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16. Abstract: Runoff during the revegetation of roadsides can transport sediment and nutrients offsite, leading surface water quality reductions. Two field experiments were conducted near Starkville, MS in 2011 and 2012 to evaluate the influence of various N and P sources and rates, fertilization timing, and mulch type on vegetative establishment and nutrient and sediment runoff losses. Stainless steel runoff frames (0.75 x 2.0 m) were installed in a randomized complete block with eight treatments and four replications during both experiments. A bahiagrass (*Paspalum notatum* Flugge), tall fescue (*Festuca arundinacea* Shreb), sericea lespedeza [*Lespedeza cuneata* (Dum. Cours.) G. Don], and common bermudagrass [*Cynodon dactylon* (L.) Pers.] mixture was seeded within each frame during Experiment I. Crimson clover (*Trifolium incarnatum* L.) was added for Experiment II. Fertilization of Experiment I consisted of 73.5 or 147 kg N ha^{-1} as 13-13-13, poultry litter, ammonium nitrate, stabilized urea, polymer coated urea, or diammonium phosphate. Experiment II mulching materials consisted of wheat straw and seven hydromulches; paper fiber, wood fiber, wood/paper fiber blend, flexible growth medium (FGM), extended term-FGM (ET-FGM), bonded fiber matrix (BFM). Runoff from natural and simulated rainfall was analyzed for PO_4^{3-}-P, total P (TP), NH_4^+-N, NO_3^- -N, total N (TN), and total solids (TS). Weekly percent vegetative coverage ratings were collected during both experiments. Experiment I results suggest fertilization program did not have an influence on vegetative establishment or TS runoff losses. Generally, the greatest N and P runoff losses occurred during the first runoff event following fertilization. Splitting 147 kg N ha^{-1} into two separate applications increased N and P losses. Application of organic plus inorganic P increased orthophosphate in runoff compared to inorganic P alone. Experiment II results indicate straw was the most effective mulch for increasing vegetative establishment and limiting solids and nutrients in runoff. However, lack of fertilizer prill dissolution may have influenced N and P runoff losses during dry conditions. FGM, ET-FGM, and BFM were more effective than paper, wood, and paper/wood fiber in reducing solids and nutrients in runoff. These experiments will provide vegetation coordinators with beneficial information regarding fertilization and mulching practices with the least environmental impact.

17. Key Words: runoff, sediment, nitrogen, phosphorus, fertilization, mulch

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Evaluation of Fertility Practices during Roadside Establishment in Mississippi to Minimize Nonpoint Source Pollutants

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Final Report
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NOTICE

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CHAPTER I

INTRODUCTION

Runoff during the establishment of newly constructed roadsides can transport sediment and nutrients from the site, leading to water quality issues. Therefore, the Mississippi Department of Environmental Quality (MDEQ) and Mississippi Department of Transportation (MDOT) have developed specific erosion control practices to be implemented during the establishment period (MDEQ, 1994; MDOT, 2001). These specifications outline plant species, fertilizer, and erosion control practices to be used during and after construction. The goal is to reach 70 percent vegetative cover within 30 days of planting while limiting nonpoint source (NPS) pollution. However, nutrient and sediment loss issues during the establishment period may still exist with the current practices.

Mississippi DOT has developed both a spring-summer and fall-winter seed mixture due to road construction taking place throughout the year. Both mixtures contain common bermudagrass [*Cynodon dactylon* (L.) Pers.], bahiagrass (*Paspalum notatum* Flugge), tall fescue (*Festuca arundinacea* Schreb.), and sericea lespedeza [*Lespedeza cuneata* (Dum. Cours.) G. Don]. However, crimson clover (*Trifolium incarnatum* L.) is also included in the fall-winter mixture. Each plant species has its specific limitations with regard to germination and growth. Common bermudagrass, bahiagrass, and sericea lespedeza are warm-season species that are slow to establish from seed. Tall fescue and crimson clover are cool-season species and have low tolerance for heat and drought (Logan et al., 1969; Beaty and Powell, 1978; Charles et al., 2001; Munshaw et al. 2001; Hannaway and Meyers, 2004).

It is necessary to consider these limitations when developing establishment practices. Temperature and precipitation are the most limiting climatic factors for plant growth (Beard, 1973). Nutrient availability is also an issue on roadsides because the topsoil is typically removed during construction, leaving the infertile subsoil as the seedbed (Booze-Daniels et al., 2000). Mississippi DEQ and DOT specify the use of mulches to compensate for environmental factors and to reduce runoff during establishment. Inorganic fertilizers are used to compensate for nutrient deficient soils. However, information concerning the period of time needed for acceptable coverage and patterns of nutrient loss during runoff is needed to improve current recommendations.

Fertilizer rates are often increased during propagation to enhance vegetative establishment (Rodriguez, 2001). Current Mississippi specifications require that 13-13-13 fertilizer be applied at a nitrogen (N) rate of 147 kg ha^{-1}. The concern is that applying N and phosphorus (P) at those rates could increase the risk of nutrient loss should runoff occur. Transport of nutrients to surface water bodies may stimulate algal and plant growth, leading to eutrophication (USEPA, 1996). Eutrophic conditions are detrimental to plant and animal life in and around those waters. Furthermore, nutrient pollution can limit surface water use for drinking.

The Mississippi NPS Management Plan lists sediment loss during roadside construction as a potential surface water pollutant but does not mention nutrients (MDEQ, 2000). Although many other states have conducted research on roadside establishment and erosion control, data supporting best practices for Mississippi roadsides is lacking. The development of roadside establishment practices that optimize vegetative coverage while limiting sediment and nutrient loss will help maintain the safety of Mississippi surface water. Therefore, the objectives of this study are: 1) to evaluate the influence of various N and P sources and rates on vegetative establishment and nutrient and sediment loss during runoff, 2) to evaluate the influence of fertilization timing on vegetative establishment and nutrient and sediment loss during runoff, and 3) to determine if mulch type has an effect on vegetative establishment and nutrient and sediment loss during runoff.

CHAPTER II

LITERATURE REVIEW

Plant Species Specified for Mississippi Roadside Plantings

Common Bermudagrass

Bermudagrass (*Cynodon* spp.) was introduced to the United States from eastern Africa in the 18th century (Hanson, 1972; Beard, 1998). It is a vigorously growing warm-season perennial, with a deep root system and extensive lateral stem growth (Beard, 1998). Due to these traits, common bermudagrass [*Cynodon dactylon* (L.). Pers.] was used as a forage grass in the southeastern United States in the late 18th and early 19th century (Dunn and Diesburg, 2004). In 1947, ‘U3’ bermudagrass became the first improved bermudagrass cultivar released (McCarty and Miller, 2002). Since then, the demands for lower growing and finer textured bermudagrasses have lead to the development of interspecific hybrid bermudagrass [*Cynodon dactylon* (L.). Pers. x *C. transvaalensis*] cultivars. However, hybrid bermudagrasses are sterile and must be vegetatively propagated by sprigs, plugs, or sod. Vegetative propagation is more expensive and requires more time to reach acceptable turf coverage than seed (Munshaw et al., 2001).

Common bermudagrass (CBG) produces viable seed and is generally used as part of roadside establishment mixtures in the southern U.S. Most roadsides are considered low maintenance areas, so rapid establishment and cost effectiveness are the main priorities. Therefore, finding the optimum seeding and fertility rates is essential. Jennings et al. (2006) recommend seeding CBG from 4.5 to 9.0 kg pure live seed (PLS) ha^{-1}. Seeding at these rates will produce a low initial biomass. However, CBG stolon fresh weights have been shown to increase as seeding rate decreases. In the transition zone, seeding at a rate of 12.2 kg PLS ha^{-1} produced more and larger stolons than seeding at 24.4, 36.6, or 48.8 kg PLS ha^{-1} (Munshaw et al., 2001). The researchers determined that the results were due to the ability of the stolons to grow larger and spread easier due to a lower initial biomass.

Lateral spread is beneficial for roadside establishment because it reduces the amount of exposed soil that can be easily eroded. Therefore, N rates are often increased during CBG establishment to encourage lateral growth (Rodriguez et al., 2001). Applying 48.8 kg N ha^{-1} twice monthly or monthly during the growing season has been shown to significantly influence establishment of hybrid bermudagrass from sprigs (Beard, 1973). However, information on N rates for seeded bermudagrasses is somewhat lacking. Munshaw et al. (2001) recommend applying a total of 244 kg N ha^{-1} to CBG in the transition zone. Their results suggest applying 48.8 kg N ha^{-1} at seeding, every 14 days until 1 July, and every 30 days until 1 September. They found that stolon weight increased with increasing N rates. Jennings et al. (2006) suggest applying 34 to 56 kg N ha^{-1} mo^{-1} (until September) after CBG stolons have reached 7.6 cm. The authors state that lowering N rates during establishment will help limit weed growth. MDOT specifications require one fertilizer application during planting. Therefore, research regarding the optimum N rates and timings will be beneficial for developing more efficient establishment practices.

Bahiagrass

Bahiagrass (*Paspalum notatum*) is a deep-rooted perennial that is native to east-central South America (Burton, 1946; Beard, 1998). Several biotypes are distributed around southeastern seaports, suggesting that it was introduced to the U.S. through seaborne cargo (Burton, 1946). Bahiagrass spreads by seeds and rhizomes but seeding is the most common method of propagation (Burton, 1946). The first introduction of bahiagrass for turfgrass use was by the Florida Agricultural Experiment Station in 1913 (Chambliss and Sollenberger, 1991). ‘Pensacola’ (*Paspalum notatum* Flugge), a cultivar with improved cold tolerance compared to common bahiagrass was released in 1944. It has since become the most widely used cultivar for roadsides and pastures in the southern U.S. (Burton, 1967; Chambliss and Sollenberger, 1991).

Although used extensively, bahiagrass is slow to establish because of weak seedlings (Beaty and Powell, 1978). However, it tolerates a wide range of soil conditions and produces moderate yields with very low fertility (Chambliss and Sollenberger, 1991). Winterkill is problematic in some bahiagrass cultivars. The cultivar ‘Wilmington’ is considered to be a cold hardy but lacks the seed production of Pensacola (Chambliss and Sollenberger, 1991). Burton (1946) data indicate that no Wilmington or Pensacola winterkill was observed from 1942 in 1945 in Thorsby, Alabama (same latitude as north-central MS). Wilmington and Pensacola were compared to common bahiagrass which sustained “heavy” winterkill at temperatures below -8°C. This suggests these cultivars could survive the winters of Mississippi with little to no damage.

Selecting the correct cultivars and seeding practices will help promote successful bahiagrass establishment. Bahiagrass requires air temperatures between 29 and 32°C for germination (Chambliss and Sollenberger, 1991). Thus, summer planting is ideal if adequate moisture is present. Seeding rates of 13.5 to 17 kg seed ha^{-1} are recommended, but higher rates may hasten establishment (Chambliss and Sollenberger, 1991). Busey (1989) found that a rate of 160 kg seed ha^{-1} was required for acceptable two-month establishment of Pensacola bahiagrass. However, seed scarification has been shown to increase germination (Burton, 1946). This practice may reduce the need for the seeding rates recommended by Busey (1989).

Fertilization timing has also been examined as a way to increase bahiagrass establishment. Burton (1940) indicated that applying fertilizer at planting decreases seedling numbers. A study by Busey (1992) compared bahiagrass seedling growth at different fertilization timings. Single applications (49 kg N, 5 kg P, 20 kg K ha^{-1}) at 0, 5, and 10 weeks after planting (56 kg seed ha^{-1}) resulted in varied establishment of three cultivars. Data indicated that ‘RCP-1’, an experimental cultivar, was 58 percent established three weeks after planting, significantly different than the other two cultivars. Furthermore, the five-week post planting fertilization application produced the highest establishment ratings. He concluded that the three-leaf stage was the optimum time to fertilize bahiagrass. These data suggest fertilization timing is very important when establishing bahiagrass. This is a necessary consideration during the development of best management practices for the establishment of Mississippi roadsides.

Sericea Lespedeza

Sericea lespedeza [*Lespedeza cuneata* (Dum. Cours.) G. Don] is a warm-season perennial legume that was introduced to the U.S. from eastern Asia in the late 19th century (Pieters, 1939; Pieters et al., 1950; Hoveland et al., 1971). It became popular as a soil conservation species during the 1930s (Pieters et al., 1950; Ball and Mosjidis, 2007). Since then it has been utilized as a forage crop in the southern U.S. (Hoveland et al., 1971). Sericea lespedeza is drought resistant, can be grown on a wide range of soils, and does not require N fertilization because of the N_2 fixing capabilities of legumes (Ball and Mosjidis, 2007). The disadvantages of using sericea in roadside mixes are slow seed germination and poor seedling vigor (Logan et al., 1969; Mosjidis, 1990).

Seeding rates, daylength, temperature, and planting depth have been evaluated for their influence on germination and establishment. Ball and Mosjidis (2007) recommend seeding sericea lespedeza late March through May at 23 to 37 kg seed ha^{-1}. Higher seeding rates (up to 50 kg ha^{-1}) are recommended to compete with weeds (Bailey, 1951). Increasing the seeding rate from 11 to 33 kg seed ha^{-1} significantly increased first year establishment and reduced the amount of broadleaf weeds on non-herbicide treated plots (Hoveland et al., 1971). However, after year two the authors concluded that seeding rate did not affect sericea lespedeza establishment nor weed competition.

Given the optimum soil moisture, air temperatures between 20 and 30°C (Qiu et al., 1995) and daylength of 13 to 15 hours are needed for sericea lespedeza germination and development (Mosjidis, 1990). Varying day/night temperatures has been shown to reduce germination (Mosjidis, 1990). Results from the same study indicate that day/night temperatures of 26/22 or 30/26°C and daylengths of 13 or 15 hours produced the tallest seedlings. The influence of planting depth on seedling vigor has also been examined (Qiu and Mosjidis, 1993). No reduction in germination or seedling vigor was found between a 1 and 3 cm planting depth. Therefore, the researchers state that a 3 cm planting depth (in sandy loam soils) may be used when there is insufficient moisture in the upper soil layer.

With adequate soil moisture, the fertilizer applied for the non-leguminous plant species in the MDOT seed mixtures could encourage weed growth. Thus, it is necessary to have as many sericea lespedeza plants germinate and develop as possible before the onset of substantial weed pressure. Although we have no control over moisture, summer planting should be done during periods of 20 to 30°C temperatures and 13 to 15 hour days to ensure the best possible conditions for germination.

Tall Fescue

Tall fescue (*Festuca arundinacea* Schreb.) is a cool-season grass native to southern European regions (Beard, 1998). It was introduced to the U.S. in the late 19th century as a forage grass (Ball et al., 2007; Bokmeyer et al., 2007). Tall fescue has a bunch-type growth habit, spreading by tillers and short rhizomes (Beard, 1973). Furthermore, it develops a deep root system and tolerates a wide range of soil pH (Dunn and Diesburg, 2004). Fungal endophytes such as *Neotyphodium* spp. can infect tall fescue. Endophyte-infected plants do not show symptoms but have increased drought tolerance and insect resistance compared to endophyte-free plants (Hill et al., 2005).

‘Kentucky 31’, released in 1943, became the first tall fescue cultivar. It quickly became a popular forage crop in the lower Midwest and upper South (Ball et al., 2007). Tall fescue did not become popular for use in home lawns until the release of ‘Rebel’, a turf-type tall fescue, in 1979 (Bokmeyer et al., 2007). Rebel spreads more aggressively than Kentucky 31, so only one-third to one-half as much seed is needed for establishment (Dunn and Diesburg, 2004). The recommended seeding rate for non turf-type cultivars such as Kentucky 31 is 17 to 23 kg seed ha^{-1} (Ball et al., 2007).

Soil temperature, sowing depth, and P fertilization have been shown to have an influence on tall fescue establishment. Hill et al. (1985) found that tall fescue germination decreased from approximately 75 to 0 percent as the constant temperature increased from 25 to 35°C. Furthermore, they concluded that soil temperatures of 18 to 21°C were necessary for successful establishment when weed competition was high. Furthermore, there is a risk of establishment failure when seeding in late spring or early fall failure due to moisture stress and weed competition (Smith and Johns, 1975).

Days required for tall fescue emergence have been shown to increase as planting depth decreases (Charles et al., 1991). Tall fescue emergence was delayed on average by six days for each 15 mm increase in planting depth. Furthermore, Charles et al. (1991) found that there was a planting depth by soil temperature interaction. Days to emergence decreased as soil temperature increased, with the largest difference occurring at the 45 mm depth (9 days at 24°C to 65 days at 3°C).

Phosphorus fertilization has also been shown to increase tall fescue establishment on soils with low soil test P. Establishment on soils with sand contents of 0 to 100 percent were examined (Summerford and Karcher, 2007). Results suggest P application had the greatest influence on tall fescue establishment in soils with 80 and 100 percent sand (5.6 and 4.1 ppm soil test P, respectively). However, fertilizer applications to the soils with at least 7 ppm P had no effect on establishment. Infertile subsoil is normally used to construct roadsides in northern Mississippi. This suggests soil test recommended P fertilization will most likely be necessary prior to seeding new roadsides.

Crimson Clover

Crimson clover (*Trifolium incarnatum* L.) is a winter-annual legume native to the Mediterranean region. It was introduced into the U.S. in 1819 but did not become an important forage until 1880 (Ball et al., 2007). Generally planted in the fall, crimson clover puts on most of its growth in the spring. Flowering is initiated when daylength is greater than 12 hours (Hannaway and Meyers, 2004). It grows best on well-drained soils and will tolerate soil pH from 5 to 8 (Hannaway and Meyers, 2004; Hancock, 2009). However, seedlings do not tolerate drought or poorly-drained soils (Hannaway and Meyers, 2004).

Data regarding germination and establishment of crimson clover is limited, but air temperature, seed size, and seeding rate have been shown to have variable effects. A laboratory study was conducted to determine optimum air temperatures for crimson clover germination (Ching, 1975). Complete germination was completed in 36 hours at 20°C, 24 hours earlier than seeds exposed to 10°C. Only 20 percent of the seeds exposed to 30 °C germinated (Ching, 1975). Williams et al. (1968) found that leaf area and shoot weight increased as crimson clover seed size increased. These results agree with those of Evers (1982), who found differences in seed size among clover species. Crimson clover had a greater average seed weight than arrowleaf clover (*Trifolium vesiculosum* Savi.) and therefore, significantly more seedling nodules and leaves. The larger the seed size, the less seed is applied on a weight basis. This could be detrimental to roadside establishment due to lack of seedlings to hold soil in place and compete with weeds.

The recommended seeding rate for crimson clover is 23 to 34 kg seed ha^{-1} (Hannaway and Meyers, 2004). However, if seeded with small grain and/or ryegrass the rates should be reduced to 17 to 23 kg seed ha^{-1}. Philipp et al. (2010) seeded crimson clover at 9.4 to 18.8 kg PLS ha^{-1} and found that the higher seeding rate significantly increased seedling number. These results were observed across two seeding methods, no-till and broadcast. Crimson clover is only included in the MDOT fall-winter seed mixture due to its lack of heat tolerance. However, it is necessary to develop practices that optimize fall establishment due to the ability of crimson clover to fix N for other plant species.

Sediment and Nutrient Runoff Losses

Sediment

Construction sites are a primary contributor of sediment due to land disturbing activities (Hayes et al., 2005). From a volume standpoint, sediment is the most abundant contaminant in runoff water (Daniel et al., 1979). Losses from 38 to 250 MT ha^{-1} yr^{-1} have been reported from construction sites (Wolman and Schick, 1967). Sediment in runoff water can lead to sediment deposition, which deteriorates aquatic habitats (Waters, 1995). Therefore, vegetation establishment on newly constructed roadsides must be done as quickly as possible to provide erosion control and slope stability.

It has been well documented that bare soil areas on newly sloped construction sites lose a significant amount of sediment and contribute to surface water turbidity. Hayes et al. (2005) observed total solid (TS) losses of 5.65, 11.8, and 13.4 MT ha^{-1} from bare soil plots across three locations. Montoro et al. (2000) data indicate TS loss from bare soil plots was 3.4 MT ha^{-1}. However, Markewitz and Glazer (2009) found greater TS loss. Their results show a loss of 25.1 MT ha^{-1} from bare soil sites. The variability in runoff contaminant loads is likely due to differences in the study sites (Daniel et al., 1979).

Furthermore, rainfall frequency and vegetative cover have been shown to influence TS losses during runoff. In a laboratory study, Montenegro et al., (2013) concluded the finest soil particles were lost in the first runoff event (30 min event), leading to the highest TS concentrations. Four subsequent runoff events over the next four hours produced TS concentrations approximately 25 percent less than the first event. Benik et al. (2003) observed sediment yield was greatly reduced from spring to fall rainfall simulations due to vegetative growth. These results are similar to ones of Mostaghimi et al. (1994). Vegetative growth between June and July simulations reduced TS concentration by 4600 mg L^{-1}.

However, increasing vegetative cover in a one-month period often requires fertilizer applications. These applications can lead to nutrient loss during runoff events from sloped terrain. Nitrogen and phosphorous movement into surface water can cause an increase in algal growth, leading to the depletion of dissolved oxygen in the water. In severe cases, this can render surface water bodies inhabitable to aquatic plant and animal species (Starrett et al., 1995).

Nitrogen

Nitrogen (N) plays a role in the form and function of many compounds in the plant such as proteins, chlorophyll, and hormones (Carrow et al., 2001). Adequate N levels are also necessary to maintain plant health. Nitrogen influences turfgrass drought tolerance, color, density, and growth rate (Rodriguez et al., 2000). Visual symptoms of N deficiencies usual appear as the gradual loss of green color (chlorosis) in the older leaves

(Carrow et al., 2001). Nitrogen is applied more frequently than any other essential plant nutrient. However, the mobility of N in the environment should be addressed when choosing N sources, N rates, and making applications.

