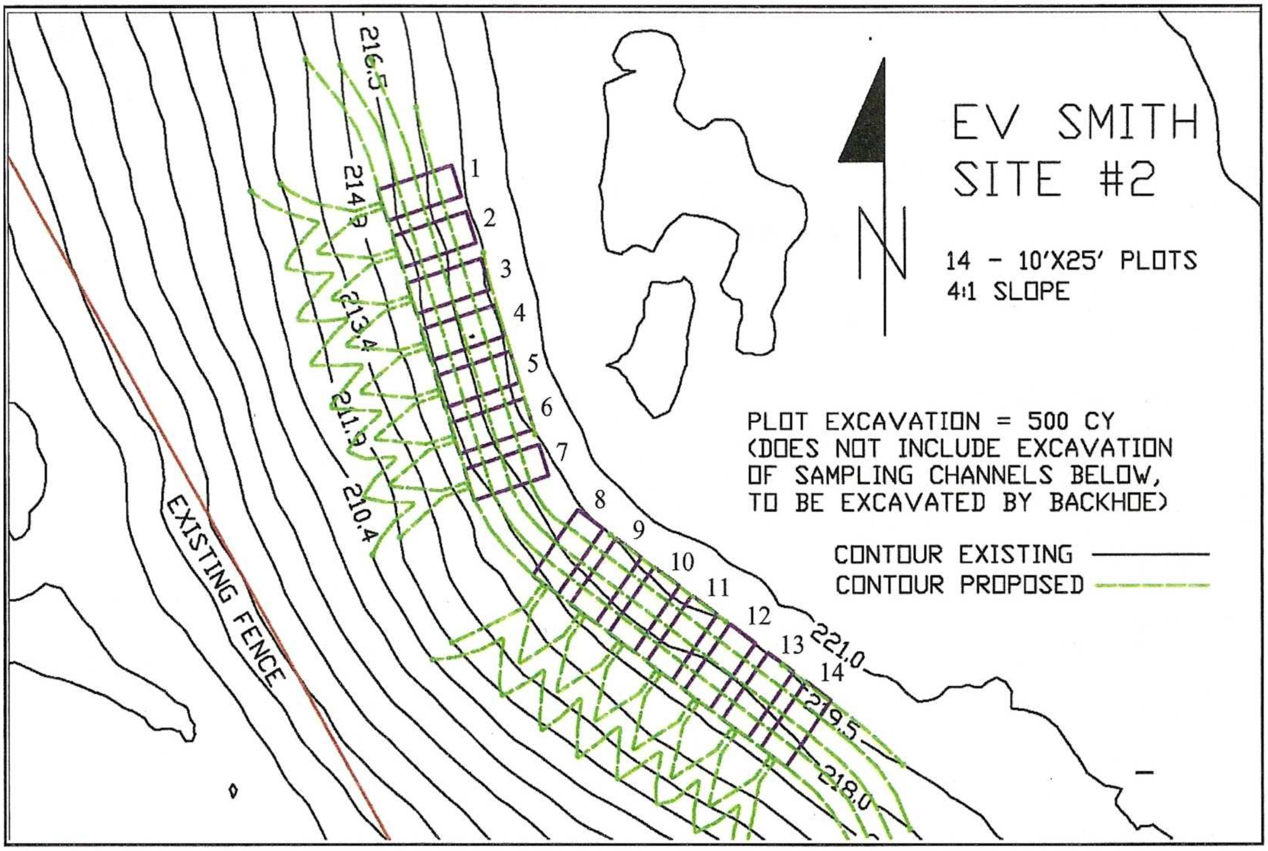

Figure 4: Experimental site showing plot layout area with erosion and sediment control, Site 2. Drawn by Mark Dougherty. Contour elevations are in feet.