Organic and inorganic N sources are available for use as fertilizer (Havlin et al., 2005). By-products of plant and animal processing such as sewage sludge and poultry litter are used as organic sources. However, the release of N depends on microbial activity to mineralize the N into inorganic forms such as: ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-), nitrous oxide (N_2O), nitric oxide (NO), and elemental N (N_2). Plants use root interception, mass flow, and diffusion to absorb N as NH_4^+ and NO_3^- (Havlin et al., 2005). Quick-release (soluble) N fertilizer sources such as ammonium nitrate NH_4NO_3, urea $CO(NH_2)_2$, and ammonium sulfate $(NH_4)_2SO_4$ are often applied during establishment to quickly supply plants with NH_4^+ and NO_3^-. However, plant recovery of soluble N sources is only approximately 40 to 60 percent (Havlin et al., 2005), meaning close to half is lost to the environment.

Slow-release N sources were created to reduce fertilizer N loss into the environment (Havlin et al., 2005). These products release NH_4^+ and NO_3^- over several weeks or months. This reduces the loss of N to the atmosphere (volatilization) and to surface and groundwater during runoff and leaching (Havlin et al., 2005). Products such as sulfur-coated urea (SCU), polymer-coated urea (PCU), and isobutylidine urea (IBDU) contain varying N contents, release times, and release characteristics. Thus, the development of a fertilizer program for roadside establishment must be based on the soil and environmental conditions specific to the site.

Increasing N fertilizer rates and application frequencies is a standard practice during establishment (Rodriguez et al., 2001). However, excess N fertilization on sloped sites can lead to N loss during runoff. Daniel et al. (1979) found that all soluble water quality parameters except (NO_3^- + NO_2^-)-N were independent of runoff flow when no fertilizer had been applied to the bare soil site. The (NO_3^- + NO_2^-)-N concentration maximum values of 1.00 mg L^{-1} were found to be inversely proportional to flow. These concentrations were higher than the average dissolved NH_4^+-N concentrations of 0.10 mg L^{-1}. Faucette et al. (2005) evaluated nitrogen loss from bare soil over three rainfall simulations during a year period. Total NO_3-N losses from the bare soil were approximately 56 mg m^{-2} during the first two simulations (at planting and three months after planting) but dropped to 20.1 mg m^{-2} during the third (one year after planting). The researchers concluded the amount of NO_3-N loss in each treatment was significantly correlated with the amount of NO_3-N in the treatment at the time of application (Faucette et al., 2005).

Mostaghimi et al. (1994) compared bare soil (no fertilizer applied) and hydroseeding (40.8 kg N ha^{-1} applied). A high-pressure sprayer was used to apply the hydroseed mixture that contained newspaper mulch, tall fescue and annual ryegrass seed, 15-30-15 fertilizer, and lime. Rainfall simulation results indicate total kjeldahl N (organic N + NH_3) loss of 18.2 and 26.5 mg L^{-1} for bare soil and hydroseeding, respectively. Concentrations were reduced to 4.3 (hydroseed) and 11.0 mg L^{-1} (bare soil) during rainfall simulations the next month. The researchers attribute the reductions to the vegetation that had been established on the hydroseeded plots between simulations. These results are an indicator that nutrient loss can be significantly reduced with one month of vegetative growth. The key, however, is to minimize N losses immediately following fertilizer application.

It has been well documented the greatest N losses occur during the first runoff event following fertilization. Furthermore, N source and rate have been shown to influence N loss during runoff (Gaudreau et al., 2002; Easton and Petrovic, 2004; Burwell et al., 2011). Soluble urea applied at 100 kg N ha^{-1} resulted in the highest NO_3^--N concentrations in runoff when compared to organic and slow release fertilizers at 50 or 100 kg N ha^{-1} (Easton and Petrovic, 2004). They concluded N losses during runoff follow solubility trends. When comparing N losses from manure to inorganic N sources, Gaudreau et al. (2002) found largest loss from a single runoff event came three days after applying $(NH_4)_2SO_4$ at 50 kg N ha^{-1}. Thus, applying a slow release N source during the establishment of a sloped site may reduce N losses during runoff. Burwell et al. (2011) did not find differences in N loss between urea and SCU applied at the same rate. Differences did occur between NH_4NO_3 and urea formaldehyde (UF). However, the urea and SCU were applied in a different year than NH_4NO_3 and UF, making it difficult to compare all four N sources. Burwell et al. (2011) did not apply any phosphorus (P) during establishment or analyze runoff for P. Mississippi DOT establishment specifications include the application of a complete fertilizer. Therefore, it is necessary to study P losses during runoff.

Phosphorus

Although N is often seen as the most important plant nutrient, P is also important to overall plant health. Phosphorus is involved in almost all metabolic processes involving energy storage and transfer within in the plant (Rodriguez et al., 2000; Carrow et al., 2001). The highest P requirement is in new leaves and meristematic tissue, and visual symptoms of a P deficiency include reduced shoot growth and reddish color. Symptoms often occur when soil available P is low and rooting is limited (Carrow et al., 2001). Therefore, P application may be necessary during establishment (depending on soil test results).

Similar to N, organic and inorganic P fertilizer sources are available. Animal and municipal wastes constitute organic sources. Manure accounts for 98 percent of organic P applied (Havlin et al., 2005). Organic P must be mineralized to inorganic orthophosphate ($H_2PO_4^-$) or (HPO_4^{-2}) for plant uptake by diffusion and mass flow. However, inorganic P species can become fixed due to surface adsorption to mineral surfaces (labile P) or precipitated as secondary P compounds. Phosphorous fixation is highly dependent on soil pH. Acidic soils can lead to P precipitation as Fe/Al-P minerals. The ion $H_2PO_4^-$ is primarily taken up by plants when the soil pH is below 7.2 (Havlin et al., 2005). Furthermore, inorganic P fertilizer sources can have an influence on soil pH (Havlin et al., 2005).

Rock phosphate (RP) is the most common raw material for P fertilizers. Acid or heat-treating RP to increase water-soluble P is a common practice during P fertilizer production (Havlin et al., 2005). Triple superphosphate (TSP), created by treating RP with H_3PO_4, has a high P content (17-23% P) and no effect on soil pH. However, TSP and P fertilizers in general have the potential to be transported from the application site during runoff events. Phosphorus concentrations above 0.02 mg L^{-1} can increase algal growth in surface water (Sawyer, 1947; Vollenweider, 1968; Daniel et al., 1998).

Therefore, the transfer of P fertilizer to surface water during runoff from sloped sites is an issue.

Phosphorus loss during runoff has been shown to be influenced by P source and rate. It has been well documented that increasing P rates of a given source, organic or inorganic, will increase P losses during runoff (Gaudreau et al., 2002; Shuman, 2002; Easton and Petrovic, 2004; Schroeder et al., 2004) However, research comparing P source effects is limited. Gaudreau et al. (2002) compared manure and inorganic fertilizer applied at 100 and 50 kg P ha^{-1}, respectively. Their results indicate dissolved P concentration in runoff three days after application was 206 percent larger from plots treated with inorganic fertilizer than manure. The following three runoff events resulted in greater P losses from plots treated with manure. These results are similar to those of Vietor et al. (2004). They found P losses from plots treated with manure (42 kg P ha^{-1}) to be similar or greater than from plots treated with inorganic fertilizer (50 kg P ha^{-1}). Currently, MDOT specifies an inorganic P source to be applied during establishment. Research is needed to determine if an organic source would be better suited for their applications. However, the amount of STP must be taken into account prior to fertilization with any P source.

Soils with high STP can contribute high concentrations of P to runoff (Sharpley, 1995). Thus, depending on the site, total P (TP) concentrations in runoff could be higher than the 0.02 mg L^{-1} needed for algal growth. Soupir et al. (2004) found TP concentrations up to 6.89 mg L^{-1} from bare soil plots across three simulated rainfalls. Hydroseed losses were 17.59 mg L^{-1} due to fertilizer applied in the hydroseed mixture. A second set of three simulated rainfalls produced TP concentrations of 4.06 and 4.31 mg L^{-}

^{1} for hydroseed and bare soil, respectively. The authors attribute the reductions to an increase in sediment bound P (SBP) between simulations. Therefore, treatments that reduce sediment loss may also reduce P loss in runoff (Soupir et al., 2004).

Daniel et al. (1979) reported similar results. They found that 90 percent of TP loss across three watersheds was associated with sediment loss. Faucette et al. (2006) reported a TP loss of 22.67 mg kg^{-1} from bare soil plots. However, Faucette et al. (2004) did not find a significant correlation between sediment and TP loss. These results suggest that sediment loss does have a relationship with TP loss but the strength of the relationship may vary depending on site-specific conditions. The literature does agree that sediment and nutrient loss in runoff can be reduced with the use of erosion control products (Box and Bruce, 1996).

Erosion Control Products

Mulches

There are a variety of mulches available for erosion control on newly seeded sites. Mulches can be broken down into two categories, loose and hydraulically applied (hydromulches) (Lancaster, 1997). Loose (long fiber) mulches such as straw and wood chips are applied by hand or machine blown onto areas after seeding. These mulches have little resistance to wind and water flow so application on steep slopes is limited (Lancaster, 1997). Hydromulches generally consist of short wood and paper fibers that are mixed with water and machine sprayed over an area. The advantage to hydromulches is that seed and fertilizer can be mixed with mulch and water and applied together (Lancaster, 1997). Furthermore, polyacrylamide (PAM), a synthetic polymer, is often added to the mixture to reduce soil erosion (Markewitz and Glazer, 2009). Both loose and hydromulches have been shown to increase vegetation establishment and reduce erosion.

Current MDOT specifications require loose mulch in the form of straw or hay be applied after seeding at 4490 kg ha^{-1} (MDOT, 2001). Loose mulches have been shown to minimize soil temperature change, retain moisture, and reduce soil erosion (Adams, 1966; Dudeck et al. 1970; Singer and Blackard, 1978; Hamilton, 1999). Results from Dudeck et al. (1970) indicate seeded areas protected with wood excelsior had 5°C lower soil temperatures than no mulch plots. When compared with bare soil, evaporation in the top six inches of soil was reduced by 3.8 mm after straw mulch application (Adams, 1966). Furthermore, straw mulch reduced runoff 8 to 26 cm compared to bare soil over a three-year period (Adams, 1966). Runoff volume was reduced by 40 percent compared to bare soil during a 15 minute, 50 mm hr^{-1} rainfall simulation by Foltz and Dooley (2003). Mostaghimi et al. (1994) results suggest that straw mulch reduces average runoff depth 1.2 cm compared to bare soil.

Foltz and Dooley (2003) and Mostaghimi et al. (1994) attributed their findings to increased surface retention and infiltration on plots with mulch cover. Conclusions by Adams (1966) suggest greater infiltration rates were due to the ability of the straw to absorb raindrop impact energy, preventing soil surface sealing. Benik et al. (2003) found that straw mulch reduced runoff depth 1.8 cm when soil moisture was 10 percent and 0.3 cm when soil moisture was 20 percent. Therefore, soil moisture may be a factor in runoff control and should be accounted for when mulching newly seeded roadsides.

The use of loose mulches to reduce sediment loss has also been extensively documented. Tacked straw mulch prevented rill erosion for three hours under intense simulated rainfall (61 mm hr^{-1}). This was compared to the one-minute delay by paper mulch (Israelsen et al., 1980). Meyer et al. (1970) results indicate sediment loss from plots mulched with 2245 kg straw ha^{-1} was not different from plots mulched with 4490 kg straw ha^{-1}. These results could have direct implications for MDOT mulching specifications. Currently MDOT requires 4490 kg straw ha^{-1} (MDEQ, 1994; MDOT, 2001). Mulching costs could be reduced if the mulching rate was changed to 2245 kg straw ha^{-1}. However, further research over multiple locations and years is needed to compare to Meyer et al. (1970) results.

Mostaghimi et al. (1994) results indicate straw mulch yielded the lowest sediment concentration when compared to bare soil, hydromulching, and two water-based soil strengthening polymers. McLaughlin and Jennings (2007) found that TS in runoff from plots mulched with excelsior matting were 11 to 75 percent lower than that of plots mulched with straw. These results agree with those of Benik et al. (2003). Sediment loss from plots mulched with straw was approximately 10 times greater than from plots covered with a wood-fiber blanket. These results can possibly be explained by the difference in application method and the average weight per unit area of each control practice. The straw mulch was applied by the researchers hand-scattering it at 0.45 kg m^{-2}; whereas, the wood-fiber blanket was applied by industry professionals and had a average weight per unit area of 0.68 kg m^{-2}. Although there were considerable sediment loss differences between the straw and wood-fiber blanket, it must be noted that both were significantly better at controlling sediment loss than bare soil (Benik et al., 2003).

Hydromulches are more expensive to apply but provide an alternative to loose mulches. Benik et al. (2003) observed that a runoff depth from plots treated with a fiber-bonded matrix was lower than that of straw mulch across two moisture levels. Furthermore, the flexible growth medium Flexterra® (PROFILE Prodcuts, LLC., Buffalo Grove, IL) has been shown to reduce sediment loss 91 percent compared to straw mulch (McLaughlin and Jennings, 2007). The researchers concluded that Flexterra® significantly reduced erosion and grass establishment compared to the excelsior treatment. The cost and lack of establishment is a potential drawback to using these types of products during roadside establishment. In a separate location, TS from Flexterra® plots was greater (not significantly) than straw mulch. However, this was likely due to mulch failure of individual plots relative to others with the same treatment (McLaughlin and Jennings, 2007). Mostaghimi et al. (1994) found that hydromulching with newspaper mulch produced the least amount of runoff compared to bare soil, straw mulch, and two water-based soil strengthening polymers. However, the newspaper produced the largest sediment concentrations due to concentrated flow within incipient gullies.

The reduction in runoff and sediment in areas covered with loose and hydromulches has been correlated with reductions in nutrient loss. Faucette et al. (2004) found significant positive correlations between TS and NO_3-N (0.83). Furthermore, PO_4 loss was highly correlated with NO_3-N (0.96). These results agree with those of Soupir et al. (2004). The largest reduction in total phosphorus (TP) and total nitrogen (TN) was observed in straw mulch plots during two rain simulations (Soupir et al., 2004). The authors concluded that treatments that reduced TS the greatest also reduced nutrient loading the greatest. In the same study hydromulch treatments increased TP and TN compared other treatments. However, this was due to the application of 450 kg P ha^{-1} and 260 kg N ha^{-1} during hydromulching. All other treatments except for the bare soil control received 60 kg P ha^{-1} and 60 kg N ha^{-1} (Soupir et al., 2004). Results from Mostaghimi et al. (1994) indicate no significant difference in TN and TP between hydromulch and straw mulch treatments. Nitrogen and P fertilizer in their hydromulch mix were applied at 41 and 82 kg ha^{-1}, respectively. The straw mulch treatments did not receive any fertilizer. Faucette et al. (2005) found that up to 15.3 percent of TN applied was lost from hydromulch treatments over three 78 mm hr^{-1} simulated rainfalls. This was compared to 0.7 percent for yard waste and poultry litter treatments. The researchers attributed their results to the inorganic N fertilizer applied with hydromulch treatments. Polyacrylamide is often added to loose and hydromulches as a tackifier to further reduce the potential of nutrient and sediment losses during runoff.

Polyacrylamide

Polyacrylamide (PAM) refers to a class of polymers that are composed of acrylamide and acrylate chains (Lee et al., 2010). The use of PAM to stabilize soil has been studied since the 1950s (Green and Stott, 2001). It has been shown to increase infiltration and reduce erosion (Lentz and Sojka, 1994). Polyacrylamide can also be used to control surface sealing, increase seedling emergence, and reduce fertilizer and pesticide losses (Green and Stott, 2001). The versatility of PAM has made it popular for use on construction sites. Applications of dry or liquid PAM can be made on bare soil, before mulching, during hydromulching, or after mulching with loose or hydromulch. Therefore, it provides an additional element to traditional mulching practices.

Markewitz and Glazer (2009) compared sediment loss from bare soil, hydroseeded, and hydroseeding + Silt Stop 634® PAM (Applied Polymer Systems, Inc., Woodstock, GA) plots. Cumulative total solid (TS) loss from hydroseeding and hydroseeding + PAM treatments were significantly different than the bare soil but not different from each other. McLaughlin and Brown (2006) observed Silt Stop 705® PAM (Applied Polymer Systems, Inc., Woodstock, GA) significantly reduced turbidity but not TS when applied with various ground covers. They concluded that PAM acted as a flocculating agent rather than an erosion control tool.

Whitley (2011) tested different Silt Stop 705® PAM rates (22, 45, and 91 kg ha^{-1}) applied to soil 3 to 5 days prior to rainfall simulation. She reported turbidity and total suspended solids (TSS) decreased as PAM rate increased. She concluded the water volume necessary to apply lower rates of PAM created soil surface seals, resulting in greater runoff volumes. These results differ from Soupir et al. (2004), which indicate the low rate (1.68 kg ha^{-1}) of Complete Green PAM (Complete Green Co., El Segundo, CA) applied before planting produced the largest reduction in runoff volume. However, it must be noted that the PAM and application method used was different than those used by Whitley (2011). Dry PAM applied with fertilizer before planting reduced TS 50 percent compared to the control, whereas, reductions from PAM applied in solution were 19 to 30 percent (Soupir et al., 2004).

Dry PAM also produced the greatest reductions in TP concentration in runoff. However, the low rate of PAM applied in solution was the most effective in reducing TN concentration (Soupir et al., 2004). Polyacrylamide applied with furrow-irrigation has also been shown to significantly reduce TP losses in runoff compared to untreated furrows. However, the PAM did not reduce NO_3-N losses (Lentz et al., 1998). Furthermore, Mostaghimi et al. (1994) found no significant reductions in TN or TP between plots treated with SoilTex PAM (Allied Colloids Ltd., Yorkshire, England) and bare soil. These results show PAM has the ability to reduce runoff and nutrient loss. However, information regarding nutrient loss from various hydromulches treated with PAM is limited.

Summary

Mississippi DOT has specifications for plant species, fertilization, and erosion control products to be used when establishing newly constructed roadsides. Common bermudagrass, bahiagrass, sericea lespedeza, tall fescue, and crimson clover each have characteristics that allow them to establish and thrive under various environmental conditions. However, lack of soil fertility and moisture on roadsides often leads to poor establishment. The application of inorganic N and P as fertilizer is specified to promote establishment following seeding. However, sediment and nutrient losses due to runoff readily occurs on sloped sites during establishment. Previous research has indicated sediment and nutrient losses from sloped sites can vary greatly depending on the establishment practices used. Loose and hydromulches and polyacrylamide have been shown to significantly reduce these losses. However, the researchers almost always indicated losses were dependent on the site. Conducting runoff research at various sites in northern Mississippi is necessary to provide MDOT with information on fertilization programs and erosion control products to use when establishing newly constructed roadsides.

CHAPTER III

MATERIALS AND METHODS

Experiment I

The experiment was conducted on a roadside in northern Mississippi (lat: 33.485328 log: -88.850483) July through September 2011 and June through August 2012. Lack of roadside construction near Mississippi State University required the creation of an experimental area on a previously established roadside. In 2011, three applications of glyphosate [N-(phosphonomethyl)glycine] at 5.6 kg ai ha^{-1} were made, resulting 100 percent control of existing vegetation. The experimental area was then disked and tilled to provide an adequate seedbed. In 2012, a sod cutter (Ryan Jr.; Schiller Grounds Care, Inc., Johnson Creek, Inc.) was used to remove existing vegetation and the top 7.6 cm of soil from an area adjacent to the 2011 experiment. This was done to reduce Mississippi soil test phosphorus (MSTP) level from high to medium and reduce weed seed in the seedbed.

The soil on both sites is classified as Marietta fine sandy loam (fine-loamy, siliceous, active, thermic Fluvaquentic Eutrudepts) (USDA-NRCS Soil Survey Division, 2010). However, soil used to construct the roadside was likely sourced from a separate location. A particle size analysis was conducted using the hydrometer method (Bouyoucos, 1936). The initial physical and chemical properties of the soils from both years are shown in Table 3.1.

Individual plots consisted of stainless steel frames (200 cm x 75 cm) which contained a 75 cm x 7.6 cm x 7.6 cm flume with a downward facing port welded to one end. Each frame was installed 7.6 cm into the soil, on a 10 percent slope following seedbed preparation. Alleys (0.3 m) were left between each frame. Rubber hoses (3 m) were attached to the ports of each flume and inserted into individual 68 L collection containers downhill from the runoff frames.

Soil samples were collected prior to initiation of the experiment. Ten soil cores were removed from each plot at a depth of 0 to 15 cm. Samples were mixed to form a composite sample and analyzed for pH, cation exchange capacity (CEC), P, and potassium (K) using Mississippi Soil Test Methods (Lancaster, 1980; Cox, 2001). Samples were analyzed for NH_4^+ and NO_3^- by first extracting a 20 g sample of moist soil with 1 *N* KCl. Following centrifugation, soil extracts were filtered through #2 Whatman filter paper. Ammonium and NO_3^- concentrations were determined using colorimetric procedures on an automated, segmented flow, Flow Solution 3100 analyzer (O.I. Corporation, College Station, TX) (Bremner and Keeney, 1966; Keeney and Nelson 1982; Dorich and Nelson, 1984; Greenberg et al., 1992). A separate 20 g soil sample was weighed into a tin and oven-dried at 105°C to correct for soil moisture content.

The experiment was arranged as a randomized complete block with eight treatments and four replicates in both years (Table 3.2). A total of 73.5 or the Mississippi Department of Transportation (MDOT) specified 147 kg N ha^{-1} was applied to all treatments except the untreated control over the course of the experiment. Nitrogen and P sources consisted of 13-13-13 (MDOT standard), poultry litter, stabilized urea, polymer coated urea, diammonium phosphate, ammonium nitrate, and triple super phosphate.

Poultry litter was chosen to represent an organic fertilizer that can be easily sourced in Mississippi. Stabilized urea (Uflexx®; Koch Agronomic Services, LLC, Wichita, KS) is urea coated with N-(nbutyl)thiophosphoric triamide (urease inhibitor) and dicyandiamide (nitrification inhibitor) which slows the rate of urea hydrolysis and conversion of ammonium to nitrate, respectively. It was selected as a soluble N source that would reduce N loss by minimizing NH_3 volatilization. Polymer coated urea was chosen for its slow release properties. A polymer coated urea application at seeding may provide N throughout the entire establishment period. Diammonium phosphate was selected because it has a high P content and will also supply N. Triple super phosphate is used by MDOT as a supplemental P source. Thus, it was used in the experiment to balance P rates across treatments. Potassium was applied as muriate of potash (KCl) to ensure an accurate comparison of N and P rate and source response.