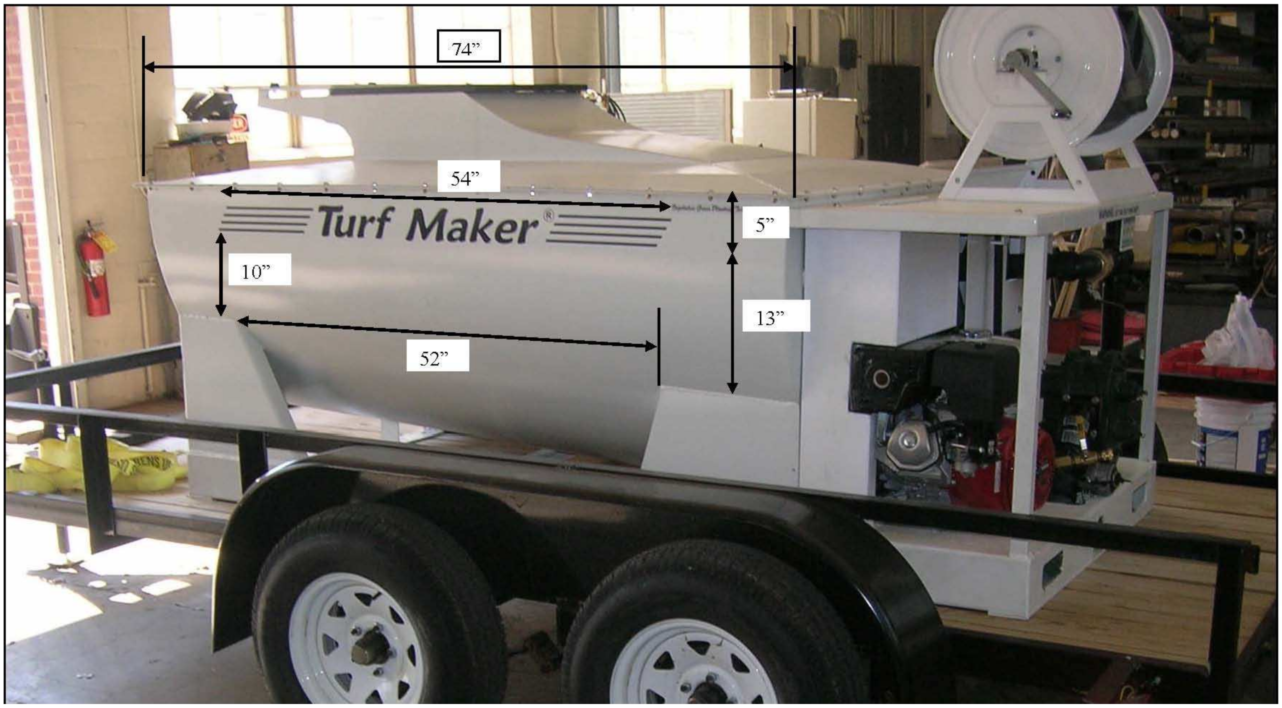

Figure 5: Hydroseeder used to apply hydromulch treatments. Gasoline-powered, belt-powered, belt-driven hydroseeder shown on tandem-axle trailer. Dimensions are shown in inches.

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Figure 6: Proportional Coshocton wheel sampler installed with runoff downspout in excavated trench at E.V.Smith.

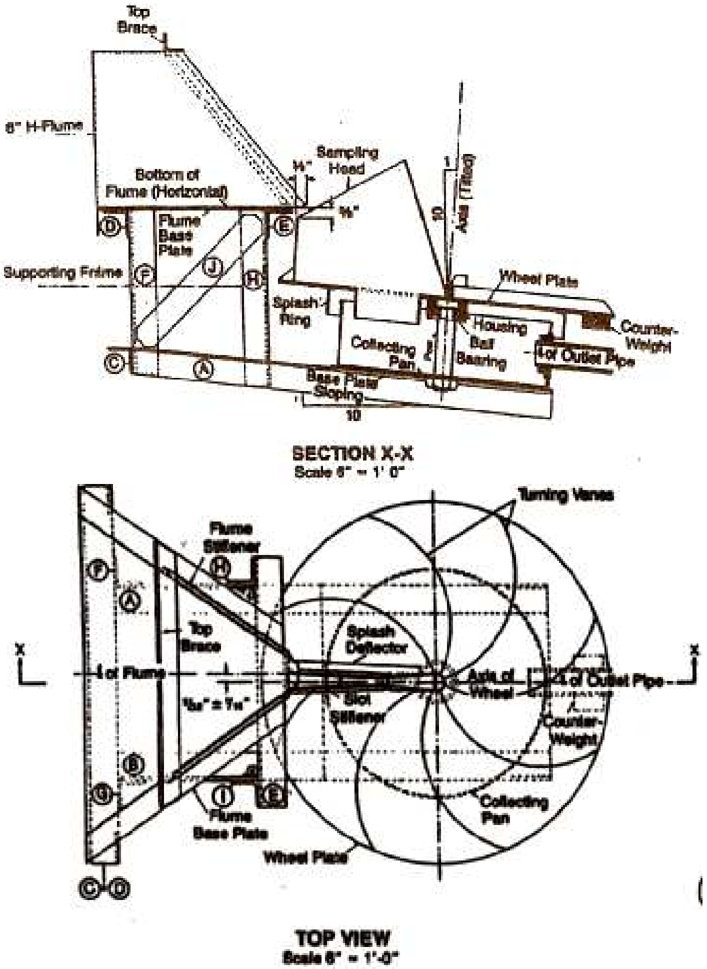

Figure 7: Fabricated Coshocton wheel installed at test plots. Top figure courtesy of Bonta (2002).