Fertilizer application timing differences, 0 and 15 days after seeding (DAS) were used to evaluate the influence of fertilization before and after germination. Ammonium nitrate was to chosen as a readily available, soluble N source and applied 15 DAS to the poultry litter and diammonium phosphate programs. Fifteen DAS was chosen as the second fertilizer application date because MDOT aims to reach 70 percent vegetative cover within 30 days of planting (Mark Thompson, personal communication). All fertilizer was broadcast by hand using shaker bottles. Hand rakes were used to incorporate the fertilizer approximately 1.3 cm into the soil.

The MDOT spring-summer seed mixture of common bermudagrass [*Cynodon dactylon* (L.) Pers.], bahiagrass (*Paspalum notatum* Flugge), tall fescue (*Festuca arundinacea* Schreb.), and sericea lespedeza [*Lespedeza cuneata* (Dum. Cours.) G. Don] was used during both years. Bahiagrass, tall fescue, and sericea lespedeza were each seeded at 28.1 kg seed ha^{-1}. Common bermudagrass was seeded at 22.5 kg seed ha^{-1}. All seeding was done by hand following fertilization, using shaker bottles. Seeding dates were 14 July 2011 and 14 June 2012. After seeding, the soil was lightly raked to increase seed to soil contact. Mulch was not applied to the 2011 study area following seeding. However, straw mulch was applied at 4490 kg ha^{-1} in 2012 to satisfy MDOT roadside establishment specifications (MDOT, 2001). In both years, 0.25 cm of irrigation was applied by hand, every other day, for the first 14 DAS.

In 2011, each plot was subjected to simulated rainfall 14, 30, and 56 DAS to evaluate nutrient and sediment losses during runoff. The second simulation was moved from 28 to 30 DAS due to natural rainfall. In 2012, the only simulation was conducted 14 DAS. This was due to runoff producing natural rainfall events occurring 5 of 7 days prior to the scheduled 28 DAS simulation and during the beginning of the 56 DAS simulation. All rainfall simulations followed the United States Department of Agriculture’s (USDA) National Phosphorus Research Project (NPRP) protocol (USDA, 2008). The rainfall simulator (Tlaloc 3000; Joern’s Inc., West Lafayette, IN) was based off of the designs of Miller (1987) and Humphry et al. (2002). A Fulljet ½ HH SS 50 SWQ nozzle (Spraying Systems, Co., Wheaton, IL) was installed on the simulator 3 m above the soil surface. Source water used for each simulation was collected from a municipal source and transported to the research site in a 2271 L tank. Source water from each simulation was analyzed for pH, NH_4^+-N, NO_3^--N, and $PO_4^{3—}$P (Table 3.3). Nutrient analyses were conducted using colorimetric procedures on an automated, segmented flow, Flow Solution 3100 analyzer. The phenate method was used to analyze NH_4^+-N, cadmium-reduction method for NO_3^--N, and ascorbic acid reduction method for PO_4^{3-}-P (Fiore and O'Brien, 1962a; Fiore and O'Brien 1962b; Murphy and Riley, 1962; Greenberg et al., 1992).

A Field Scout TDR 300 (Spectrum Technologies, Inc., Plainfield, IL) was used to collect soil volumetric water content through time-domain reflectometry prior to each simulation. The dimensions of the rainfall simulator (2.8 m x 2.3 x) allowed simulated rainfall to be applied to two plots simultaneously. Rainfall intensity was 66 mm hr^{-1}, in order to match that of a ten-year, one-hour precipitation event for northern Mississippi (NOAA, 1977). Time until runoff initiation was recorded and runoff events lasted 30 minutes following initiation. During each simulation, runoff volume (L) was determined on a weight basis. Runoff samples were collected every five minutes after runoff began and continued for 30 minutes (i.e. sample 1 = 0-5 min., sample 2 = 5-10 min, etc.). One-liter subsamples were taken from each five-minute sample by stirring the container to suspend all solids and submerging the bottle into the container.

Runoff produced by natural rainfall was collected for 56 DAS. Runoff was collected in 68 L containers installed downhill from the runoff frames. Following runoff collection, containers were weighed to determine runoff volume. One L subsamples were taken from each container by stirring the container to suspend all solids and submerging the bottle into the container. Subsamples from natural and simulated rainfall were stored on ice in coolers for transport to the laboratory. Samples were frozen if analysis could not be conducted within a 24-hour period following collection (Greenberg et al., 1992).

Prior to analysis, subsamples from simulated and natural rainfall were split equally into two 250 mL plastic bottles. The subsample of one bottle was vacuum filtered through a 0.45-µm nylon filter for analysis of PO_4^{3-}-P, NH_4^+-N, and NO_3^--N. The subsample in the remaining bottle was used for total P (TP), total N (TN), and total solids (TS) analyses. Total P (organic P + PO_4^{3-}-P) was analyzed by first digesting a 35 mL aliquot of subsample in a H_2SO_4 – HNO_3 digestion outlined by Greenberg et al. (1992). The digest was analyzed colorimetrically on an automated, segmented flow, Flow Solution 3100 analyzer using the ascorbic acid reduction method (Murphy and Riley, 1962). Total N (organic N + NH_4^+-N + NO_3^--N) was analyzed using a modified micro-kjeldahl procedure. A 25 mL aliquot of subsample was digested in a H_2SO_4 – salicylic acid solution and analyzed colorimetrically on the Flow Solution 3100 analyzer using the phenate method (Schuman et al., 1973; Greenberg et al., 1992). Total solids (TS) were analyzed using the procedure described by Greenberg et al. (1992). A pipette was used to transfer 5 mL aliquots of well-mixed subsamples into a pre-weighed evaporation dishes. The dishes were placed into a forced-air drying oven at 103-105°C until one hour following evaporation. Dishes were removed and placed in a desiccator to cool before being weighed on an analytical balance.

Weather and establishment data were also collected during the experiment. Weather stations were placed at each field site to record temperature, humidity, photosynthetically active radiation, and rainfall. Visual vegetation coverage ratings measured on a 0 to 100% scale (0% = no cover and 100% = full coverage) were taken weekly. A digital photo of each plot was taken weekly using a light box (Length = 61 cm x Width = 51 cm x Height = 61 cm). The images were batch analyzed using a turfgrass analysis macro (Karcher and Richardson, 2005) for SigmaScan Pro software (ver. 5.0, SPSS Science Marketing Dep., Chicago, IL) to determine percent green pixels in each image.

Data was analyzed using Statistical Analysis System (v. 9.3, SAS Inst., Cary, NC). Main and interaction effects for vegetative coverage and natural rainfall data were examined with analysis of variance using the General Linear Model (GLM) procedure (Type III sums of squares). Data were separated by year due to an interaction between fertilizer program and year. Furthermore, data were separated by DAS if there was an interaction between fertilizer program and DAS. Fisher’s Protected Least Significant Difference ($LSD_{0.05}$) was used to separate fertilizer program means if data was balanced. Least Squares Means (LS-means $\alpha = 0.05$) was used to separate means in unbalanced datasets.

The Generalized Linear Mixed Models (GLIMMIX) procedure was used to examine the main and interaction effects for simulated rainfall data. Repeated measures analysis was conducted. Sample time was specified as the repeated measure and fertilizer program within replication was specified as the subject. An appropriate covariance structure was selected for the within subjects model by examining the Akaike information criterion (AICC). The entire model (between and within subjects) was fit using the selected covariance structure, and Least Squares means ($\alpha=0.05$) was used to separate means. Pearson’s correlation coefficient (r) was used to evaluate the relationships between runoff parameters for both simulated and natural rainfall.

Experiment II

The experiment was conducted at the Mississippi State University R.R. Foil Plant Research Facility October through December 2011 and September through November

2012. Seedbed preparation in both years was the same as Experiment I. The soil on the experimental site is classified as a Marietta fine sandy loam (fine-loamy, siliceous, active, thermic Fluvaquentic Eutrudepts) (USDA-NRCS Soil Survey Division, 2010). A particle size analysis was conducted using the hydrometer method (Bouyoucos, 1936). The initial physical and chemical properties of the soils from both sites are shown in Table 3.4.

Experimental plots consisted of the area contained within the stainless steel runoff frames used in Experiment I. However, frames were installed a on a 15 percent for Experiment II. Soil samples were collected from each plot and analyzed using the same procedures as Experiment I.

The experiment was arranged as a randomized complete block with eight mulch treatments and four replicates (Table 3.5). Mulching material consisted of wheat straw (MDOT standard), paper fiber (Terra-Mulch® Cellulose, PROFILE Products, LLC, Buffalo Grove, IL), wood fiber (FINN TRU-Wood, FINN Corp., Fairfield, OH), 70/30 percent wood/paper fiber blend (FINN TRU-Blend Wood/Paper, FINN Corp., Fairfield, OH), 75 percent wood fiber flexible growth medium (FGM) (Flexterra® FGM, PROFILE Products, LLC, Buffalo Grove, IL), 50/20 percent wood/coconut fiber extended term-FGM (ET-FGM) (CocoFlex™ ET-FGM, PROFILE Products, LLC, Buffalo Grove, IL), and 68 percent straw bonded fiber matrix (BFM) (HydroStraw BFM, HydroStraw, LLC, Manteno, IL). These materials were chosen to represent common mulching materials used for vegetative establishment on sloped terrain.

Following tillage, fertilization and seeding of wheat straw treatments was done by hand using shaker bottles. Bahiagrass, tall fescue, and sericea lespedeza were each seeded at 28.1 kg seed ha^{-1}. Common bermudagrass and crimson clover (*Trifolium incarnatum*

L.) were each seeded at 22.5 kg seed ha^{-1}. Fertilizer (13-13-13) was applied to the plots during seeding at 147 kg N ha^{-1} and incorporated approximately 1.3 cm into the soil using hand rakes. All seed was broadcast across the soil surface and lightly raked to improve seed to soil contact. Wheat straw was applied by hand at 2245 or the MDOT specified 4490 kg ha^{-1}.

All other mulches were applied using a Finn T-60 hydroseeder (FINN Corp., Fairfield, Ohio) at manufacture recommended label rates for a 15 percent slope. The hydroseeder sprayer was calibrated by determining the amount of time necessary to spray a mulch mixture volume equal to one-half the mulch mixture volume needed per plot. Hydroseed mixtures contained mulch, tackifier, fertilizer, and seed. Paper fiber, wood fiber, and 70/30 paper/wood blend mulches are not manufactured with tackifier. Therefore, a label rate, 6.7 kg tackifier ha^{-1}, (E-Tack, FINN Corp., Fairfield, OH) was added to hydroseeder tank containing mulch, seed, and fertilizer. All hydromulch mixtures were allowed to agitate for 30 minutes prior to application. The label amount of mulch was applied using two passes across each plot. During application, adjacent plots were cover with a tarp to avoid contamination.

Rainfall simulations were conducted 14, 28, and 56 DAS in both years using the same procedures as Experiment I. Results from rainfall simulation source water analysis are listed in Table 3.6. Runoff produced by natural rainfall events was collected for 56 DAS in both years. All runoff samples were collected and analyzed using the same procedures as Experiment I. Weather and establishment data were also collected in same manner as Experiment I.

Data was analyzed using Statistical Analysis System (v. 9.3, SAS Inst., Cary, NC). Main and interaction effects for vegetative coverage and natural rainfall data were examined with analysis of variance using the General Linear Model (GLM) procedure (Type III sums of squares). Data were separated by year due to an interaction between fertilizer program and year. Furthermore, data were separated by DAS if there was an interaction between fertilizer program and DAS. Fisher's Protected Least Significant Difference ($LSD_{0.05}$) was used to separate fertilizer program means if data was balanced. Least Squares Means (LS-means $\alpha = 0.05$) was used to separate means in unbalanced datasets.

The Generalized Linear Mixed Models (GLIMMIX) procedure was used to examine the main and interaction effects for simulated rainfall data. Repeated measures analysis was conducted. Sample time was specified as the repeated measure and fertilizer program within replication was specified as the subject. An appropriate covariance structure was selected for the within subjects model by examining the Akaike information criterion (AICC). The entire model (between and within subjects) was fit using the selected covariance structure, and Least Squares means (α=0.05) was used to separate means. Pearson's correlation coefficient (r) was used to evaluate the relationships between runoff parameters for both simulated and natural rainfall.

Table 3.1 Initial chemical and physical properties of Marietta soil from experiments conducted summer 2011 and 2012 on a roadside (lat: 33.485328 log: -88.850483) near Starkville, MS. Samples were taken from a depth of 0 to 15 cm.

Soil property	Year	
	2011	2012
pH 1:2	7.9	8.1
CEC‡, $\text{cmol}_c\ \text{kg}^{-1}$	18.5	17.0
NH_4^+-N, kg ha^{-1}	5.6	5.2
NO_3^--N, kg ha^{-1}	13.3	30.1
MSTP†, kg ha^{-1}	91.0	52.0
K, kg ha^{-1}	511.1	260.6
Sand, %	58.7	56.1
Silt, %	18.9	21.7
Clay, %	22.4	22.2
Texture	Sandy clay	Sandy clay

†MSTP, Mississippi Soil Test

‡CEC, cation exchange capacity

Table 3.2 Fertilizer program name, fertilizer applied, nitrogen (N) rate, phosphorus (P) rate, and fertilizer application timing used during summer 2011 and 2012 experiments conducted on a roadside (lat: 33.485328 log: -88.850483) near Starkville, MS.

Experiment 1					
Program name	Fertilizer	N rate (kg ha^{-1})	P rate (kg ha^{-1})	K rate (kg ha^{-1})	App. timing (DAS†)
Control	untreated	0	0	0	n/a
Standard	13-13-13	147	64	121	0
Split	13-13-13	73.5	32	60.5	0
	13-13-13	73.5	32	60.5	15
Poultry	poultry litter 4-2-2	98	21.3	40.5	0
	triple super phosphate 0-46-0	0	10.7	0	0
	KCl 0-0-60	0	0	20.0	0
	ammonium nitrate 34-0-0	49	0	0	15
	triple super phosphate	0	32	0	15
	KCl	0	0	60.5	15
SU‡	stabilized urea 46-0-0	73.5	0	0	0
	triple super phosphate	0	32	0	0
	KCl	0	0	60.5	0
	stabilized urea	73.5	0	0	15
	triple super phosphate	0	32	0	15
	KCl	0	0	60.5	15
Half	13-13-13	73.5	32	60.5	0
PCU§	polymer coated urea 43-0-0	73.5	0.0	0.0	0
	triple super phosphate	0.0	32	0.0	0
	KCl	0.0	0.0	60.5	0
DAP¶	diammonium phosphate 18-46-0	29.4	32	0.0	0
	ammonium nitrate	44.1	0.0	0.0	15
	KCl	0.0	0.0	60.5	15

† DAS, days after seeding

‡SU, stabilized urea

§PCU, polymer coated urea

¶DAP, diammonium phosphate

Table 3.3 Experiment I yearly mean rainfall simulation source water analysis.

Parameter	Year	
	2011	2012
pH	8.8	9.0
NH_4^+-N, mg L^{-1}	0.02	0.02
NO_3^--N, mg L^{-1}	0.01	0.05
PO_4^{3-}-P, mg L^{-1}	0.07	0.06

Table 3.4 Initial chemical and physical properties of Marietta soil from experiments conducted fall 2011 and 2012 at Mississippi State University R.R. Foil Plant Research Facility (lat: 33.485328 log: -88.770875). Samples were taken from a depth of 0 to 15 cm.

Soil property	Year	
	2011	2012
pH 1:2	7.6	8.2
CEC‡, cmol$_c$ kg^{-1}	14.0	13.2
NH_4^+-N, kg ha^{-1}	7.6	4.5
NO_3^--N, kg ha^{-1}	40.1	38.4
MSTP†, kg ha^{-1}	108.3	64.4
K, kg ha^{-1}	254.3	110.4
Sand, %	63.6	48.6
Silt, %	25.7	36.2
Clay, %	10.8	15.3
Texture	Sandy loam	Loam

†MSTP, Mississippi Soil Test

‡CEC, cation exchange capacity

Table 3.5 Mulch type, composition, and application rates used during Experiment II in fall 2011 and 2012 conducted at Mississippi State University R.R. Foil Plant Research Facility (lat: 33.485328 log: -88.770875).

Mulch	Mulch composition	Application rate (kg ha^{-1})
wheat straw	100% wheat straw	2245
wheat straw	100% wheat straw	4490
paper fiber	100% paper fiber	2245
wood fiber	100% wood fiber	2245
70/30 wood/paper	70% wood fiber 30% paper fiber	2245
flexible growth medium (FGM)	75% wood fiber 10% tackifier 5% interlocking fibers	3368
extended term-FGM (ET-FGM)	51% wood fiber 22% coconut fiber 10% tackifier 8% interlocking fibers	3368
bonded fiber matrix (BFM)	68% wheat straw 12% natural fiber 10% tackifier	3368

Table 3.6 Experiment II yearly mean rainfall simulation source water analysis.

Parameter	Year	
	2011	2012
pH	9.1	8.7
NH_4^+-N, mg L^{-1}	0.02	0.04
NO_3^--N, mg L^{-1}	0.01	0.07
PO_4^{3-}-P, mg L^{-1}	0.07	0.03

CHAPTER IV

RESULTS AND DISCUSSION

Experiment I

Vegetative Coverage

Visual evaluations and digital photographs were taken weekly during the experiment to determine percent vegetative coverage. Correlation coefficients between visual coverage ratings and percent coverage calculated by digital image analysis (DIA) were 0.95 ($P \leq 0.0001$) and 0.96 ($P \leq 0.0001$) in 2011 and 2012, respectively. Digital image analysis results will be referenced from seeding to 49 days after seeding (DAS). Following 42 DAS, percent coverage estimated by DIA was skewed due to canopy shading. Therefore, visual evaluation results will be referenced the final 28 days of the establishment period. Days after seeding was significant in both years, but there was not a fertilizer program by DAS interaction in either year. Data were pooled across fertilizer program and presented by DAS (Fig. 4.1).

Seedling emergence began between 10 and 14 days of each year. Coverage differences between years in the subsequent weeks were due to weed pressure in 2011. The removal of existing vegetation and 7.6 cm of soil from the 2012 experimental site reduced the amount of weed seed in the seed bank, leading to fewer weeds during the establishment period. The results suggest fertilization of split, poultry, SU, and DAP 15 DAS did not influence establishment. This is may be due to lack of vegetation and nutrient loss venerability following fertilization. Vegetative coverage was less than 10 percent in both years during the 15 DAS fertilization. Furthermore, fertilizer was applied to the soil and mulch surfaces in 2011 and 2012, respectively. Runoff producing natural rainfall events occurring 21 DAS in 2011 and 22 DAS in 2012 may have transported applied nutrients offsite.

The Mississippi Department of Transportation (MDOT) goal is to reach 70 percent vegetative cover within 30 DAS (David Thompson, personal communication). Species specified for the MDOT summer-spring mixture are slow to establish from seed. Therefore, 70 percent coverage 30 DAS may be difficult to achieve under non-irrigated conditions. Results from our experiment 30 DAS indicate approximately 40 and 20 percent coverage in 2011 and 2012, respectively. Although less than 70 percent, vegetation that did grow the first 30 DAS likely reduced runoff losses. Gross et al. (1991) found that low density vegetation significantly reduced sediment loss compared to bare soil. Coverage reached 70 percent, approximately 37 DAS in 2011 and 45 DAS in 2012. Observations made during both years suggest the majority of vegetative coverage in 2011 was due to summer annual weeds. In 2012, the majority of coverage was desired species.

Significant increases in weekly coverage occurred in both years until 49 and 56 DAS in 2011 and 2012, respectively. This illustrates one of the problems associated with using DIA to evaluate percent coverage of unmown vegetation. Canopy shadowing late in the establishment period influenced percent coverage results. Hoyle et al. (2013) found canopy height influenced the ability of DIA to estimate percent tall fescue and large crabgrass (*Digitaria sanguinalis* L.) coverage. In our experiment DIA was not able to differentiate shadows from bare soil, leading to an underestimation of coverage. Visual evaluation results indicate percent coverage continued to increase in both years. At 70 DAS, coverage was approximately 100 percent in both years.

Slow germination of warm-season species in the MDOT spring-summer seed mixture increased the time needed to reach 70 percent coverage in both years. Furthermore, results suggest fertilizer program did not influence vegetative growth. Future research should focus on comparing planting timings for the MDOT spring-summer mixture and evaluating other plant species for summer plantings.

Natural Rainfall

Rainfall and Runoff Depth

Approximately the same amount of rainfall events occurred in 2011 (18) and 2012 (16). Of those rainfall events, five in each year produced runoff during the 56 d establishment period. Runoff producing natural rainfall events occurred 7, 11, 22, 29, and 54 DAS in 2011 and 21, 22, 24, 27, 28 DAS in 2012 (Fig. 4.2). There were no significant differences in runoff collected between fertilizer programs. This is not a surprising result considering there were no significant vegetative coverage differences between fertilizer programs. There was significant positive correlation between rainfall and runoff in both years. However, when data were pooled across fertilizer program and date neither the 2011 ($r = 0.44$, $P \leq 0.0001$) nor the 2012 ($r = 0.62$, $P \leq 0.0001$) correlation between rainfall and runoff was strong. This may be due to the variability in runoff collected during each event.

Mulching and rainfall intensity influenced runoff. Maximum rainfall (~100 mm) for one event was approximately the same in both years, 54 and 28 DAS in 2011 and 2012, respectively. Furthermore, the amount of runoff collected from the aforementioned events was similar (~20 mm). In 2011, plots were not mulched but there was approximately 80 percent vegetative cover 54 DAS. This is compared to mulched plots in 2012 with 17 percent cover. Thus, straw mulch applied in 2012 may have significantly reduced runoff. These results are similar to Adams (1966), Mostaghimi et al. (1994), and Foltz and Dooley (2003) who found varying runoff reductions following loose mulch application. Reductions during those studies varied due to type and amount of mulch and rainfall intensity and duration.