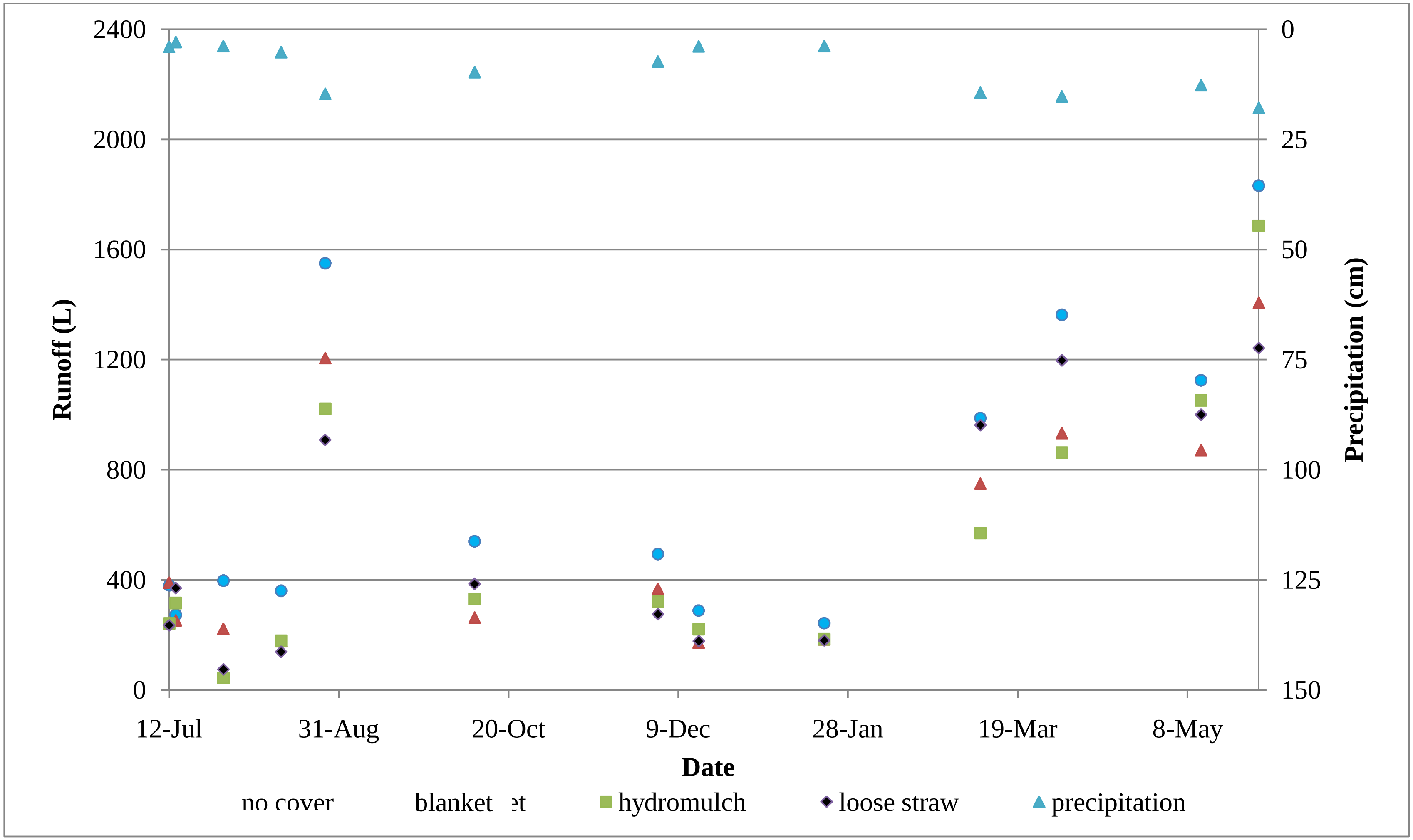

Figure 8: Average runoff (L) for each treatment and storm during the study period, indicating response of runoff to variable storm depths (cm) indicated on top of the graph (2008-2009).