Burwell et al. (2011) results show a 55 and 10 percent loss of simulated rainfall when bermudagrass cover was 20 and 90 percent, respectively. Our 2011 results were similar, with 50 percent runoff loss at 32 percent coverage and 20 percent loss at 80 percent coverage. Burwell et al. (2011) did not apply mulch, but the experimental site consisted of clay soil and a 30 percent slope. The lack of runoff differences between the experiments may be due to rainfall intensity and duration differences. Their constant intensity was greater but duration was shorter. Natural rainfall during our experiment lasted 5 h (29 DAS) and 15 h (54 DAS) at varying intensities. The influence of rainfall intensity and duration was also evident in our 2012 experiment.

In 2012, runoff 24 and 28 DAS are similar. However, rainfall was 42 mm greater, 28 DAS. This is a result of rainfall intensity over time. Rain 24 DAS fell in a 2 h period, whereas, rain 28 DAS fell over a 24 h period. These results suggest rainfall intensity over time, rather than total rainfall may be a more appropriate predictor of runoff. Huang et al. (2013) found runoff intensity increased with increased rainfall intensity and duration. Results from our experiments also indicate total solids (TS), total nitrogen (TN), and total phosphorus (TP) lost during runoff produced by natural rainfall were correlated with runoff collected.

Total Solids in Runoff

Statistical analyses for TS runoff losses indicated there was not a significant interaction between fertilizer program and DAS in either year. Furthermore, fertilizer program was not significant in either year. These results follow the same trend as previously discussed runoff results. Thus, data were pooled across fertilizer program and presented by DAS (Fig. 4.3). Results suggest TS runoff losses were influenced by runoff depth. In 2011, correlation coefficients ranged from 0.59 ($P \leq 0.0001$) to 0.87 ($P \leq 0.0001$). Coefficients were lower in 2012, ranging from 0.49 ($P = 0.0052$) to 0.79 ($P \leq 0.0001$).

Total S runoff losses were generally greater in 2011 than 2012. However, it is difficult to compare years considering the differences in rainfall and vegetative coverage across runoff dates. The only similar rainfall amount (10 mm) occurred 22 DAS in both years. Vegetative coverage was 7 percent greater in 2011 than 2012, but TS losses were 60 percent greater. This may be a result of the mulch applied in 2012. These results are similar to those of Montenegro et al. (2013). They found mulching with rice straw at 3600 kg ha^{-1} reduced TS runoff losses 91 percent compared to bare soil. Therefore, MDOT specified mulching may significantly reduce TS runoff losses. Total N runoff losses from our experiments generally followed the same trend as TS.

Total Nitrogen Runoff Losses

Similar to TS runoff losses, there was not a significant fertilizer program by DAS interaction for TN losses. However, it was necessary to separate data by fertilizer program and DAS to explain losses from those programs receiving N fertilizer 15 DAS (Fig. 4.3).

In 2011, TN runoff losses and runoff depth were significantly correlated at every runoff date. Correlation coefficients ranged from 0.49 ($P = 0.0056$) to 0.84 ($P \leq 0.0001$). However, TN runoff losses were more strongly correlated with TS, with correlation coefficients ranging from 0.65 ($P \leq 0.0001$) to 0.84 ($P \leq 0.0001$). Correlations between TN and runoff depth in 2012 resulted in similar results as 2011, with coefficients ranging from 0.49 ($P = 0.0052$) to 0.91 ($P \leq 0.0001$).

There was not a significant correlation between TN and TS losses 21 DAS in 2012 (0.26 $P = 0.14$). Coefficients for the other three events ranged from 0.57 ($P = 0.0009$) to 0.88 ($P \leq 0.0001$). The lack of significance 21 DAS in 2012 may be due to variability in the TN data. The coefficient of variation 21 DAS was 28 percent greater than any other event. This may be due to the event 21 DAS being the first event following 15 DAS fertilization of Split, Poultry, SU, and DAP plots. The results indicate TN runoff losses from Split, Poultry, SU, and DAP plots were 750 to 1600 g N ha^{-1} greater than losses from all others. These results are consistent with those of Burwell et al. (2011), which found the greatest N losses during the first runoff event following fertilization.

The results from the first runoff event (22 DAS) following 15 DAS fertilization in 2011 show differences ranging from 70 to 570 kg N ha^{-1}. Furthermore, TN runoff loss was significantly greater from SU plots than any other fertilizer program. This was the only runoff event in which TN loss from one fertilizer program was significantly greater than losses from all other programs. This is an interesting result considering the greatest amount of N was applied to the Standard program 0 DAS.

Total N lost from Standard plots was not significantly different than from Half and Spilt the first two runoff events after seeding in 2011. These results may be due to applied irrigation and organic-N lost during runoff. Plots were irrigated with 0.25 cm water every other day the first 14 DAS. This may have dissolved fertilizer prills and moved nutrients into the soil. Total N lost from control plots was 70 percent of TN lost from Standard. These results are similar to Mostaghimi et al. (1994). They found kjeldahl N (organic N + NH_4^+-N) runoff concentrations from bare soil to be 89 percent of soil treated with a hydroseed mixture containing N fertilizer. The results from our and Mostaghimi et al. (1994) experiments suggest the majority of N runoff losses are due organic-N. However, ammonium (NH_4^+) and nitrate (NO_3^-) nitrogen are often used as a measure of water quality.

Inorganic Nitrogen Runoff Losses

A significant interaction occurred between fertilizer program and DAS in both years for ammonium-N runoff losses. Fertilizer program and DAS were significant for nitrate-N but the interaction was not. Data were separated by fertilizer program and presented by DAS (Table 4.1). It must be noted that simulated rainfall was applied to all plots 14 DAS of both years. Furthermore, N fertilization occurred 15 DAS of both years to Spilt, Poultry, SU, and DAP plots.

There were two runoff events prior to the rainfall simulation and fertilization in 2011. The increase in nitrate-N runoff losses from the first to second event indicate applied N fertilizer had not completely underwent nitrification prior to the event 7 DAS. Therefore, most N was lost as ammonium, leading to significant ammonium-N loss differences. Ammonium-N losses 7 DAS from Standard plots, which received the most N during seeding, were significantly greater than from Split and Half. However, there were no significant ammonium-N runoff loss differences between the three fertilizer programs 11 DAS. These results suggest applying the MDOT specified 13-13-13 at a half rate during seeding may reduce ammonium-N runoff losses during the first runoff event. It has been well documented the greatest nutrient runoff losses occur during the first runoff event following fertilization (Shuman, 2002; Vietor et al., 2004; Faucette et al., 2005; Burwell et al. 2011). Therefore, practices such as fertilizer incorporation must be implemented to reduce runoff losses following fertilization.

Polymer coated urea was selected as an inorganic slow-release N source and applied at half the Standard rate at seeding. The ammonium-N loss results indicate urea contained within the polymer-coat was hydrolyzed and partially released during the 7 DAS event. The greatest PCU runoff losses occurred during the 11 DAS event, indicating the polymer coat did not release N in a linear pattern over time. These results suggest PCU may not be an acceptable N source for limiting runoff losses during roadside establishment. However, further research should examine runoff loss differences between soluble and slow-release N sources following roadside plantings.

Splitting the total applied fertilizer into two applications also appears to be an unacceptable practice to limit N runoff losses. Split and SU plots received a half rate

(73.5 kg N ha^{-1}) 15 DAS, whereas Poultry and DAP received 49 and 44.1 kg N ha^{-1}, respectively. Therefore, total N applied during the establishment period was 147 kg ha^{-1} to Split, SU, and Poultry and 73.5 kg ha^{-1} to DAP. Results from the first runoff event following 15 DAS fertilization in both years indicate nitrate and ammonium-N runoff losses from these four programs were greater than from all others. This is likely a result of applying fertilizer to the soil surface in 2011 and mulch surface in 2012. Lack of incorporation increased the potential of applied nutrients to be lost in runoff. Spilt, Poultry, and SU ammonium-N losses were significantly greater than all other programs 22 DAS in 2011. Furthermore, nitrate and ammonium-N losses from Poultry were significantly greater than from all other programs 29 DAS in 2011. Overall, ammonium plus nitrate-N runoff losses during the 56 d establishment period where greater under the Spilt, Poultry, SU, and DAP programs than the Standard program.

The greatest total ammonium plus nitrate-N runoff losses during natural rainfall were 3 percent of applied N (2012 DAP). The majority (76%) was lost during the first runoff event. Ammonium plus nitrate-N runoff losses from Standard were 0.6 and 0.7 percent of applied N in 2011 and 2012, respectively. Of that, 48 percent in 2011 and 55 percent in 2012 were lost in the first runoff event. Runoff losses during natural rainfall were minimal compared to total N applied during each fertilizer program. However, the results suggest N source and rate do have an influence on inorganic N runoff losses during roadside establishment. Further research is needed to determine if application placement has an influence on inorganic N runoff losses from newly constructed roadsides.

Total Phosphorus Runoff Losses

Similar to TN results, there was not a significant interaction between fertilizer program and DAS in either year. However, it was necessary to separate data by fertilizer program and DAS to explain the variability that existed each year (Fig. 4.3). Total P losses were not as strongly correlated with runoff depth and TS as TN. In both years, correlation strength fluctuated with TS losses. The strongest correlations with TS losses were 54 DAS in 2011 (0.77 $P \leq 0.0001$) and 27 DAS in 2012 (0.67 $P \leq 0.0001$). This may be a result of data variability in both years.

The runoff event 7 DAS in 2011 resulted in the greatest TP losses from plots treated with Spilt and DAP. Standard plots, which received the most P during 0 DAS fertilization, lost less TP than the untreated plots. There were no significant TP differences between any fertilizer program during that event. It is difficult to speculate on the exact cause of the variability. Potentially, the sediment bound P lost during runoff overshadowed any differences that may have been seen between P sources and rates. Daniel et al. (1979) found that 90 percent of TP lost during runoff was associated with sediment load. Our experimental soil test P was 91 and 52 kg ha^{-1} in 2011 and 2012, respectively. Therefore, variability in TS losses between fertilizer programs may have lead to variability in TP losses.

Less variability occurred in 2012. This may be due to applied mulch effectively reducing TS in runoff. Total P lost from SU plots was significantly greater than from all other programs during the first runoff event. Split and Poultry were fertilized with the same amount of P as SU, 15 DAS. However, TS losses were 40 (Spilt) and 70 (Poultry) kg ha^{-1} less than SU. The combination of applied P plus sediment bound P and less variation may have contributed to the significant difference seen in the first runoff event of 2012. Although not significantly greater than all other programs, TP runoff losses from Spilt, Poultry, SU were the greatest in the second and fourth runoff event of 2012.

Relationships between sediment bound P, applied P, and TP runoff losses are apparent. However, it was difficult to determine how strong the relationships were due to data variability. Vietor et al. (2004) found similar results. Total P loss differences from treatments with various P rates did not occur. They found significant positive relationships between inorganic P in runoff and soil test P.

Inorganic Phosphorus Runoff Losses

A significant interaction between fertilizer program and DAS occurred for orthophosphate (PO_4^{3-}-P) runoff losses. Data were separated by fertilizer program and DAS (Table 4.2). The Poultry program consisted of an application of both organic-P from poultry litter (4-2-2) and inorganic P from concentrated super phosphate (0-46-0) at seeding. The intent was to supply seedlings with plant available P while the organic-P was being mineralized. This resulted in greater orthophosphate runoff loss during the first event of 2011. Losses were at least 1.7 times greater than any other single loss. Furthermore, losses were significantly greater than from all programs except DAP during the second runoff event of 2011. The application and subsequent runoff loss of P from organic sources has been well documented (Sharpley, 1997; Gaudreau et al. 2002; Schroeder et al. 2004; Vietor et al. 2004). Although total applied P to Poultry was half of Standard, the addition of inorganic-P to the Poultry program may have caused greater orthophosphate runoff losses.

Losses from Standard were not significantly different than from Half during any runoff event in either year. These results differ from Shuman (2002) who found increasing the P rate from 5 to 11 kg ha^{-1} applied as 10-10-10 significantly increased orthophosphate concentration in runoff the first two events after application. Mass orthophosphate loss was not presented. The researcher did indicate mass loss results were nearly identical to concentration in terms of pattern of transport. It also must be noted Shuman (2002) simulated rainfall on a 5 percent slope and the first two runoff events were 4 and 24 h after fertilization. Theses difference may have lead to result differences between the two experiments.

Orthophosphate runoff losses from Standard were not significantly different from Split the first two runoff events of 2011. However, losses were significantly less than Spilt the first two events following the 15 DAS fertilizer application in 2011. Similar to inorganic N results, 15 DAS fertilization to Spilt, Poultry, and SU significantly increased orthophosphate runoff losses compared to all other programs. Results indicate orthophosphate lost from SU was significantly greater than all programs except Split the first runoff event of 2012. Furthermore, losses from Spilt, Poultry, and SU were approximately 10 times greater than from all other programs 22 DAS is both years. The greatest total loss was 1.4 percent of applied P (2011 Poultry). Therefore, total losses from all programs were minimal compared applied P. This may be a result of conducting the experiments on a 10 percent slope. Additional research on slopes with varying gradients is necessary to confirm these results.

Simulated Rainfall

Runoff Depth and Total Nitrogen, Phosphorus, and Solids in Runoff

Repeated measures analysis of runoff, TN, TP, and TS data indicated there was not a significant interaction between fertilizer program and sample time for any rainfall simulation in either year. Furthermore, fertilizer program was not significant for any simulation in either year. Sample time was significant for all simulations so data were pooled across fertilizer program and presented by sample time (Table 4.3). Similar to natural rainfall results, significant correlations existed between runoff depth, TS, TP, and TN runoff losses. The strongest correlations were between TN and TS losses. Significant correlations with coefficients [$r > 0.6$ ($P \leq 0.0001$)] existed for every simulation and every sample time except 20 minutes, 14 DAS in 2011. Total P losses were not significantly correlated with any other parameter during the 2011, 14 and 30 DAS simulations. Similar to natural rainfall results, this may be due to the data variability. As previously mentioned, it is possible the variability in sediment bound P loss lead to the variability in TP loss. Therefore, TP loss does not have a distinct trend across the six sample times in the first two simulations of 2011. However, TP losses increased for each sampling period during the 56 and 14 DAS simulations in 2011 and 2012, respectively. Runoff, TN, and TS losses generally increased or decreased during all simulations

Simulated rainfall lost as runoff increased across sampling time during every simulation. Runoff amounts the first two simulations of 2011 were similar although vegetative cover was 27 percent greater the second simulation. However, antecedent soil moisture 30 DAS was 4 percent greater than 14 DAS. Shuman (2002) simulated rainfall at 50 mm hr^{-1} and found runoff volume significantly increased as soil moisture increased.

Therefore, lack of runoff differences between 14 and 30 DAS may be a function of both soil moisture and vegetative cover. There was approximately 60 percent more vegetative coverage (visual) 56 than 14 DAS. This resulted in 2.7 mm less runoff per sample time. Vegetative cover also had an influence on TS, TN, and TP losses.

Overall, TS, TN, and TP runoff losses decreased as vegetative cover increased in 2011. Similar to natural rainfall results, mulching in 2012 limited runoff losses. Total S and P lost during the 14 DAS simulation in 2012 were less than the 56 DAS simulation in 2011. However, TN losses were greater. Nitrogen applied 0 DAS may have still been near the soil surface due to lack of plant uptake and runoff events prior to the 2012 simulation. Ammonium plus nitrate-N runoff losses were 69 percent of TN losses during the 14 DAS simulation in 2012. This is compared to 18 percent during the 56 DAS simulation in 2012. Overall, trends of inorganic N runoff losses were similar to TN losses across sampling periods.

Inorganic Nitrogen Runoff Losses

Sample time was significant for every simulation and fertilizer program was significant for two of four simulations for both ammonium and nitrate-N. Data were separated by fertilizer program and sample time in order to effectively explain significant fertilizer program differences during each simulation (Fig. 4.4 and Fig. 4.5).

Nitrate-N runoff losses generally decreased across sample time for every simulation in 2011 and increased across sample time in 2012. Mulch cover in 2012 may have delayed the transport of applied N, leading to greater losses later in the simulation. Although greater, nitrate-N losses from Standard plots were not significantly different than from Split and Half 14 DAS in either year. These results are consistent with ammonium-N losses during the same simulations. However, PCU applied in 2011 significantly increased ammonium-N loss.

Ammonium-N runoff losses from PCU plots were significantly greater than all other fertilizer programs across all sampling times 14 DAS in 2011. It must be noted that ammonium-N runoff losses were never greater than 20 g ha^{-1} for a single sample time and totaled 89 g ha^{-1} for the 14 DAS simulation. These losses were less than nitrate-N, which were never greater than 100 g ha^{-1} and totaled 198 g ha^{-1}. Ammonium plus nitrate-N losses from PCU during the 14 DAS simulation were 0.4 percent of applied N. Burwell et al. (2011) also simulated rainfall 14 DAS (following two runoff producing natural rainfall events). They found combined ammonium plus nitrate-N runoff losses from 50 kg N ha^{-1} applied as sulfur-coated urea to be 0.9 percent of applied N. Differences between the experiments may be attributed to greater slope and rainfall intensity during Burwell et al. (2011).

Ammonium and nitrate-N runoff losses were significantly greater from SU plots than from any other fertilizer program during the second 2011 simulation. Significant differences occurred for every sampling period except 5 minute nitrate-N. Stabilized urea (SU) contains both a urease [N-(n-butyl) thiophosphoric triamide] and nitrification (dicyandiamide) inhibitor. Therefore, ammonification and subsequent nitrification of urea in SU applied 15 DAS was delayed. This may have reduced N lost by ammonia volatilization and leaching compared to applied ammonium nitrate. Therefore, a greater amount of ammonium and nitrate-N were present (compared to other treatments) near SU soil surface during the simulation. Unlike inorganic N, orthophosphate runoff losses were not significantly influenced by fertilization 15 DAS.

Inorganic Phosphorus Runoff Losses

Repeated measures analysis did not result in a significant interaction between fertilizer program and sample time for any simulation. Sample time was significant for all three simulations in 2011 and fertilizer program was significant the final simulation of 2011. Similar to inorganic N, results were separated by fertilizer program and sample time to effectively explain significant fertilizer program differences during each simulation (Fig. 4.6).

The combination of poultry litter and CSP applied 0 DAS to Poultry resulted in the greatest orthophosphate runoff losses during the 14 DAS simulation in both years. Furthermore, losses were significantly greater than all other fertilizer programs during the 15 and 30 minute samples times in 2011. Orthophosphate losses from Standard plots were greater than from Split and Half during every sample time in 2011. Due to data variability, differences were not statistically significant except between Standard and Split the final three sample times. These results indicate that both P source and rate may have an influence on orthophosphate runoff losses.

Edwards and Daniel (1994) fertilized tall fescue with poultry litter and inorganic fertilizer at the same P rate. They found two times greater dissolved P in runoff from tall fescue fertilized with inorganic P. Gaudreau et al. (2002) results indicate increasing P rate applied as CSP and manure to established bermudagrass significantly increased dissolved P runoff concentrations. Both of these studies were conducted on established turfgrass. Therefore, P was applied to the turfgrass surface and more likely to be transported offsite during runoff.

Inorganic P applied to the soil surface 15 DAS increased orthophosphate runoff losses during the second simulation in 2011. Losses from Split, Poultry, and SU plots were greater than from all other programs for each sample time. Total orthophosphate runoff loss from Split, Poultry, and SU ranged from 89 to 116 g ha^{-1} during the 30 DAS simulation. This was 0.13 to 0.18 percent of total P applied. Shuman (2002) rainfall simulations, 4, 24, 72, and 168 hours after P application, resulted in a 9.7 (4 h) to 0.2 (168 h) percent loss in applied P. Although our experiments and results somewhat differed, the conclusion can be made that the greatest potential for N and P runoff losses is immediately after fertilization. Furthermore, practices such as incorporating fertilizer into the soil and mulching will reduce nutrient movement due to runoff.

Experiment II

Vegetative Coverage

Visual evaluations and digital image analysis (DIA) were used in the same manner as Experiment I to assess percent vegetative coverage on a weekly basis. Correlation coefficients between visual evaluations and percent coverage calculated by DIA were 0.91 ($P \leq 0.0001$) and 0.93 ($P \leq 0.0001$) in 2011 and 2012, respectively. A significant interaction occurred between mulch and days after seeding (DAS) in both years. Similar to Experiment I, canopy shading near the end of the establishment period skewed DIA results. Thus, visual cover data were separated by mulch treatment and DAS for each year (Table 4.4).

Seedling emergence began approximately 14 DAS in both years. However, due to fall planting dates, the only desired species that germinated were tall fescue and crimson clover. Unlike Experiment I, weeds were not problematic in either year.

Therefore, percent vegetative cover data accurately reflects percent tall fescue and crimson clover.

A comparison of years indicates greater percent cover in the Half, Standard, and ET-FGM treatments in 2012 than 2011. This was may be due to the 5 week earlier planting date in 2012. Vegetative cover in the other five treatments was generally less in 2012 than 2011. The difference in 2012 was due to the 70 mm natural rainfall event that occurred 8 DAS. Although it totaled a 15 hour event, there were two high intensity, short duration periods that caused significant mulch loss from Paper, Wood, Blend, FGM, and BFM (personal observation). Seed and fertilizer were applied in conjunction with those mulches during hydroseeding. Therefore, it is likely seed and nutrients were also lost in runoff, resulting in less potential seedlings. ET-FGM was also hydroseeded but significant mulch loss was not observed.

Considering seed loss in 2012, results suggest the MDOT fall-winter species established in less time when straw mulch was applied after seeding. These results are consistent with those of Barkley et al. (1965), Richardson and Diseker (1965), McLaughlin and Brown (2006). Furthermore, percent cover in straw mulch applied at 2245 kg ha^{-1} (Half) and MDOT specified 4490 kg ha^{-1} (Standard) was not significantly different for any date in either year, except 21 DAS in 2012. Richardson and Diseker (1965) also compared straw mulch applied at 2245 and 4490 kg ha^{-1}. They concluded the 2245 kg ha^{-1} rate was the most beneficial for vegetative establishment on sloped terrain.

Research comparing vegetative establishment following the application of various hydromulches is lacking. Of the hydromulches in our experiment, three (Paper, Wood, and Blend) were applied at 2245 kg ha^{-1} and three (FGM, ET-FGM, and BFM) were applied at 3368 kg ha^{-1}. Rate difference between the two groups was due to mulches being applied at label rates based slope gradient. Our results suggest the slowest establishment was due to Paper application during both years. Wood and Blend vegetative cover was greater than Paper cover during the establishment period in both year. Cover ratings of FGM, ET-FGM, and BFM were similar for every date in 2011. However, seed loss due to runoff from FGM and BFM early in the 2012 establishment period may have reduced cover compared to ET-FGM.

The MDOT goal of 70 percent vegetative coverage in 30 days was not achieved in either year. Cover in straw mulched plots reached 70 percent, 77 and 56 DAS in 2011 and 2012, respectively. The difference in years was likely due to the 5 week earlier planting date in 2012. Considering the seed mixture used in the experiments is for fall-winter plantings, increasing the seeding rate of tall fescue and crimson clover may decrease time to 70 percent cover. Further research should evaluate seeding rates and alternative species for use during fall-winter plantings.

Natural Rainfall

Rainfall and Runoff Depth

A greater number of natural rainfall events occurred in 2011 (12) than in 2012 (6). Of those, four events produced runoff during both years (Fig. 4.7 and Fig. 4.8). There was not a significant interaction between mulch and DAS in either year. Treatment and DAS were significant in 2011, whereas only DAS was significant in 2012. Data were separated by mulch for each runoff date in order to explain runoff variation and mulch treatment differences.

Runoff collected was positively correlated with the rainfall amount in both years. Correlation coefficients were 0.84 ($P \leq 0.0001$) and 0.71 ($P \leq 0.0001$) in 2011 and 2012, respectively. Results indicate runoff losses from Standard plots in 2011 were less than from all other mulches for every date except 47 DAS. Mostaghimi et al. (1994) compared runoff losses from soil treated with a variety of erosion control products. They concluded straw mulch was the most effective erosion control product for reducing runoff. Few significant differences occurred between mulch treatments in our studies due to high variability in collected runoff. In 2011, the greatest percent rainfall lost as runoff occurred 37 DAS. During the event, rainfall lost as runoff ranged from 10 (Standard) to 13 (ET-FGM) percent.

Rainfall and subsequent runoff depths were generally greater in 2012 than 2011. As previously mentioned, a 70 mm rainfall event occurred 8 DAS in 2012. Mulch losses during the event lead to the greatest amount of collected runoff across mulch treatments. The greatest percent of rainfall lost as runoff occurred 35 DAS in 2012. An average of 47 percent of rainfall was lost as runoff. A combination of high soil moisture and high intensity rainfall contributed to these results. Similar to 2011, high variability overshadowed any significant runoff differences between treatments in 2012. Across the four events, runoff collected from Half, Standard, FGM, and ET-FGM was similar, but none of the four mulches was consistently more effective at reducing runoff.

Total Solids in Runoff

Statistical analyses for TS runoff losses indicated there was a significant interaction between mulch and DAS during both years. Data were separated by mulch for each runoff event (Fig. 4.9). Similar to runoff results, TS losses were generally greater in

2012 than 2011. Significant positive correlations between runoff depth and TS occurred 26 DAS [r = 0.78 ($P \leq 0.0001$)] in 2011 and 35 and 38 DAS [r = 0.68 ($P \leq 0.0001$) and r = 0.74 ($P \leq 0.0001$), respectively] in 2012. These results coincide with low coefficients of variation. Thus, TS variability may have contributed to the insignificantly correlated dates.

In 2011, TS runoff losses from Half and Standard were less than from all other mulches. Standard reduced TS losses 32 percent compared to Half across the four runoff events in 2011. However, the only significant difference between Half and Standard occurred 33 DAS. Maximum TS runoff losses never exceeded 25 kg ha^{-1} for a single event (Paper, 37 DAS). Furthermore, TS in runoff from Paper 37 DAS was significantly greater than from all other mulch. There were no significant differences in TS runoff losses between Wood, Paper, and Blend or between FGM, ET-FGM, and BFM for the other three events.

Total solids losses from Half, Standard, and ET-FGM plots were less than from all other mulches in 2012. This may be due to greater mulch and vegetative cover. It is likely the observed mulch lost from Paper, Wood, Blend, FGM, and BFM 8 DAS contributed to greater TS runoff losses. There were no significant differences between Half and Standard for any 2012 event.

Total Nitrogen Runoff Losses

Similar to TS results, there was a significant interaction between mulch and DAS when TN data were analyzed. Therefore, data were separated by mulch and DAS (Fig. 4.9). Significant correlations existed between TS and TN 26, 33, and 47 DAS in 2011 and 21, 35, and 38 DAS in 2012.

Considering significant correlations between TS and TN in both years, it is not surprising TN runoff losses were generally greater in 2012 than 2011. However, it must be noted the first runoff event of 2011 occurred during the 14 DAS rainfall simulation. The second event occurred 26 DAS as a result of natural rainfall. Results from Experiment I indicate the largest percent of applied fertilizer are lost during the first runoff event during fertilization. This may partially explain the differences between 2011 and 2012 TN runoff losses during the first event produced by natural rainfall.

Results indicate Half TN runoff losses were not significantly different than Standard in either year. Losses from Half and Standard were less than from all other treatments 26 DAS in 2011, whereas they are greater than from all others 8 DAS in 2012. This may be a result of fertilizer application method and non-runoff producing rainfall. Granular fertilizer was applied to the soil surface to both Half and Standard prior to mulch application. Furthermore, there were no rainfall events prior to the 8 DAS event in 2012. Runoff from high intensity rainfall 8 DAS may have transported partially dissolved fertilizer prills offsite, leading to greater TN losses.

These results indicate granular fertilization during dry environmental conditions may increase nutrient transport offsite if runoff was to occur prior to non-runoff producing rainfall. Fertilizer applied with the hydromulches was dissolved prior to incorporation with seed and mulch in the hydroseeder. Furthermore, water applied with hydromulch may have moved nutrients into the soil profile and created more favorable germination conditions by increasing soil moisture. This is an apparent benefit to using hydromulch rather than straw mulch during dry conditions.

Although TN runoff losses were the greatest from Half and Standard for the first runoff event of 2012, across all other events (2011 and 2012) the greatest losses were generally from Paper, Wood, or Blend. Applying those mulches above the recommended label rate on a 15 percent slope may be necessary to reduce losses. Of the hydromulches applied at 3368 kg ha^{-1}, TN runoff losses from BFM were significantly greater than from FGM and ET-FGM, 21 DAS in 2012. This may be a result of greater TS losses from BFM than FGM and ET-FGM. The observed mulch loss during runoff 8 DAS may have reduced runoff mitigation performance of all hydromulches except ET-FGM.

Inorganic Nitrogen Runoff Losses

Analyses of inorganic N data indicated a significant interaction occurred between mulch and DAS for both ammonium and nitrate-N runoff losses in both years. Results were separated by mulch and DAS (Table 4.5). Half, Standard, and BFM were the most effective in reducing inorganic N runoff losses 26 DAS in 2011. Ammonium and nitrate-N losses from Half, Standard, and BFM were significantly lower than from Wood and Blend during the event. BFM used in the experiment is composed of 68 percent wheat straw, whereas the other hydromulches are a majority paper or wood fiber. Thus, mulch fiber length may influence runoff losses.

The 26 DAS event was the second runoff event of 2011. Therefore, ammonium and nitrate-N losses appear to be significantly less than those from the first event in 2012. Results from the first runoff event (8 DAS) in 2012 support the hypothesis that fertilizer applied to Half and Standard had not been completely dissolved and moved into the soil profile prior to runoff. Ammonium plus nitrate-N lost from Half and Standard during the 8 DAS event was 1.5 and 2 percent of applied N, respectively.

Ammonium plus nitrate-N loss 8 DAS from BFM was 0.5 percent of applied N. This was less than all other mulches. The other three events in 2012 did not produce ammonium plus nitrate N losses greater than 0.4 percent of applied N (Blend, 21 DAS). Similar to Experiment I, these results indicate applied N is most vulnerable to being transported offsite via runoff during the first rainfall event following fertilization.

Total Phosphorus Runoff Losses

Total P runoff losses were strongly correlated [$r = >0.6$ ($P \leq 0.0001$)] with TS 26 and 47 DAS in 2011 and 8 and 21 DAS in 2012. Similar to Experiment I, these results indicate there is a relationship between TP and TS in runoff. Reducing sediment loss during runoff may reduce TP transported offsite. Furthermore, it is apparent mulch type influences the amount of TP lost during runoff.

Total P runoff losses were generally greater in 2012 than 2011. The greatest single losses were 51 and 950 g ha^{-1} in 2011 and 2012, respectively. There were no significant TP differences between Half and Standard in either year except 38 DAS in 2012. Total P lost from the Half plot in the fourth replication 38 DAS was approximately three times greater than from plots in the other replications. Therefore, it is possible sediment contamination of the fourth replication sample lead to the increased TP loss.

Results indicate a significant difference occurred between FGM, ET-FGM, and BFM during the 26 DAS event in 2011. BFM losses were 27 and 41 percent lower than ET-FGM (significant) and FGM (not significant), respectively. There were no significant differences between the three mulches in 2012. Significant differences did occur between Paper, Wood, and Blend during the 35 DAS event in 2012. Blend losses were 40 and 55 percent lower than Wood and Paper, respectively. Greater differences between groups of hydromulches applied at the same rate may have occurred if the slope was greater than 15 percent. Future research should be conducted to evaluate failure of loose and hydromulch during runoff on range of slope gradients.

Inorganic Phosphorus Runoff Losses

In general, orthophosphate runoff losses were less than inorganic N losses. This may be due to greater affinity of P in soil solution to adsorb to soil particles (Havlin et al., 2005). Runoff loss trends of inorganic N and orthophosphate were the same in both years. There were no significant orthophosphate loss differences between Half and Standard for any event in either year. In 2011, losses from all hydromulched plots were greater than from Half and Standard. An evaluation of the hydromulches indicated BFM had the least amount of orthophosphate lost during runoff. In 2012, the greatest losses were generally from Half and Standard plots. However, Half and Standard total losses across the four events were 0.7 and 0.6 of applied P. Comparatively, the lowest total loss was 0.3 percent of applied P (FGM). Therefore, orthophosphate runoff losses during natural rainfall from all mulches were minimal compared to applied.

Simulated Rainfall

Soil Volumetric Water Content, Runoff Initiation Time, and Runoff Depth

Soil volumetric water content (VWC) and runoff initiation time (RIT) data were collected once for each plot during each simulation, whereas runoff depth was collected six times, once for each sample time. Therefore, VWC and RIT results are averages across the four replications and runoff depth results are averages across sample time and replication. Data were separated by mulch and simulation due to a significant interaction between mulch and DAS for each year (Tables 4.7, 4.8 and 4.9).

In general, 14 DAS antecedent VWC, RIT, and runoff depths were less in 2011 than 2012. Results indicate there were no significant differences between Half and Standard during the 14 DAS simulation in either year. Although not significant, Half and Standard soil VWC and RIT were greater and runoff depth was less than all other mulches in both years. Considering the intensity of the simulation (66 mm ha^{-1}) was that of a 10 year storm, these results suggest use of straw mulches may be more appropriate than hydromulches on a 15 percent slope. Mostaghimi et al. (1994) made similar conclusions after comparing runoff mitigation of straw mulch to hydromulch on a 10 percent slope. Runoff losses from Paper, Wood, and Blend were generally greater than from FGM, ET-FGM, and BFM during the 14 DAS rainfall simulations. Application rate differences between the two groups may have lead to these results.

Fewer differences occurred between mulches during the 28 and 56 DAS simulations. Runoff from Paper, Wood, and Blend was greater than from all other mulches during the 28 DAS simulation in 2011. The results differed in 2012, with the greatest runoff from FGM. In total, 93 percent of rainfall applied to FGM was lost as runoff. This is compared to Half and Standard which lost 69 and 64 percent, respectively. However, vegetative cover in Half and Standard plots was 20 percent greater than in FGM plots during the simulation.

Runoff from Paper was significantly greater than from all others during the 56 DAS simulation in 2011. Paper vegetative cover 56 DAS was 18 percent. Observations indicated lack of coverage lead to rill erosion and concentrated flow towards to the end of the simulation. During the 56 DAS simulation in 2012, Half and Standard RIT was greater and runoff losses were less than all other mulches. This is likely a result of Half and Standard vegetative cover being approximately 10 to 50 percent greater.

Total Solids in Runoff

Similar to runoff results, TS in runoff was less in 2011 than 2012 (Tables 4.7, 4.8 and 4.9). Total solids in runoff from Paper, Wood, and Blend were significantly greater than from all other mulches during the 14 DAS simulation in 2011. Erosion resulted in total losses of 51.6 kg TS ha^{-1} from Blend during the 30 minute simulation. This is compared to total losses of 2.2 and 3.2 kg ha^{-1} from Half and Standard, respectively. Although greater, losses from FGM, ET-FGM, and BFM were not significantly different than Half and Standard. McLaughlin and Brown (2006) found no differences in total sediment loss between straw (2200 kg ha^{-1}) and BFM (3360 kg ha^{-1}) on a 10 percent slope. Less mulch cover and greater antecedent soil moisture 14 DAS in 2012 may have increased TS in runoff compared to 2011. The greatest TS runoff losses during the event were 230 kg ha^{-1} (Paper), whereas the least were 106 kg ha^{-1} (Standard).

Results from the 28 DAS simulation in 2011 indicate TS losses from Paper were not significantly different from Wood or Blend. However, differences did occur in 2012. Blend and Wood reduced TS loading by 21 and 26 percent compared to Paper, respectively. During the same event, losses from Half, Standard, and ET-FGM were significantly less than from all other mulches. In 2011, 56 DAS losses from Paper were significantly greater than from all other mulches. There were no other significant differences between mulches. Results from the 56 DAS simulation in 2012 were similar to those from the 28 DAS event. These results suggest paper mulch applied at 2245 kg ha^{-1} is the least effective in limiting soil erosion on a 15 percent slope.

Total Nitrogen Runoff Losses

As previously mentioned, the first 2011 runoff event occurred during the 14 DAS rainfall simulation. Similar to TS results, TN losses were the greatest from Paper, Wood, and Blend during the 14 DAS simulation (Tables 4.7). The greatest total loss was 2.5 kg ha^{-1} (Blend), which was significantly greater than losses from all others except Wood. Comparatively, Standard losses were 99 percent less than Blend losses. There were no significant differences between Half, Standard, FGM, ET-FGM, or BFM during the 14 DAS simulation in 2011.

Similar to natural rainfall results, the greatest TN runoff losses during the 14 DAS simulation in 2012 were from Half and Standard. Losses were significantly greater than from all other mulches except Wood. Considering TS results, Half and Standard TN losses were most likely influenced by inorganic rather than organic N in runoff.

Total nitrogen runoff losses 28 DAS in 2011 were similar to those from 14 DAS, whereas 2012 results differ (Tables 4.8). The greatest TN lost (1.3 kg ha^{-1}) was from Paper, which was significantly greater than losses from Half, Standard, FGM, and ET-FGM. The simulation conducted 56 DAS in 2011 resulted in significantly greater TN losses from Paper than from all other mulches (Tables 4.9). Losses were 6.9 times greater than the next greatest loss (Blend). Total N runoff losses from Paper were also greater than from all other mulches 56 DAS in 2012. Due to data variability these losses were only significantly greater than from Half, Standard, and ET-FGM. These results suggest runoff losses late in the establishment period were more influenced by organic rather than inorganic N.

Inorganic Nitrogen Runoff Losses

Results indicate Paper, Wood, and Blend were the least effective at reducing ammonium and nitrate-N runoff losses during 2011 (Fig. 4.10). Nitrate-N losses from these three mulches were greater than from all other mulches across all three simulations. The greatest total nitrate-N loss for one simulation was 738 g ha^{-1} (Blend, 14 DAS). Comparatively, 5.7 g ha^{-1} was lost from Standard during the same simulation.

Ammonium-N runoff losses during the 2011, 14 DAS event were generally greater than nitrate-N losses. The greatest ammonium-N runoff losses, 1380 g ha^{-1}, were from Blend. These results suggest a fraction of the applied fertilizer had not been nitrified. This is not as concerning from a water quality standpoint as the total ammonium plus nitrate-N lost during the first runoff event. During the 2011, 14 DAS simulation ammonium plus nitrate-N runoff losses (2118 g ha^{-1}) from Blend were 64 percent of the total losses across the establishment period (natural and simulated rainfall). Although losses from Blend were greater 14 DAS, Paper ammonium plus nitrate-N runoff losses (930 g ha^{-1}) were 67 percent of the total lost. In comparison, Half and Standard ammonium plus nitrate-N losses were 5 and 16 percent of the total loss, respectively. It must be noted Half losses during the 28 DAS simulation were 76 percent of the total loss. However, Half total loss was 0.1 of applied N, whereas the greatest loss of applied N was 2.2 percent (Blend). Results indicate there were no ammonium or nitrate-N loss differences between FGM, ET-FGM, and BFM in either year.

Ammonium and nitrate-N runoff losses during 2012 simulations were generally greater than 2011. During the 14 DAS simulation, ammonium-N losses from Half were significantly greater than from all other mulches. Nitrate-N losses from Standard were significantly greater than all others except Half. The 14 DAS simulation was the second runoff event of 2012. However, ammonium plus nitrate-N losses from Half and Standard were approximately 10 percent greater than during the first runoff event (8 DAS). This may have been due to the high intensity rainfall during the simulation. Furthermore, losses from the first two runoff events were approximately 90 percent of the total losses for both Half and Standard. Ammonium plus nitrate-N losses were significantly greater from ET-FGM than FGM and BFM during the 14 and 28 DAS simulations. During the 56 DAS simulations, the greatest ammonium plus nitrate-N losses were from Paper, Wood, and Blend.

Total Phosphorus Runoff Losses

Total phosphorus losses were not as great as TN losses across any simulation in either year (Tables 4.7, 4.8 and 4.9). In 2011, Paper, Mulch, and Blend TP losses were greater than from all other mulches. Similar to TN results, the least amount of TP was lost from Half and Standard. These losses were 97 percent less than the greatest (Blend) for that event. In 2012, there were no significant differences between mulches 14 DAS. However, data indicate the greatest total losses were from Paper and FGM, 882 and 900 g ha^{-1}, respectively.

During the 2011, 28 DAS simulation, TP runoff losses were significantly greater from Paper and Wood than from Standard and FGM. However, during the event no total losses from any mulch exceeded 65 g ha^{-1} (Paper). Results differed in 2012. The greatest loss [672 g ha^{-1} (BFM)] was significantly greater than Standard and ET-FGM. In 2011, TP losses from Paper were significantly greater than from all other mulches 56 DAS. Losses were 7 times greater than the next greatest loss (Blend). Half, Standard, and ET-FGM reduced TP losses 60 to 67 percent from the greatest loss (Blend) 56 DAS in 2012. Therefore, straw mulch was the most effective in limiting TP in runoff during simulated rainfall in both years.

Inorganic Phosphorus Runoff Losses

Results suggest orthophosphate runoff losses from Blend were greater than from all other mulches during the 14 and 28 DAS rainfall simulations in 2011 (Fig. 4.12). Combined losses from those two simulations accounted for 69 percent of total losses during the establishment period. However, this was only 0.4 percent of applied P. Half, Standard, FGM, ET-FGM, and BFM were generally more effective in reducing orthophosphate runoff losses than Paper, Wood, and Blend during the all rainfall simulations. During the 56 DAS simulation, losses (79.4 g ha^{-1}) from Paper were greater than all others mulches. Comparatively, Half losses were 65 percent less than Paper during the same simulation.

Overall, orthophosphate runoff losses were greater in 2012 than 2011. Half and Standard losses were greater than all other mulches across the three simulations. The only significant difference between occurred 28 DAS. Furthermore, Half and Standard total losses across natural and simulated rainfall were 1.1 and 0.9 percent of applied P, respectively. There were no significant differences between mulches during the 56 DAS simulation.

Results suggest straw mulch applied at Half and the Standard MDOT rate will reduce inorganic N and P runoff losses on a 15 percent slope. However, there are situations in which hydromulches may be more appropriate for vegetative establishment of sloped terrain. Specifically, losses from Half and Standard in 2012 are concerning. It is apparent non-runoff producing rainfall is necessary following fertilization to dissolve fertilizer prills and move nutrients into the soil profile. Dissolving and applying fertilizer with the hydromulch mixture may be more effective in reducing N and P runoff losses if there is no rainfall prior to the first runoff event. Results indicate recommended rates of Paper, Wood, and Blend are too low to effectively mitigate runoff on a 15 percent slope. Performances of FGM, ET-FGM, and BFM were similar and more effective than Paper, Wood, and Blend.

It is difficult to compare solid and nutrient runoff losses during our experiment to previous research due to treatment and experimental design differences. There are many experiments comparing straw mulch to hydromulch (Mostaghimi et al., 1994; Soupir et al., 2004; McLaughlin and Brown, 2006; Babcock and McLaughlin, 2013). However, these experiments typically compared straw to one type of hydromulch, fertilization rates between the two were often different, and runoff was produced by simulated rainfall. Our experiment utilized natural and simulated rainfall, further complicating comparisons. Future research is necessary to evaluate solid and nutrient runoff losses from loose and hydromulches applied at various rates across a range of slopes.

Table 4.1 Experiment I nitrate (NO_3^--N) and ammonium (NH_4^+-N) nitrogen runoff losses during 2011 and 2012 natural rainfall. All fertilizer programs except Control received N fertilizer 0 days after seeding (DAS). The fertilizer programs Spilt, Poultry, SU, and DAP received additional N fertilizer 15 DAS.