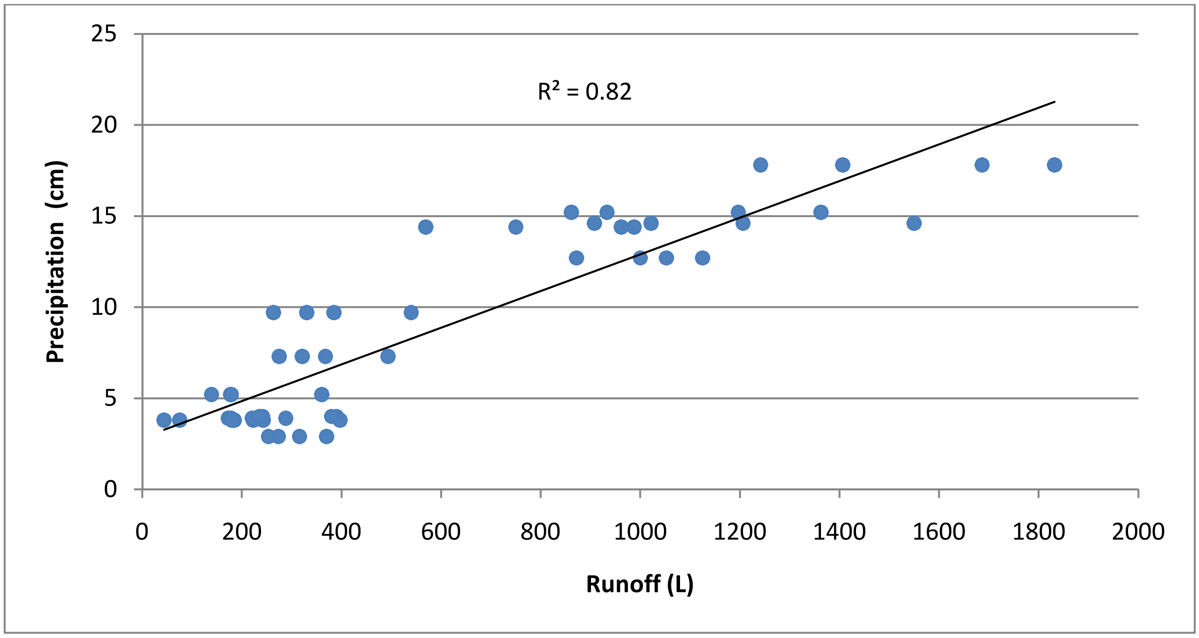

Figure 9: Regression of measured runoff volume (L) for each treatment and storm event versus storm depth (cm).