	Year†									
	2011					2012				
	Days after seeding									
Fertilizer program‡	7	11	22	29	54	21	22	24	27	28
	NO_3^--N (g ha^{-1})									
control	65 ab	203 ab	43 ab	107 bcd	7 b	139 b	43 b	34 b	2 c	23 b
standard	60 ab	212 ab	61 ab	76 cd	10 b	554 ab	113 b	260 ab	2 c	65 ab
split	53 ab	223 ab	27 b	99 bcd	11 b	984 ab	66 b	149 ab	15 abc	73 ab
poultry	40 b	153 b	73 ab	162 bc	10 b	795 ab	329 a	496 a	12 bc	218 a
SU	54 ab	415 a	55 ab	274 a	133 a	1309 ab	147 b	87 ab	33 a	90 ab
half	71 ab	291 ab	21 b	65 d	6 b	529 ab	49 b	151 ab	11 bc	30 b
PCU	61 ab	433 a	51 ab	136 bcd	21 b	318 b	48 b	264 ab	24 ab	185 ab
DAP	78 a	307 ab	99 a	167 b	23 b	1568 a	140 b	137 ab	6 bc	69 ab
cv%	38.2	57.9	76.1	44.0	231.3	103.9	59.2	134.9	96.4	112.2
	NH_4^+-N (g ha^{-1})									
control	38 c	31 b	3 c	30 bc	31 bc	6 b	6 b	12 b	1 a	3 b
standard	388 a	64 b	5 c	29 c	37 bc	41 b	28 b	15 b	1 a	8 ab
split	232 bc	48 b	229 a	78 b	48 abc	221 ab	290 a	44 ab	2 a	14 a
poultry	374 a	84 b	149 b	58 bc	27 c	133 ab	292 a	65 a	1 a	14 ab
SU	368 ab	82 b	188 ab	213 a	79 ab	352 a	181 ab	32 ab	5 a	18 a
half	211 c	50 b	3 c	26 c	38 bc	21 b	2 b	16 b	1 a	7 ab
PCU	325 abc	574 a	10 c	42 bc	50 abc	33 b	19 b	34 ab	4 a	19 a
DAP	198 c	56 b	54 c	41 bc	94 a	87 b	37 b	11 b	1 a	11 ab
cv%	35.5	28.7	59.4	50.7	67.1	136.9	114.1	99.3	129.2	77.5

(Table 4.1 continued)

†Values with the same letter within each column for each year and N species are not statistically different according to Least Squared means ($\alpha = 0.05$)
‡Abbreviations: SU, stabilized urea; PCU, polymer coated urea; DAP, diammonium phosphate

Table 4.2 Experiment I orthophosphate (PO_4^{3-}) runoff losses during 2011 and 2012 natural rainfall. All fertilizer programs except Control received P fertilizer 0 days after seeding (DAS). The fertilizer programs Spilt, Poultry, and SU received additional P fertilizer 15 DAS.

	Year†									
	2011					2012				
	Days after seeding									
Fertilizer program‡	7	11	22	29	54	21	22	24	27	28
	PO_4^{3-}-P (g ha^{-1})									
control	31 d	19 c	5 b	33 d	32 a	31 b	8 b	24 b	3 b	23 b
standard	218 bc	60 bc	6 b	83 cd	42 a	30 b	11 b	51 b	3 b	66 ab
split	146 c	51 bc	115 a	145 b	29 a	76 ab	112 a	62 b	10 ab	73 ab
poultry	444 a	123 a	114 a	207 a	55 a	64 b	137 a	178 a	9 ab	136 a
SU	144 c	50 c	145 a	128 bc	43 a	158 a	128 a	50 b	14 a	78 ab
half	150 c	55 bc	5 b	59 d	63 a	32 b	11 b	52 b	6 ab	45 b
PCU	157 bc	58 bc	6 b	49 d	47 a	24 b	13 b	52 b	3 b	57 b
DAP	261 b	95 ab	13 b	80 cd	34 a	45 b	7 b	27 b	4 b	69 ab
cv%	38.5	44.3	67.6	39.2	71.2	104.6	108.1	76.5	87.3	70.2

†Values with the same letter within each column for each year are not statistically different according to Least Squared means ($\alpha = 0.05$)

‡Abbreviations: SU, stabilized urea; PCU, polymer coated urea; DAP, diammonium phosphate

Table 4.3 Experiment 1 runoff depth and total solids (TS), total phosphorus (TP), and total nitrogen (TN) runoff losses during 2011 and 2012 simulated rainfall. Data were pooled across fertilizer program and means are presented by sample time.

	Year – Simulation Date			
	2011 – 14 DAS†			
Sample time (min)	Runoff parameter			
	runoff (mm)	TS (kg ha^{-1})	TP (g ha^{-1})	total N (g ha^{-1})
5	2.9	67	326	286
10	4.0	95	450	301
15	4.3	101	435	316
20	4.6	142	388	306
25	4.7	104	326	306
30	4.9	111	608	305
	2011 – 30 DAS			
5	3.5	67	411	251
10	4.2	66	385	197
15	4.3	64	444	179
20	4.5	63	348	166
25	4.5	62	389	161
30	4.6	63	467	161
	2011 – 56 DAS			
5	0.8	3.3	9.3	20.9
10	1.2	3.5	13.4	15.8
15	1.7	5.0	14.2	21.2
20	2.0	7.3	31.5	22.7
25	2.3	5.5	38.9	25.2
30	2.5	7.9	37.2	27.2
	2012 – 14 DAS			
5	0.2	0.8	5.6	28.9
10	0.3	1.0	5.6	23.9
15	0.4	1.1	6.1	19.2
20	0.5	1.6	6.9	23.5
25	0.7	2.4	6.6	38.9
30	0.9	3.6	8.5	68.2

†DAS: days after seeding

Table 4.4 Experiment II percent vegetative cover determined by visual evaulation in 2011 and 2012.

DAS				2011				
				Mulch†				
	half	standard	paper	wood	blend	FGM	ET-FGM	BFM
21‡	8.8 cd	11.3 bc	4.0 d	18.8 a	15.0 ab	10.0 bc	4.3 d	7.5 cd
28	17.5 a	20.0 a	20.0 a	22.5 a	17.5 a	12.5 a	12.5 a	15.0 a
35	40.0 a	40.0 a	15.0 d	32.5 ab	25.0 bc	17.5 cd	20.0 cd	15.0 d
42	42.5 a	45.0 ab	15.0 d	37.5 ab	27.5 bc	22.5 cd	25.0 cd	25.0 cd
49	50.0 a	47.5 a	13.8 e	42.5 ab	35.0 bc	25.0 cd	25.0 cd	25.0 de
56	57.5 a	60.0 a	17.5 d	42.5 b	35.0 bc	27.5 cd	27.5 cd	25.0 cd
77	72.5 a	75.0 a	25.0 d	55.0 b	50.0 bc	35.0 d	37.5 cd	30.0 d
98	90.0 a	87.5 a	62.5 c	80.0 ab	77.5 ab	72.5 bc	70.0 bc	67.5 bc
				2012				
21	8.8 bc	15.0 a	2.0 d	4.3 d	5.5 cd	5.0 d	10.0 b	3.5 d
28	27.5 ab	35.0 a	2.0 c	3.5 c	6.8 c	7.5 c	25.0 b	4.8 c
35	45.0 ab	50.0 a	3.5 c	9.3 c	11.8 c	12.5 c	37.5 b	9.3 c
42	55.0 a	55.0 a	6.3 c	13.8 c	20.0 c	17.5 c	37.5 b	16.3 c
49	62.5 a	57.5 a	7.5 d	13.8 cd	22.5 c	22.5 c	40.0 b	18.8 cd
56	70.0 a	62.5 a	15.0 c	25.0 bc	37.5 b	32.5 b	55.0 a	30.0 bc
77	80.0 a	75.0 a	20.0 d	30.0 cd	40.0 c	37.5 c	57.5 b	35.0 cd
98	88.8 a	78.8 ab	32.5 e	42.5 de	52.5 cd	55.0 cd	67.5 bc	47.5 de

† Abbreviations: DAS, days after seeding; FGM, flexible growth medium; ET-FGM, extended term-flexible growth medium; BFM, bonded fiber matrix

‡Values with the same letter within each row for each year are not statistically different according to Fisher's Protected Least Significant Difference test at α = 0.05

Table 4.5 Experiment II nitrate (NO_3^--N) and ammonium (NH_4^+-N) nitrogen runoff losses during natural rainfall in 2012 and 2012.

Mulch‡	Year†							
	2011				2012			
	Days after seeding							
	26	33	37	47	8	21	35	38
	NO_3^--N (g ha^{-1})							
half	3.8 d	3.3 b	6.8 bcd	2.1 b	542 cd	378 a	11.6 b	14.8 c
standard	2.3 d	4.9 ab	5.8 d	3.0 b	740 bcd	584 a	27.9 ab	17.2 c
paper	92.2 cd	3.8 b	6.0 cd	2.8 b	995 abcd	407 a	33.0 a	22.7 c
wood	415.0 a	21.5 a	8.7 ab	5.1 a	1547 ab	599 a	27.2 ab	84.4 a
blend	267.3 abc	13.6 ab	9.8 a	4.6 a	1058 abcd	448 a	34.4 a	43.8 b
FGM	164.3 bcd	5.1 ab	7.0 bcd	2.7 b	1528 abc	279 a	20.4 ab	17.1 c
ET-FGM	318.2 ab	8.7 ab	8.0 abc	2.9 b	1945 a	524 a	19.9 ab	19.4 c
BFM	8.1 d	3.3 b	6.0 cd	2.7 b	429 d	429 a	24.2 ab	12.6 c
cv%	94.6	140.3	18.4	29.9	61.3	61.4	54.3	45.6
	NH_4^+-N (g ha^{-1})							
half	4.6 c	3.7 b	9.0 a	2.4 ab	1633 ab	18.4 ab	1.1 c	8.9 a
standard	4.2 c	3.6 b	8.5 a	3.5 ab	2163 a	11.4 b	3.6 bc	6.8 a
paper	40.5 c	3.9 b	9.1 a	2.2 b	902 bc	16.4 ab	10.2 a	5.0 a
wood	225.7 a	7.2 a	13.4 a	3.6 a	1002 abc	32.5 a	2.6 bc	8.8 a
blend	154.3 ab	8.8 a	11.9 a	2.8 ab	1216 abc	20.3 ab	5.4 b	6.6 a
FGM	56.8 bc	3.6 b	9.2 a	2.4 ab	716 bc	10.4 b	2.3 bc	6.2 a
ET-FGM	115.7 abc	3.7 b	9.1 a	2.2 b	1293 abc	19.7 ab	3.5 bc	5.4 a
BFM	8.2 c	2.2 b	24.1 a	2.3 b	364 c	19.1 ab	2.7 bc	9.1 a
cv%	100.3	45.2	104.8	33.4	71.6	61.7	60.9	47.1

†Values with the same letter within each column for each year are not statistically different according to Least Squares Means (α = 0.05)

‡Abbreviations: FGM, flexible growth medium; ET-FGM, extended term-flexible growth medium; BFM, bonded fiber matrix

Table 4.6 Experiment II orthophosphate (PO_4^{3-}-P) runoff losses during natural rainfall in 2011 and 2012.

Mulch‡	Year†							
	2011				2012			
	Days after seeding							
	26	33	37	47	8	21	35	38
	PO_4^{3-}-P (g ha^{-1})							
half	5.9 c	3.3 cd	7.3 de	2.1 b	320 a	53.5 ab	11.6 b	43.7 ab
standard	4.8 c	3.0 d	5.3 e	2.5 b	215 ab	67.8 a	27.9 ab	44.3 a
paper	17.9 bc	7.5 ab	20.4 ab	7.5 a	126 b	26.6 ab	33.0 a	19.0 b
wood	52.3 a	7.7 ab	17.1 abc	6.3 a	119 b	45.7 ab	27.2 ab	32.2 ab
blend	30.3 abc	8.2 a	21.9 a	6.6 a	140 b	37.9 ab	34.4 a	19.1 ab
FGM	27.6 abc	5.7 abcd	12.1 cd	3.6 b	107 b	16.7 b	20.4 ab	29.7 ab
ET-FGM	41.8 ab	5.7 abc	13.7 c	3.6 b	209 ab	32.6 ab	19.9 ab	26.1 ab
BFM	13.3 c	5.3 bcd	15.8 bc	3.9 b	117 b	38.6 ab	24.2 ab	41.7 ab
cv%	77.3	31.2	28.6	34.7	65.2	71.2	55.3	53.9

†Values with the same letter within each column for each year are not statistically different according to Least Squares Means (α = 0.05)

‡Abbreviations: FGM, flexible growth medium; ET-FGM, extended term-flexible growth medium; BFM, bonded fiber matrix

Table 4.7 Experiment II antecedent soil volumetric water content (VWC), runoff initiation time (RIT), runoff depth, and total solids (TS), nitrogen (TN), and phosphorus (TP) in runoff during a rainfall simulation conducted 14 days after seeding in 2011 and 2012. Simulated rainfall intensity was 66 mm ha^{-1}.

Mulch‡	14 Days after seeding†											
	2011						2012					
	Runoff parameter											
	VWC %	RIT sec	Runoff mm	TS kg ha^{-1}	TN g ha^{-1}	TP g ha^{-1}	VWC %	RIT sec	Runoff mm	TS kg ha^{-1}	TN g ha^{-1}	TP g ha^{-1}
half	36.5 ab	340 ab	0.12 d	0.37 b	10.7 cd	1.2 b	44.7 a	294 ab	3.5 bc	21.7 cd	738 ab	41 a
standard	37.7 a	582 a	0.18 d	0.53 b	3.2 d	1.4 b	44.7 a	305 a	2.6 c	17.6 d	841 a	19 a
paper	29.5 c	138 b	1.17 bc	6.55 a	193.1 bc	36.2 a	42.1 a	200 cd	4.0 ab	38.4 a	283 d	147 a
wood	36.1 ab	197 b	1.42 ab	6.43 a	326.1 ab	43.5 a	42.6 a	205 cd	4.4 ab	30.2 abc	472 bcd	54 a
blend	36.2 ab	151 b	1.97 a	8.60 a	421.0 a	49.2 a	42.4 a	180 d	4.7 a	33.7 ab	443 cd	64 a
FGM	34.6 ab	217 b	0.30 d	0.80 b	35.7 cd	8.2 b	41.8 a	212 bcd	4.1 ab	25.6 bcd	310 cd	150 a
ET-FGM	32.5 bc	190 b	0.52 cd	1.26 b	61.4 cd	14.1 b	42.9 a	159 d	4.4 ab	21.1 cd	587 abc	40 a
BFM	35.0 ab	287 ab	0.21 d	0.42 b	15.9 cd	4.0 b	41.5 a	285 abc	4.1 ab	34.8 ab	209 d	66 a

†Values with the same letter within each column for each year are not statistically different according to Least Squares Means (α = 0.05)

‡Abbreviations: FGM, flexible growth medium; ET-FGM, extended term-flexible growth medium; BFM, bonded fiber matrix

Table 4.8 Experiment II antecedent soil volumetric water content (VWC), runoff initiation time (RIT), runoff depth, and total solids (TS), nitrogen (TN), and phosphorus (TP) in runoff during a rainfall simulation conducted 28 days after seeding in 2011 and 2012. Simulated rainfall intensity was 66 mm ha^{-1}.

	28 Days after seeding†											
	2011						2012					
Mulch‡	Runoff parameter											
	VWC %	RIT sec	Runoff mm	TS kg ha^{-1}	TN g ha^{-1}	TP g ha^{-1}	VWC %	RIT sec	Runoff mm	TS kg ha^{-1}	TN g ha^{-1}	TP g ha^{-1}
half	41.0 bc	252 a	0.46 ab	0.92 bc	37.9 bc	6.2 ab	39.9 a	276 a	3.8 cd	14.0 c	105 cd	84 abc
standard	46.1 a	225 a	0.21 b	0.42 c	4.9 c	2.2 b	41.2 a	230 ab	3.5 d	13.7 c	77 d	59 c
paper	35.8 d	242 a	0.70 a	3.45 a	61.5 bc	10.8 a	39.6 a	142 d	4.5 abc	42.6 a	226 a	86 abc
wood	35.7 d	188 a	0.61 ab	1.77 abc	85.2 ab	10.3 a	40.4 a	172 cd	4.9 ab	31.3 b	178 ab	99 ab
blend	42.4 ab	119 a	0.67 a	2.69 ab	141.7 a	9.1 ab	39.6 a	158 d	4.8 ab	33.8 ab	170 ab	99 ab
FGM	35.0 d	204 a	0.21 b	0.53 c	15.7 bc	1.8 b	40.7 a	136 d	5.1 a	31.1 b	141 bc	93 abc
ET-FGM	36.9 cd	220 a	0.32 ab	0.70 bc	43.7 bc	3.5 ab	41.3 a	139 d	4.2 bc	15.6 c	139 bc	62 bc
BFM	38.1 bcd	277 a	0.29 ab	0.55 c	11.9 c	3.1 ab	41.2 a	216 bc	4.3 bc	34.1 ab	186 ab	112 a

†Values with the same letter within each column for each year are not statistically different according to Least Squares Means (α = 0.05)

‡Abbreviations: FGM, flexible growth medium; ET-FGM, extended term-flexible growth medium; BFM, bonded fiber matrix

Table 4.9 Experiment II antecedent soil volumetric water content (VWC), runoff initiation time (RIT), runoff depth, and total solids (TS), nitrogen (TN), and phosphorus (TP) in runoff during a rainfall simulation conducted 56 days after seeding in 2011 and 2012. Simulated rainfall intensity was 66 mm ha^{-1}.

	56 Days after seeding†											
	2011						2012					
Mulch‡	Runoff parameter											
	VWC %	RIT sec	Runoff mm	TS kg ha^{-1}	TN g ha^{-1}	TP g ha^{-1}	VWC %	RIT sec	Runoff mm	TS kg ha^{-1}	TN g ha^{-1}	TP g ha^{-1}
half	33.8 a	254 a	0.68 b	2.43 b	17.5 b	10.3 b	27.8 d	206 ab	2.8 b	9.7 c	93 cd	39 c
standard	33.3 a	212 a	0.41 b	1.29 b	5.1 b	4.0 b	28.3 cd	212 a	2.6 b	10.2 c	68 d	34 c
paper	33.8 a	218 a	2.29 a	21.91 a	128.9 a	134.0 a	31.7 ab	157 c	4.4 a	58.9 a	267 a	99 ab
wood	35.5 a	223 a	0.43 b	0.62 b	8.3 b	5.8 b	33.5 a	172 bc	4.7 a	35.8 b	202 ab	73 b
blend	32.9 a	163 a	0.97 b	3.30 b	18.6 b	19.4 b	32.6 a	172 bc	4.7 a	39.0 b	215 a	102 a
FGM	33.0 a	202 a	0.48 b	1.10 b	9.4 b	10.6 b	32.3 a	169 c	4.9 a	35.2 b	195 ab	81 ab
ET-FGM	33.1 a	239 a	0.32 b	0.74 b	5.7 b	7.7 b	28.9 bcd	175 bc	4.3 a	14.9 c	109 bcd	40 c
BFM	34.3 a	242 a	0.30 b	0.79 b	4.5 b	3.8 b	31.5 abc	151 c	4.5 a	40.2 b	173 abc	88 ab

†Values with the same letter within each column for each year are not statistically different according to Least Squares Means (α = 0.05)

‡Abbreviations: FGM, flexible growth medium; ET-FGM, extended term-flexible growth medium; BFM, bonded fiber matrix

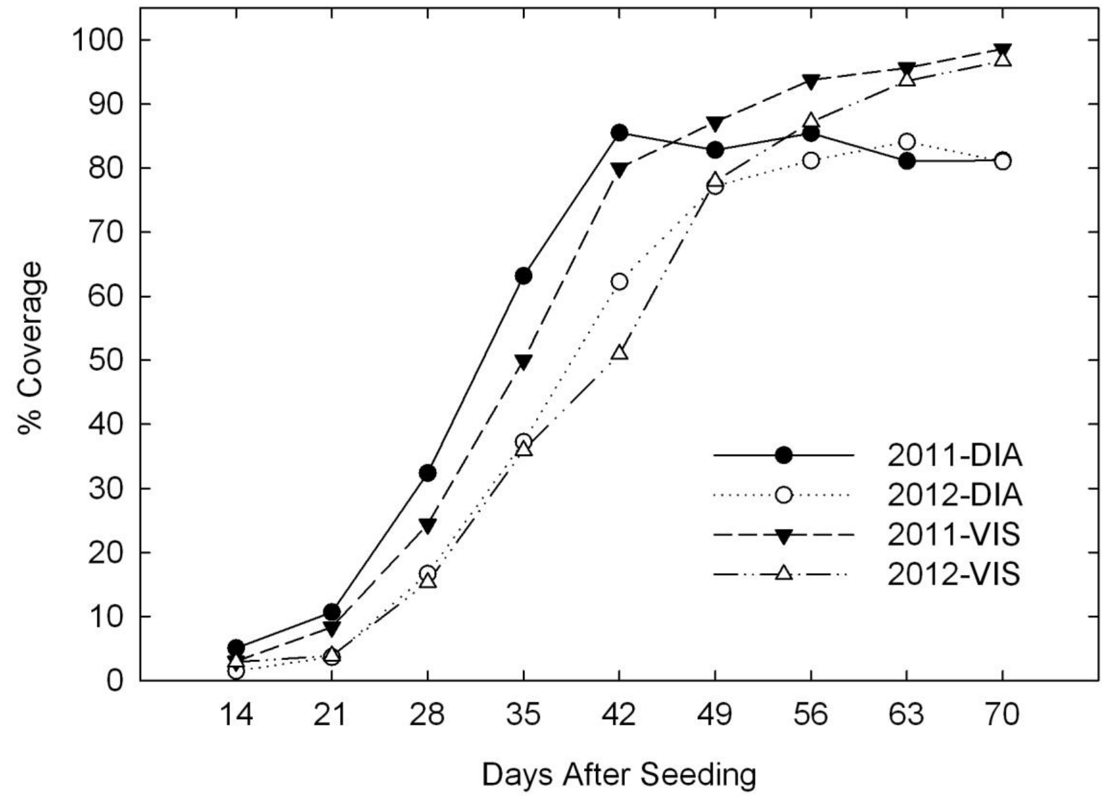

Figure 4.1 Experiment I percent vegetative coverage determined by visual evaluation (VIS) and digital image analysis (DIA) during 2011 and 2012. Data were pooled across fertilizer program and means presented by days after seeding for each year.

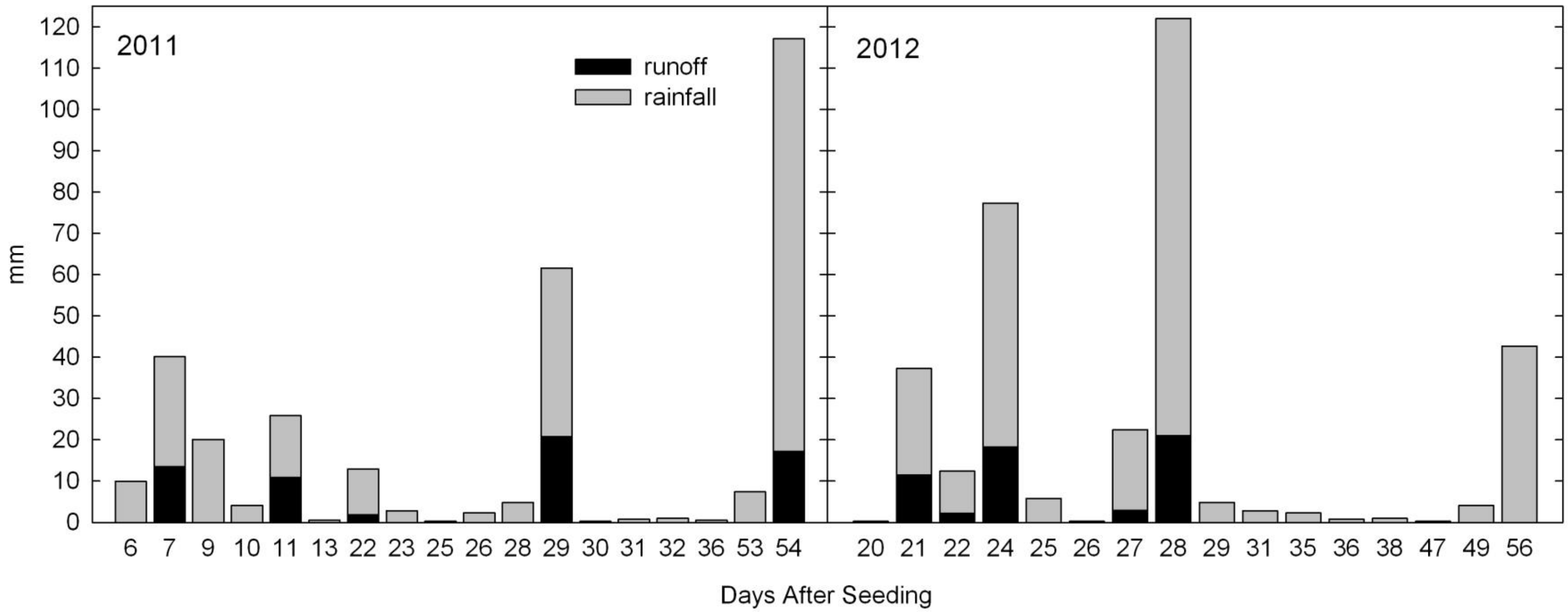

Figure 4.2 Experiment I rainfall and runoff amounts during 2011 and 2012 natural rainfall events. Data were pooled across fertilizer program and means are presented by days after seeding for each year.

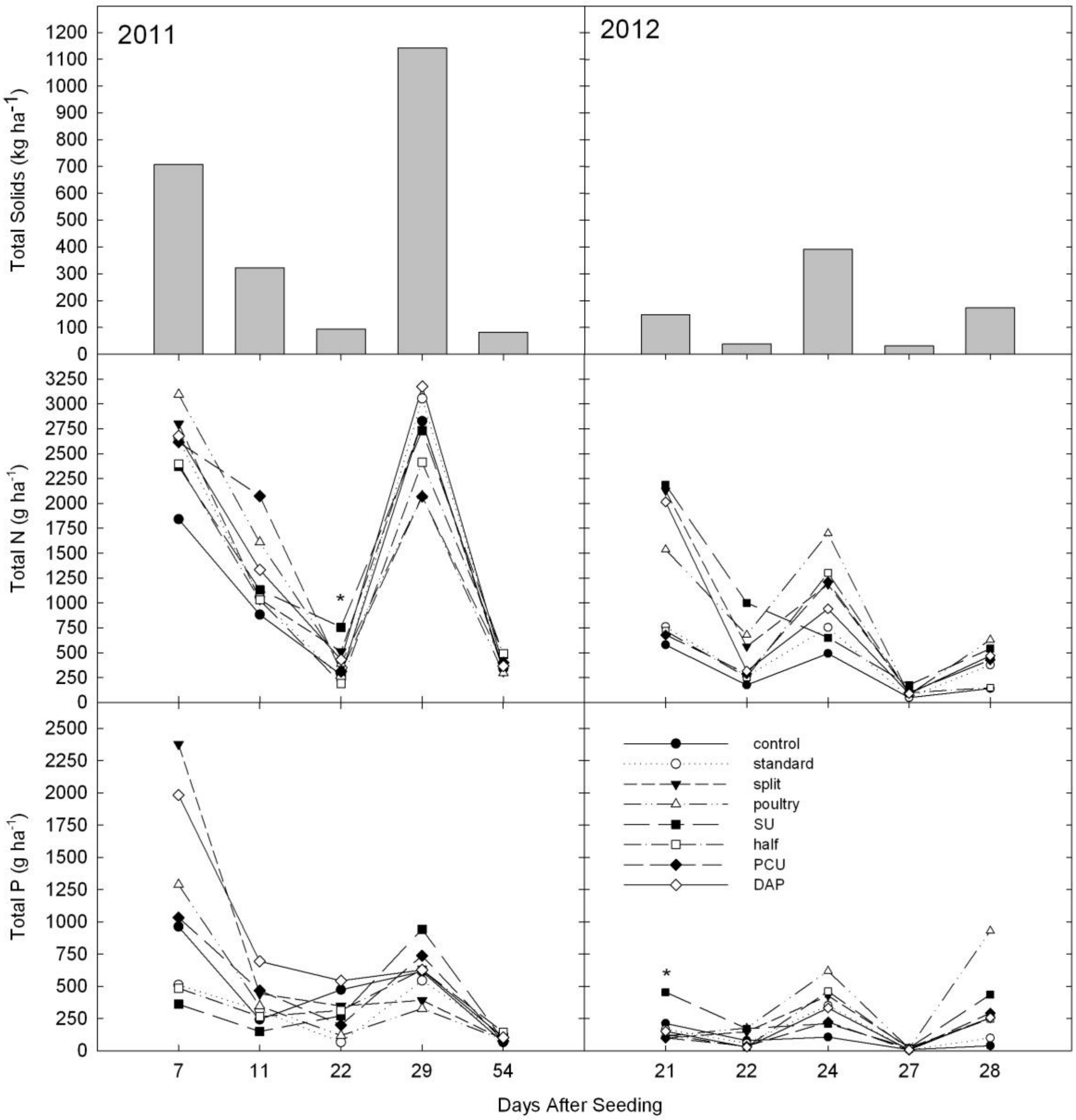

Figure 4.3 Experiment I total solids (TS), total nitrogen (TN), and total phosphorus (TP) runoff losses during 2011 and 2012 natural rainfall. Total solid losses were pooled across fertilizer program and means are presented by date for each year. An asterisk indicates a significant difference from all other fertilizer programs at that specific date according to Least Squared means ($\alpha = 0.05$).

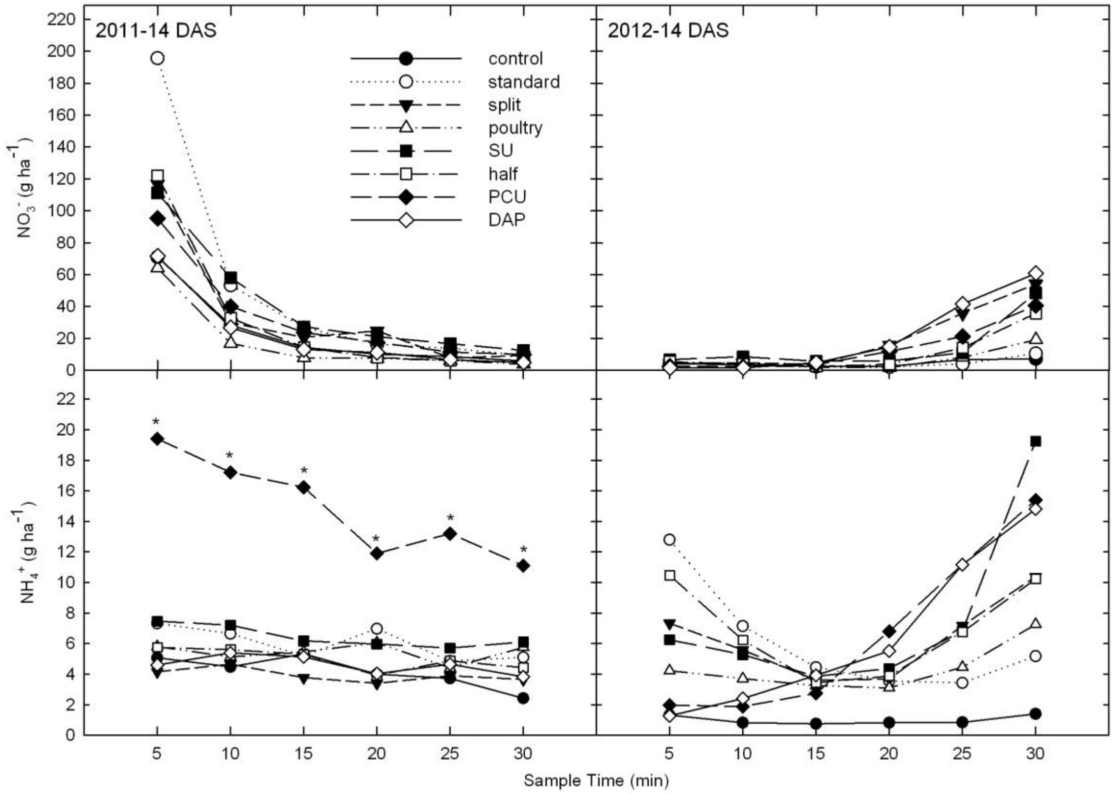

Figure 4.4 Experiment I ammonium and nitrate-N runoff losses during 2011 and 2012 simulated rainfall 14 days after seeding (DAS). An asterisk indicates a significant difference from all other fertilizer programs at that specific sample time according to Least Squared means (α=0.05).

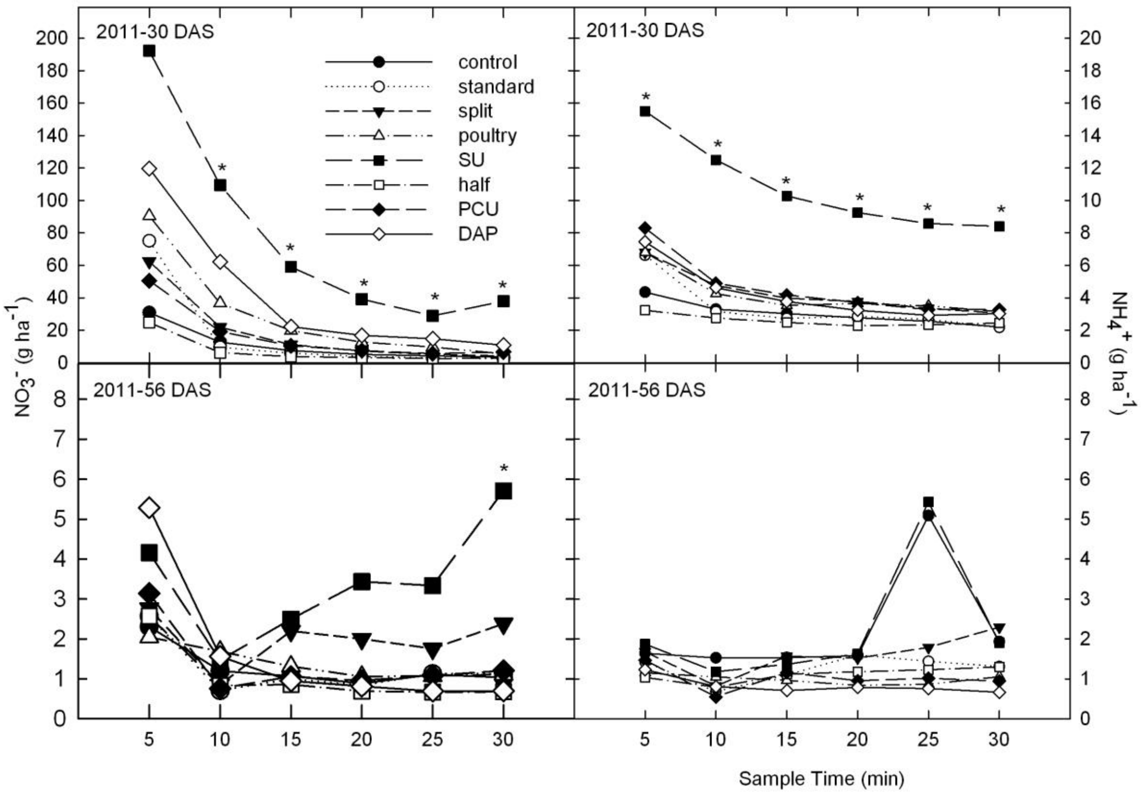

Figure 4.5 Experiment I ammonium and nitrate-N runoff losses during 2011 simulated rainfall 30 and 56 days after seeding (DAS). An asterisk indicates a significant difference from all other fertilizer programs at that specific sample time according to Least Squared means (α=0.05).

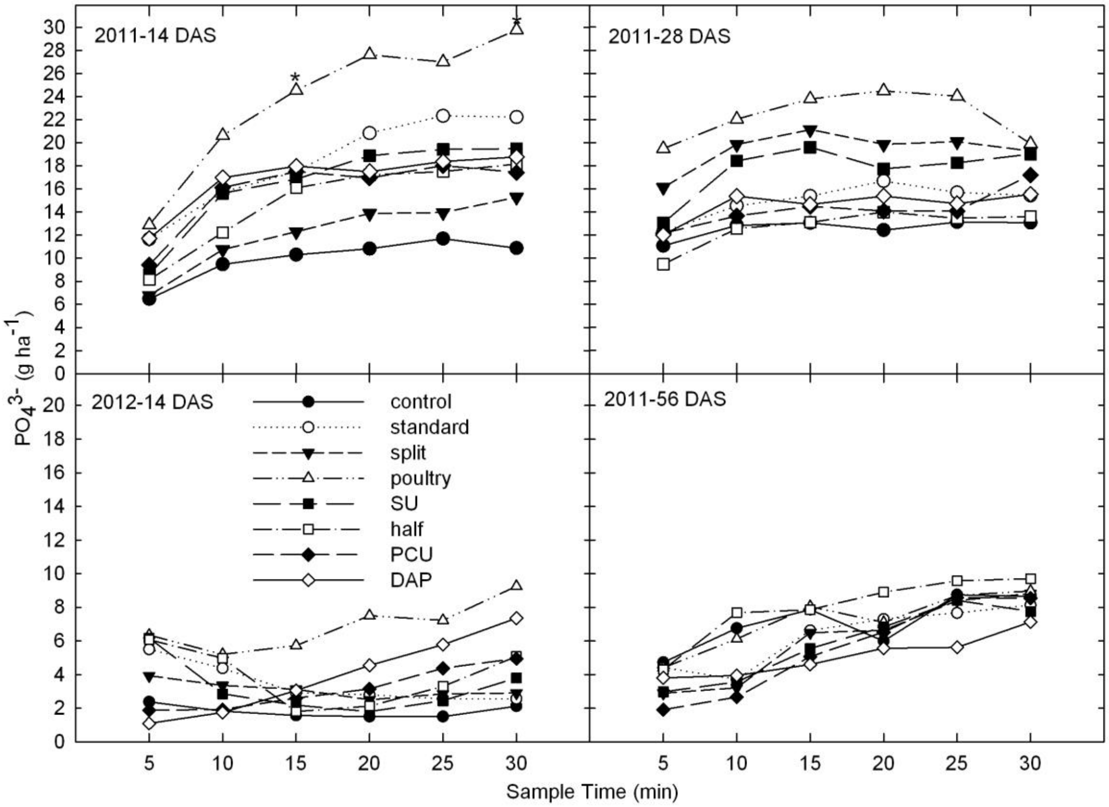

Figure 4.6	Experiment I orthophosphate (PO_4^{3-}-P) runoff losses during 2011 simulated rainfall 14, 30, and 56 days after seeding (DAS) and 2012 simulated rainfall 14 DAS. An asterisk indicates a significant difference from all other fertilizer programs at that specific sample time according to Least Squared means (α=0.05).

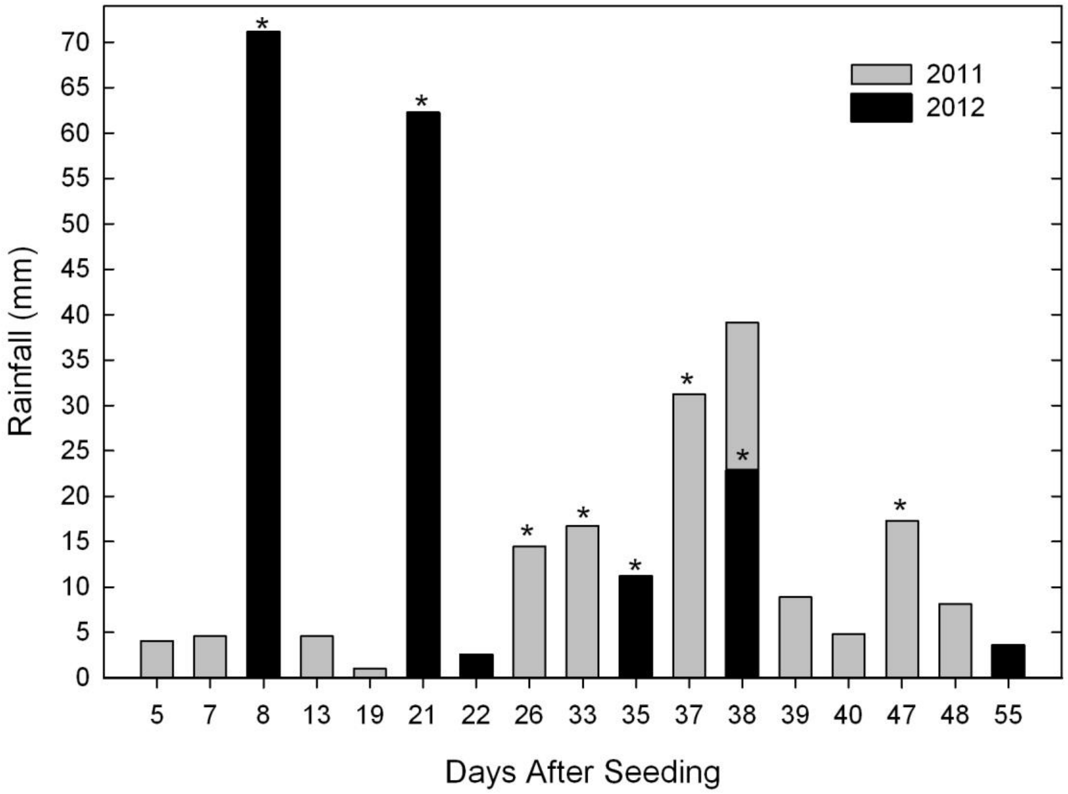

Figure 4.7 Natural rainfall that occurred fall 2011 and 2012 during Experiment II. An asterisk indicates a runoff producing natural rainfall event.

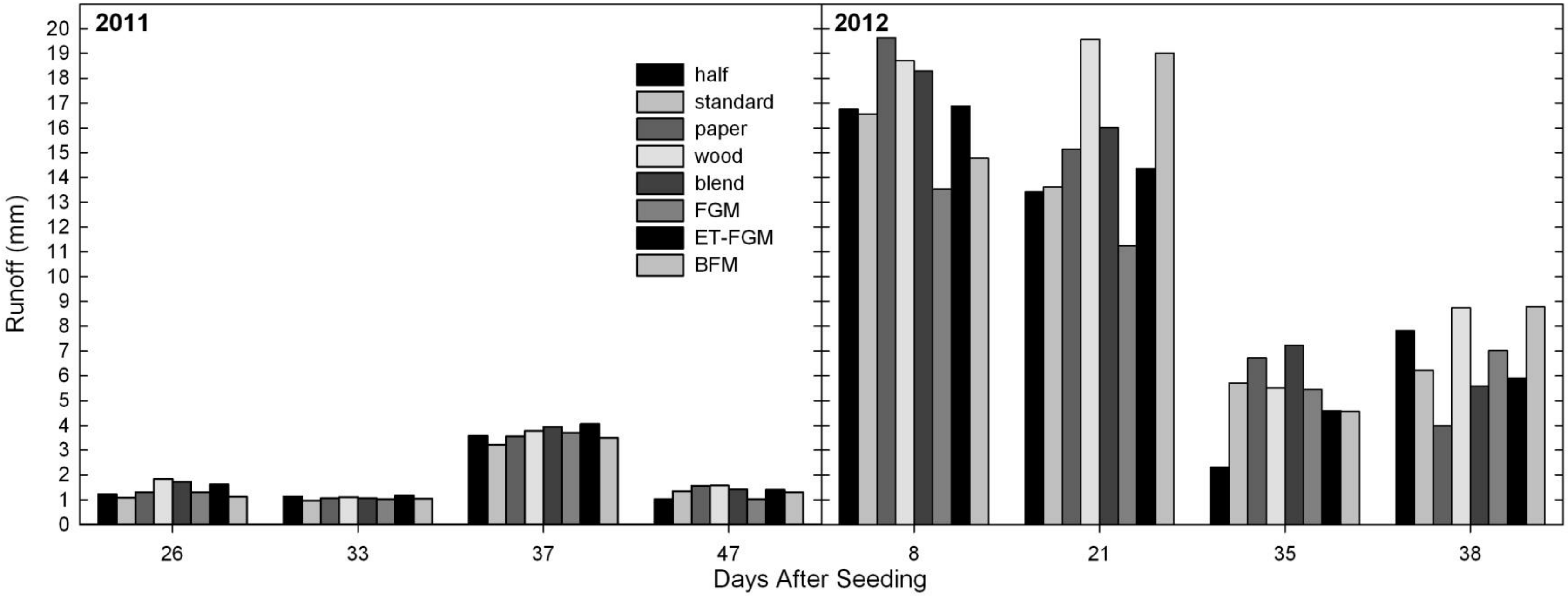

Figure 4.8 Experiment II runoff depth produced by natural rainfall in 2011 and 2012.