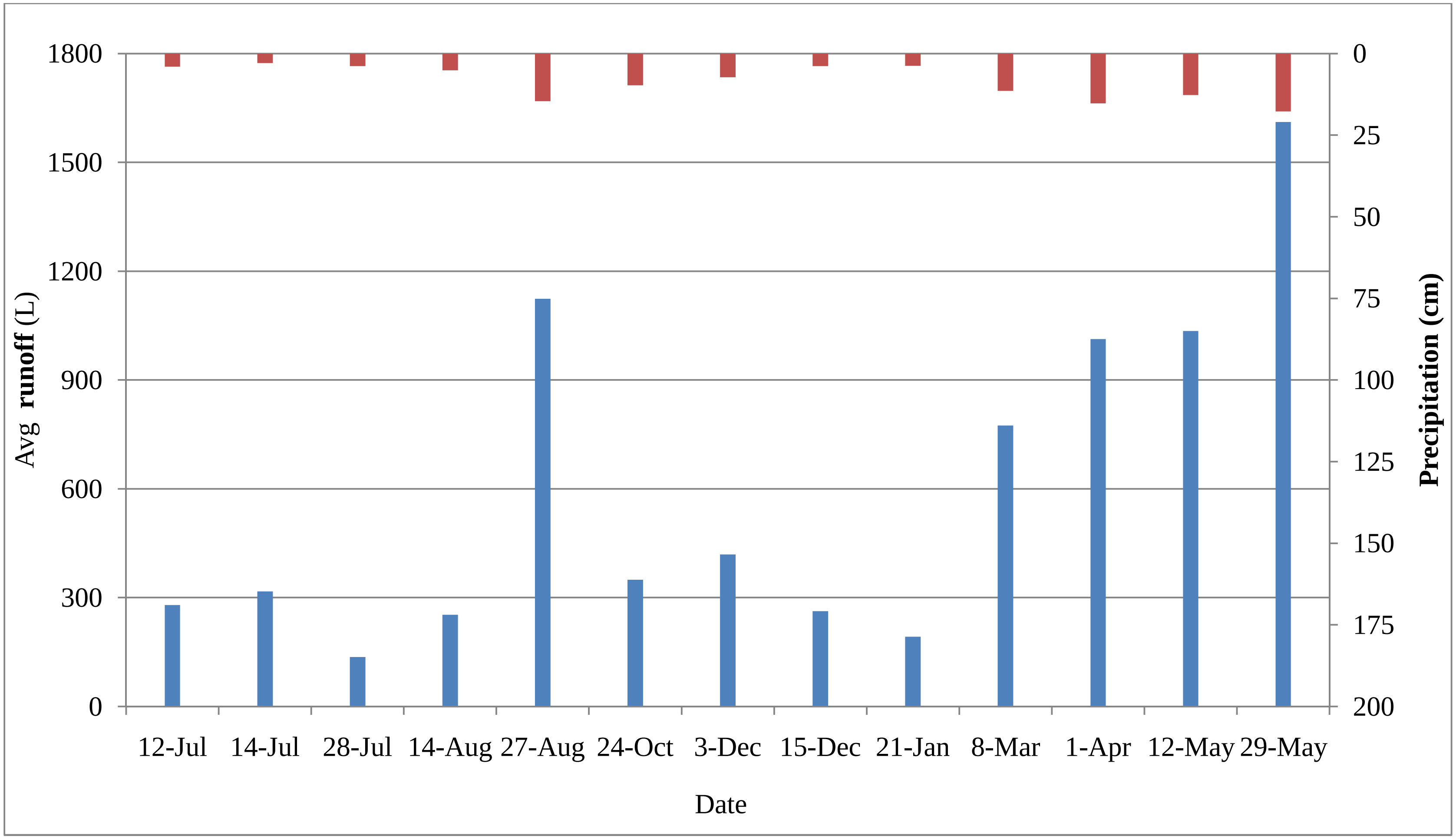

Figure 10: Average runoff (L) for all treatments and precipitation (cm) for each of the 13 rainfall events.

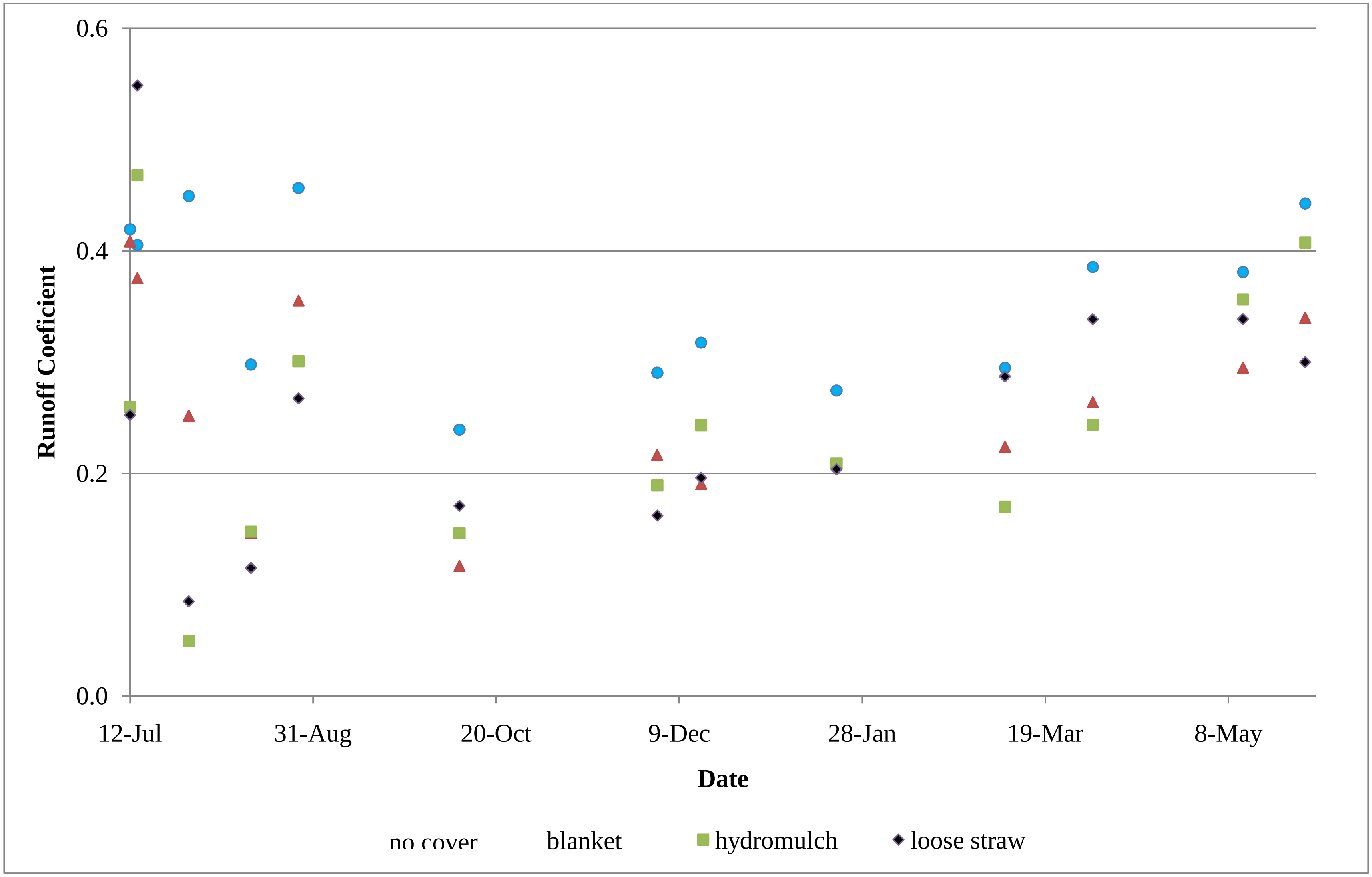

Figure 11: Average runoff coefficients for each storm and treatment during the study, suggesting different cover conditions at the beginning and end of the study period. Runoff coefficient was calculated according to formulas in Table 5.

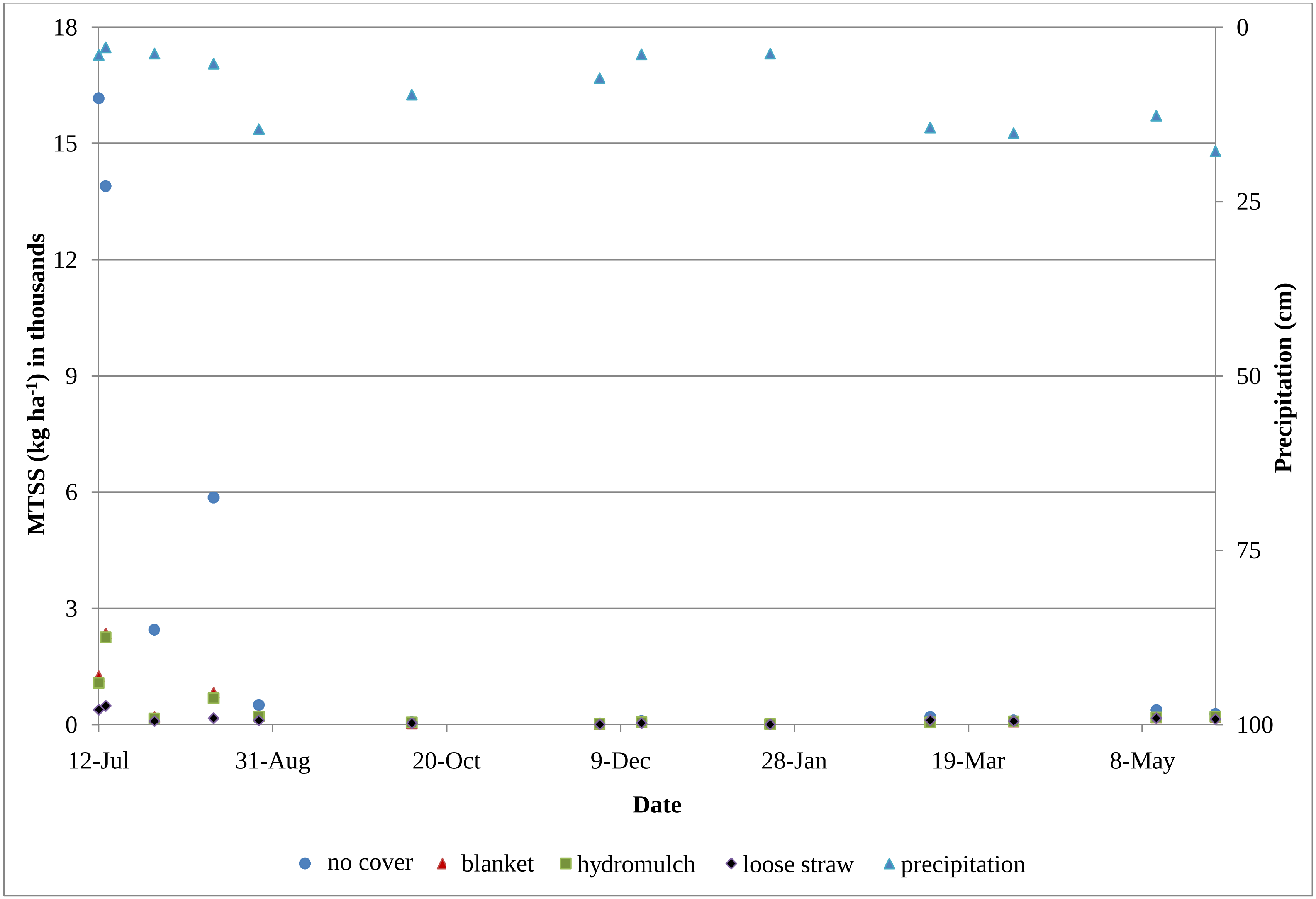

Figure 12: MTSS Load (kg ha^{-1}) and precipitation (cm) for each of the 13 rainfall events.

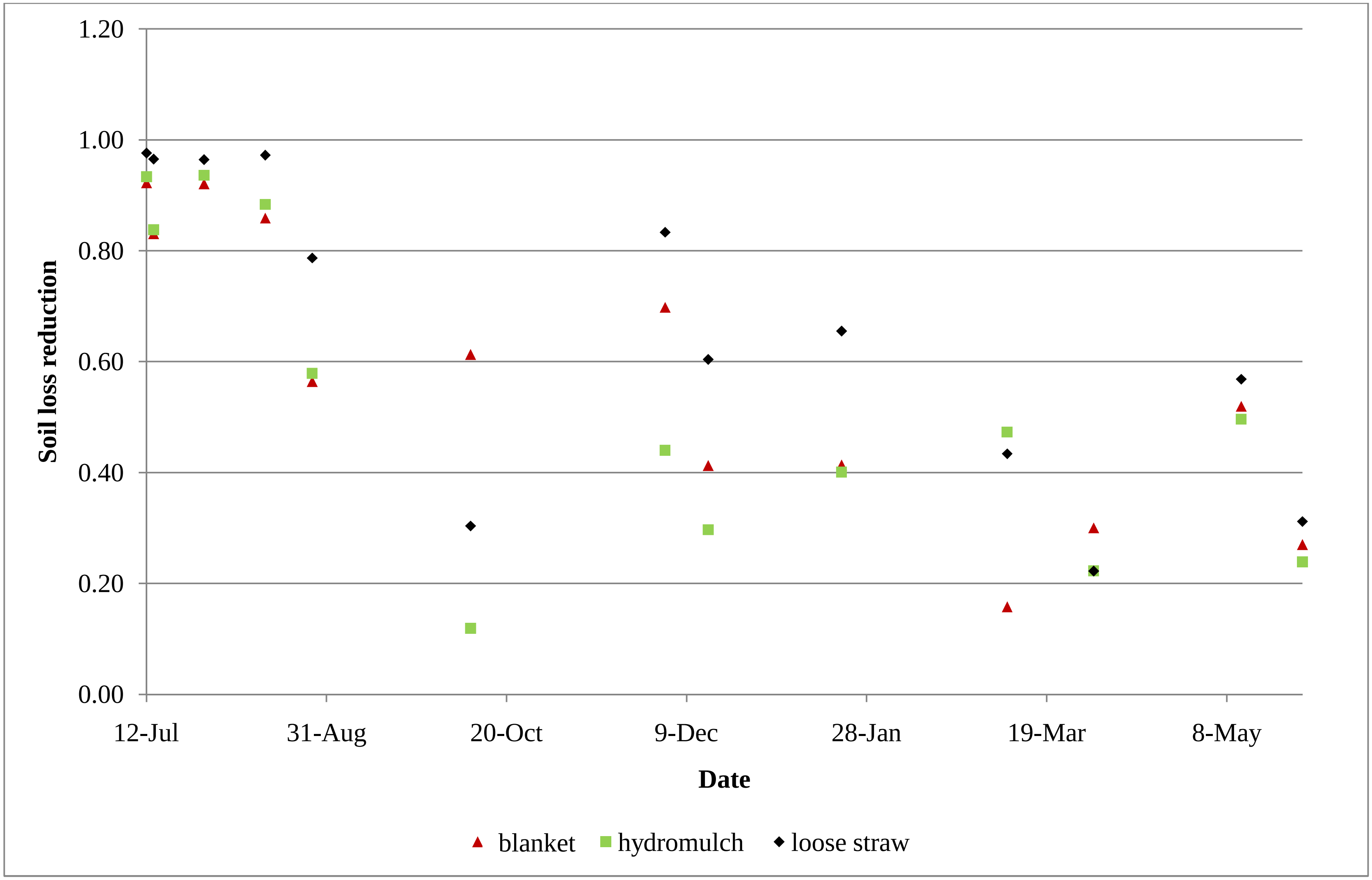

Figure 13: Soil loss reduction from cover treatments relative to no cover control during the study. Soil loss reduction was calculated according to formula shown in Table 5.

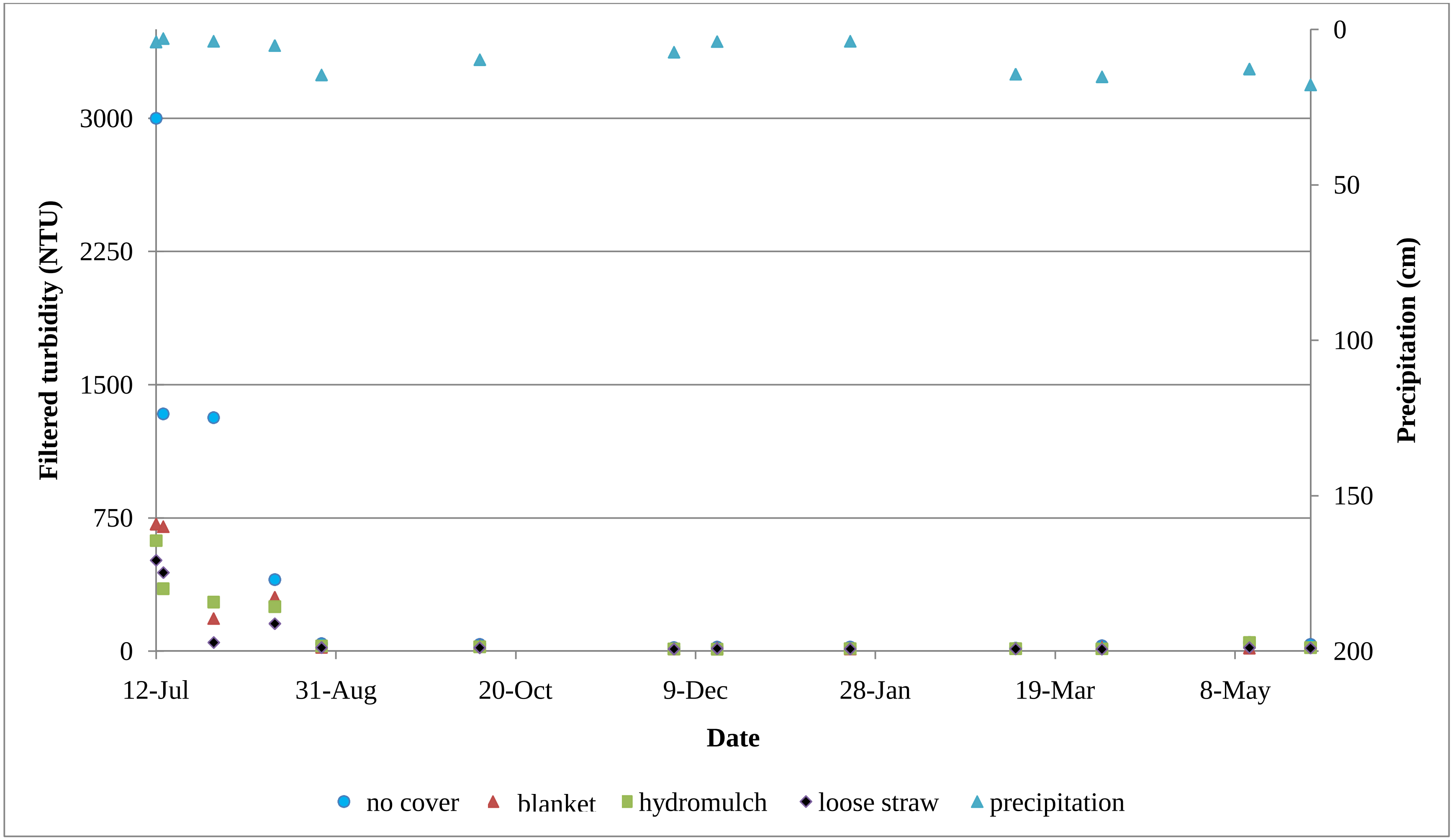

Figure 14: Filtered turbidity (NTU) and precipitation (cm) for each of the 13 rainfall events.