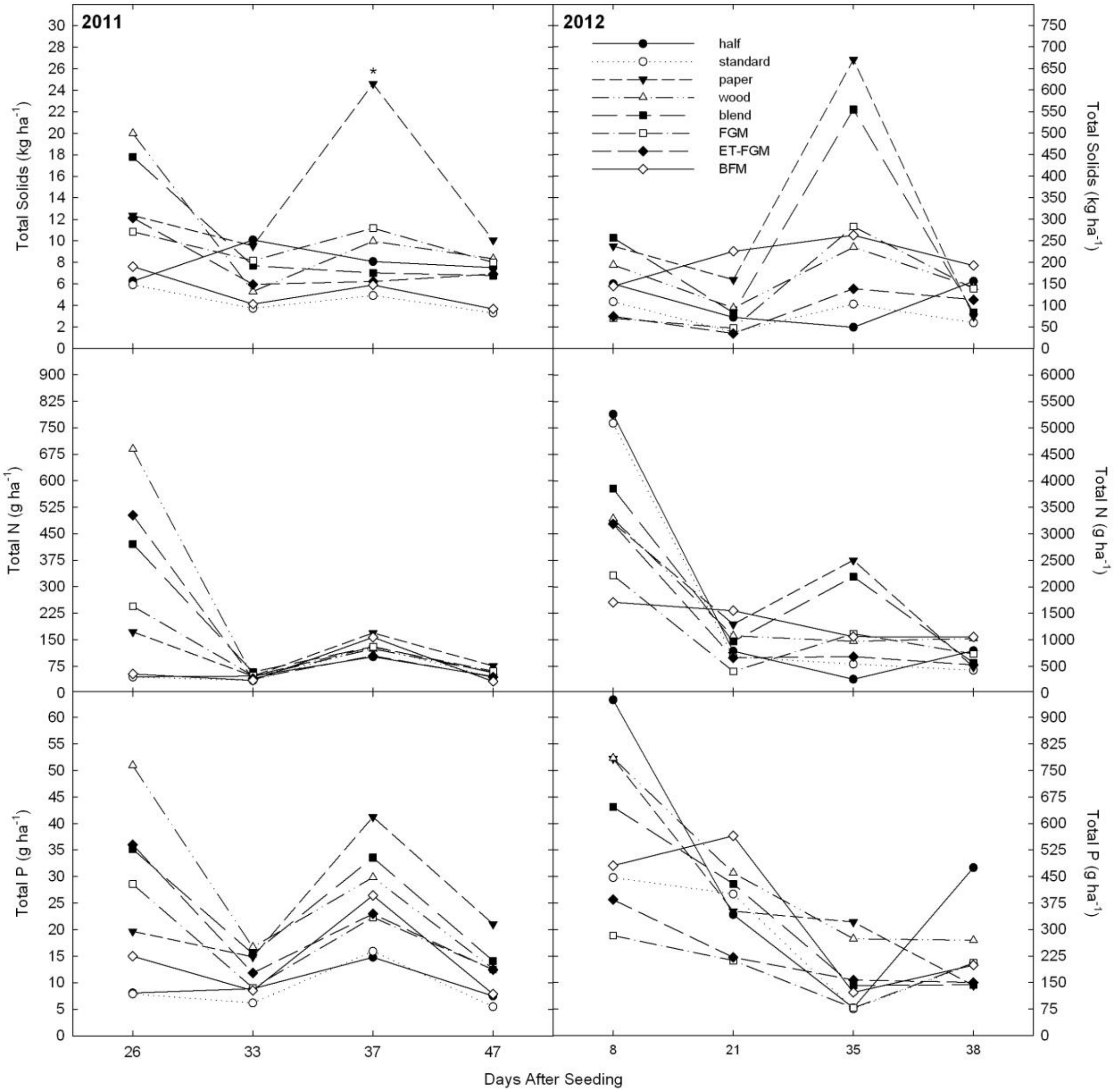

Figure 4.9 Experiment II total solids (TS), total nitrogen (TN), and total phosphorus (TP) in runoff produced by natural rainfall in 2011 and 2012. An asterisk indicates a significant difference from all other mulches at that specific sample time according to Least Squared means (α=0.05).

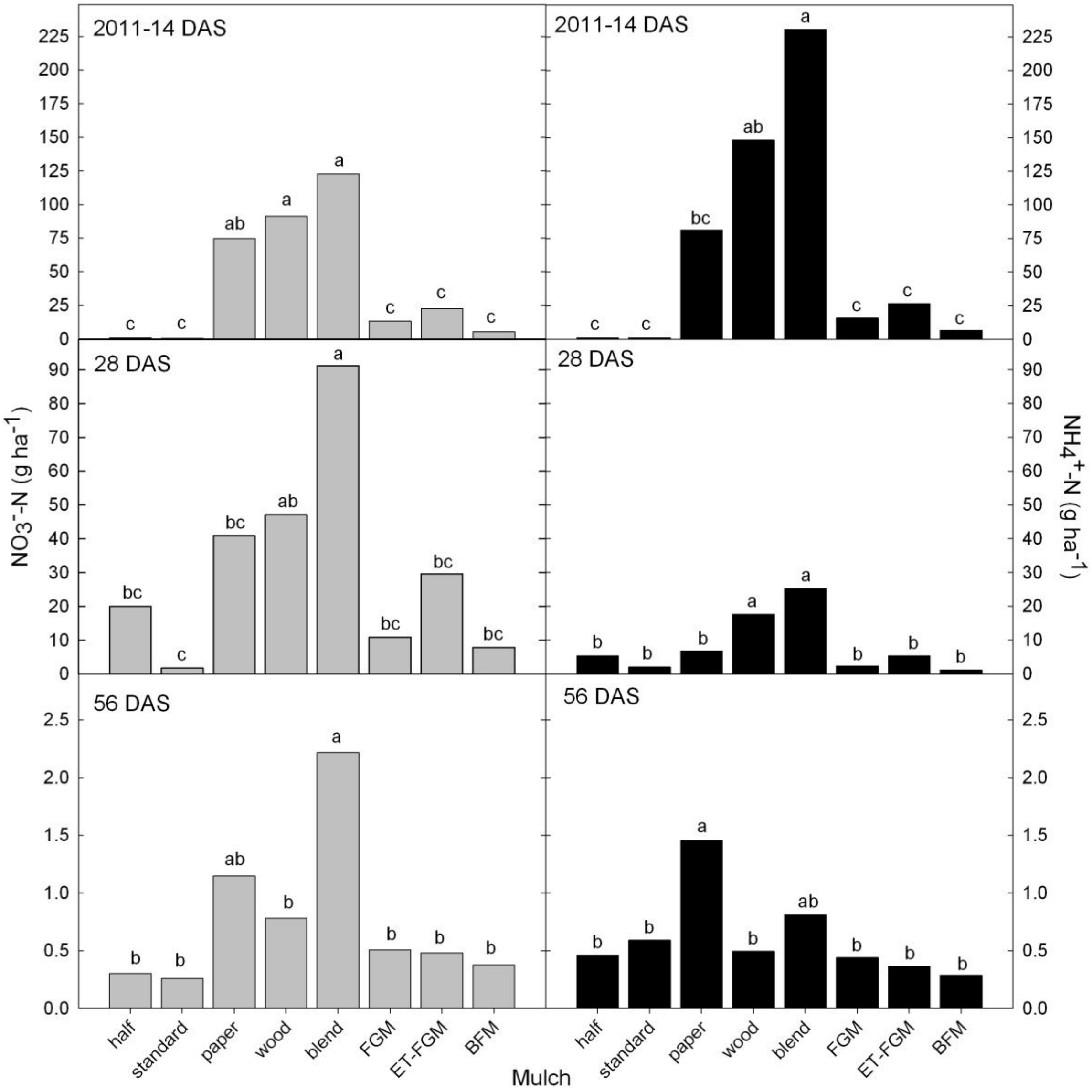

Figure 4.10 Experiment II ammonium (NH_4^+-N) and nitrate (NO_3^--N) nitrogen runoff losses during simulated rainfall 14, 28, and 56 days after seeding (DAS) in 2011. Values with the same letter for each N species and simulated rainfall date are not statistically different according to Least Squares Means ($\alpha = 0.05$)

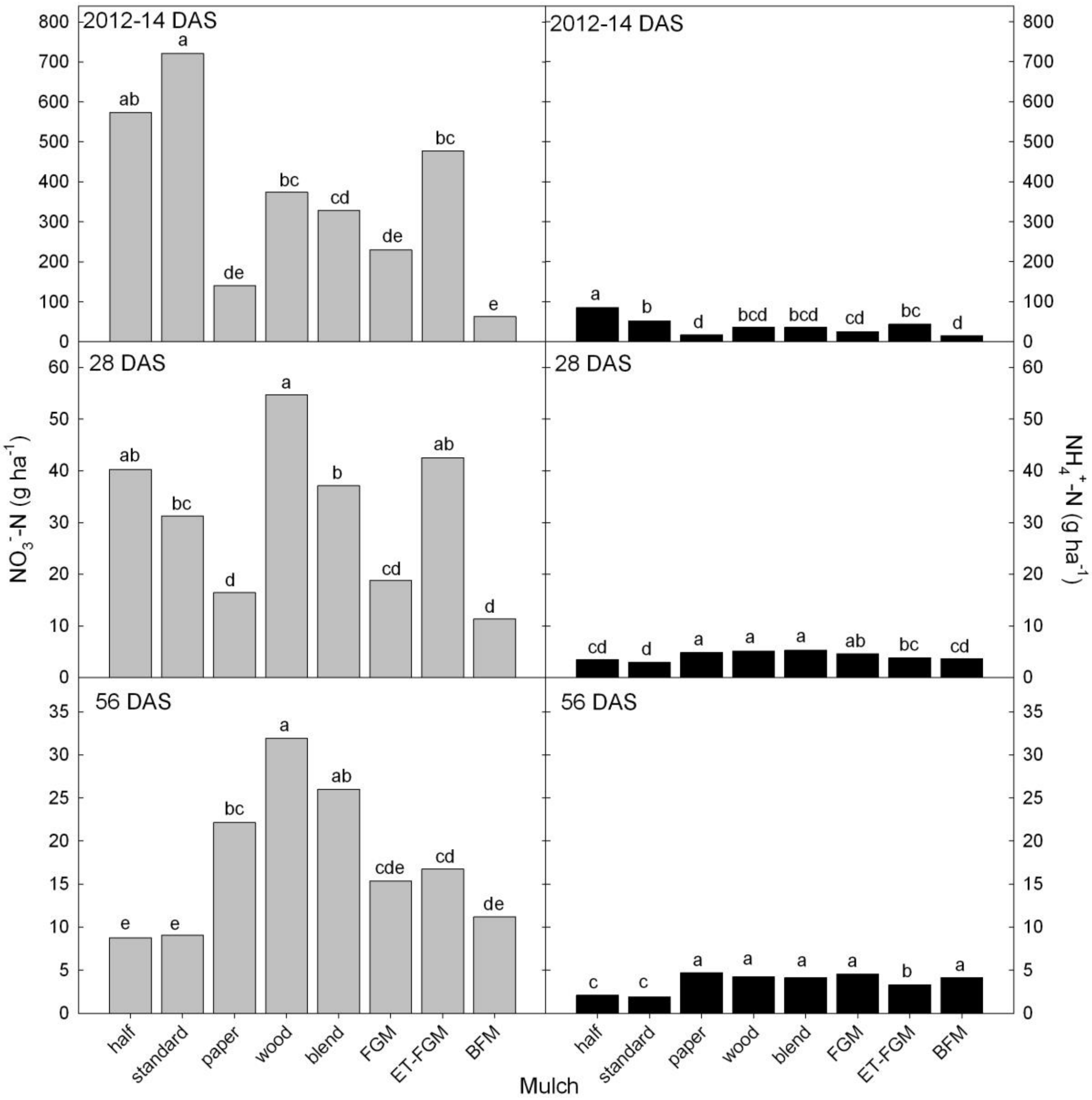

Figure 4.11 Experiment II ammonium (NH_4^+-N) and nitrate (NO_3^--N) nitrogen runoff losses during simulated rainfall 14, 28, and 56 days after seeding (DAS) in 2012. Values with the same letter for each N species and simulated rainfall date are not statistically different according to Least Squares Means ($\alpha = 0.05$)

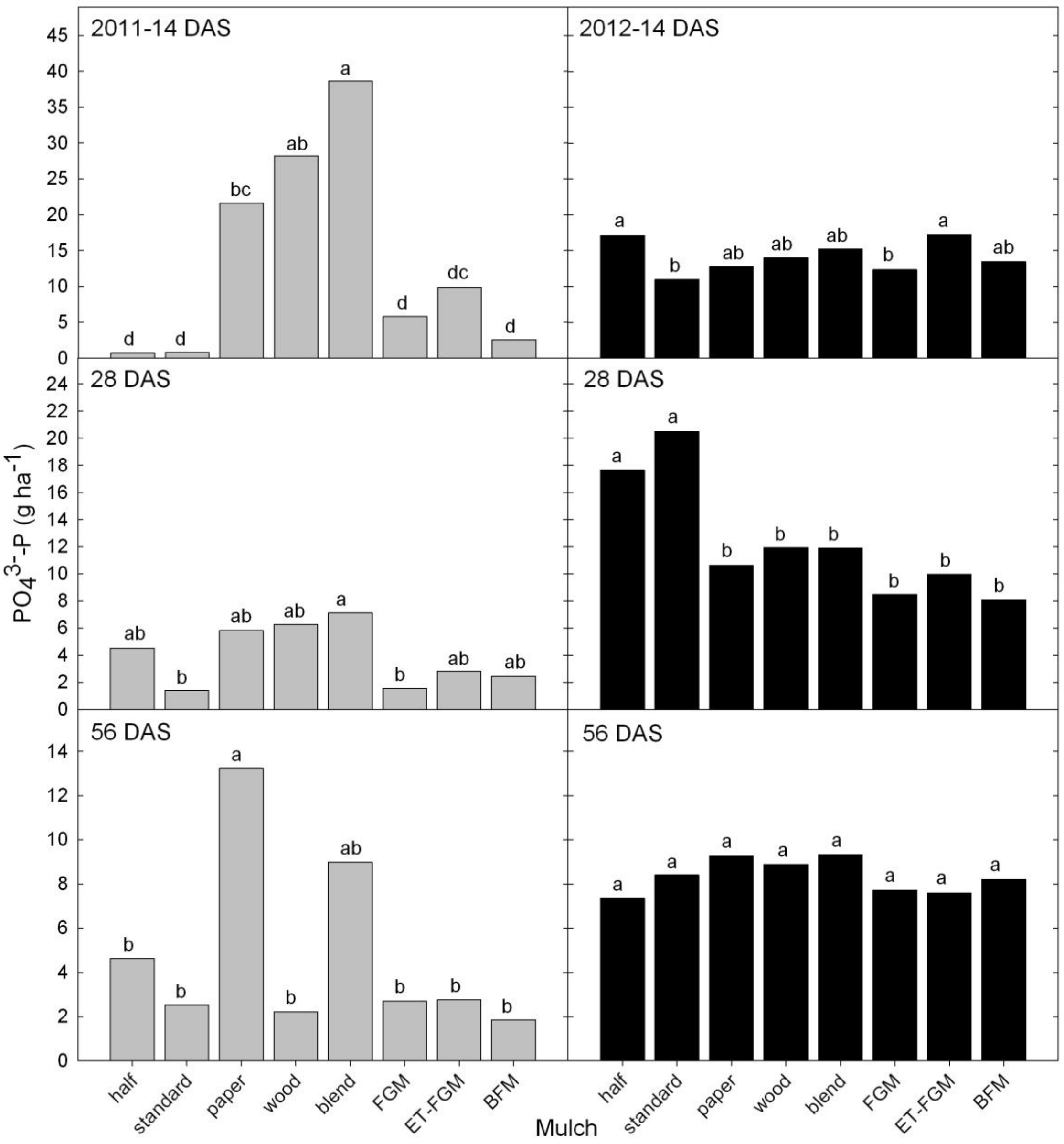

Figure 4.12 Experiment II orthophosphate (PO$_4^{3-}$-P) runoff losses during simulated rainfall 14, 28, and 56 days after seeding (DAS) in 2011 and 2012. Values with the same letter for each year and simulated rainfall date are not statistically different according to Least Squares Means (α = 0.05)

CHAPTER V

CONCLUSIONS

Experiment I

A runoff experiment was conducted during the summer of 2011 and 2012 to determine the environmental impact of granular fertilizer programs to be used for vegetative establishment following roadside construction. The Mississippi Department of Transportation (MDOT) specified fertilization of 13-13-13 at 147 kg N ha^{-1} during seeding was used as the standard program. Thus, other programs consisted of N rates of either 73.5 or 147 kg ha^{-1} and P rates of 32 and 64 kg ha^{-1}. Various N and P sources were chosen based on their nutrient release properties. The spring-summer MDOT seed mixture was seeded into runoff frames and fertilizer applications were either made at 0 and 15 DAS. The slope of experimental sites was 10 percent. Straw mulch was applied to the 2012 site at the MDOT specified 4490 kg ha^{-1}.

During the 56 days after seeding (DAS), runoff produced by simulated and natural rainfall was collected and analyzed for nutrient and total solid content. Simulated runoff events were conducted 14, 30, and 56 DAS in 2011 and 14 DAS in 2012. There were five runoff producing natural rainfall events that occurred in both years. Vegetative coverage and individual runoff events in both years were analyzed separately due to significant interactions between fertilizer program and year.

Digital image analysis (DIA) was used in conjunction with visual evaluation to determine percent cover each week. The results from DIA suggest vegetative coverage stopped increasing approximately 49 DAS in both years. Although DIA provides an objective estimate of percent coverage, caution must be used when vegetation is not being mown. Canopy shadowing can lead to an underestimation of percent green cover calculated by DIA. Hoyle et al. (2013) used calibration images to correct for shadowing in the second year. This would not be possible in our studies due to three colors existing, green (vegetation), brown (soil), and black (shadow). The DIA macro used for turfgrass establishment is only able to differentiate between two colors during analysis.

Data from DIA and visual evaluations were significantly, positively correlated. Therefore, visual evaluation results were used to make inferences about vegetative coverage the final 28 days of the establishment period. There were no significant vegetative coverage differences between fertilizer programs in either year. Results suggest cover was greater in 2011 than 2012. This was partially due to summer annual weeds. The removal of the top 7.6 cm of soil and existing vegetation in 2012 significantly reduced weed seed in the seed bank. Therefore, there was less coverage but a greater percent of desired species in 2012. The fertilization of Spilt, Poultry, SU, and DAP plots 15 DAS did not have a significant influence on vegetative coverage in either year.

The lack of significant differences between fertilizer programs makes it difficult to evaluate each program. However, it was apparent the MDOT goal of 70 percent coverage within 30 DAS was not achieved in either year. This is partially due to the time needed for the warm season species in the spring-summer seed mixture to germinate.

Species evaluation for summer plantings rather than fertilization program evaluation may be more appropriate to achieve the 30 day goal.

Similar to vegetative coverage results, there were no significant differences in runoff collected during natural or simulated rainfall between fertilizer programs. However, it was evident vegetative coverage over time and rainfall intensity and duration do influence runoff amount. Maximum rainfall (~100 mm) and runoff (~20 mm) during one event was similar in both years. Vegetative coverage was approximately 60 percent greater in 2011 than 2012 when the respective events occurred. Therefore, mulch applied following 2012 seeding may have reduced runoff potential. These results are consistent with previous runoff experiments comparing mulches to bare soil (Adams 1966; Mostaghimi et al., 1994; Foltz and Dooley, 2003).

In 2012, runoff amount was similar from rainfall events occurring 24 and 28 DAS. However, rainfall was 42 mm greater 28 DAS. The lack runoff differences may have been partially due to rainfall intensity and duration between the two events. Rainfall 24 DAS fell in a 2 h period compared to a 24 h period 28 DAS. Rainfall and runoff data were not used to create a runoff prediction model. However, results indicate rainfall intensity and duration may be more appropriate than total rainfall to predict runoff.

Simulated rainfall was applied at a constant intensity of 66 mm hr^{-1}. Similar to natural rainfall results, less runoff was collected in 2012 than 2011. Runoff amount increased across sample time for all simulations. Lack of runoff differences between fertilizer programs may be due to lack of vegetative coverage differences. Losses of total solids (TS), total nitrogen (TN), and total phosphorus (TP) during runoff were positively correlated with runoff collected.

Total solid losses during runoff from both simulated and natural rainfall were greater in 2011 than 2012. Similar to runoff results, this may be partially due to mulch applied in 2012. Losses during simulated rainfall decreased as vegetative coverage increased in 2011. Total N runoff losses were significantly correlated with TS. However, fertilization timing influenced TN lost during runoff produced by natural rainfall in both years.

The most applied N 0 DAS was to Standard plots. Total N runoff losses from Standard plots were not significantly greater than from any other fertilizer program during the first runoff event in 2011. The lack of differences was potentially due to irrigation applied the first 14 DAS and the amount of organic-N in collected runoff. Therefore, rainfall event(s) following fertilization that do not produce runoff may be beneficial in reducing runoff losses during establishment. Furthermore, reducing TS in runoff may reduce TN.

Nitrogen fertilization 15 DAS to Split, Poultry, SU, and DAP plots increased TN losses the first runoff event following fertilization. These results were apparent in both years. Lack of vegetative coverage and fertilization to the soil (2011) and mulch (2012) surface likely increased nutrient loss vulnerability. Lacking the ability to incorporate fertilizer into the soil due to vegetative growth suggests 15 DAS fertilization is not an ideal practice to reduce nutrient runoff losses.

Total P runoff losses produced by simulated and natural rainfall were not as strongly correlated to collected runoff or TS as TN. The variability that existed in the dataset likely overshadowed any P source or rate response that occurred between fertilizer programs. However, results indicate there were significant nitrate and ammonium-N and orthophosphate runoff loss differences during natural and simulated rainfall between fertilizer programs in both years.

In 2011, ammonium-N runoff losses were the greatest during the first event following seeding. Furthermore, losses from Standard plots were significantly greater than from Split or Half plots during that event. This was the only significant ammonium or nitrate-N difference that occurred between the Standard and Half rate of 13-13-13 in either year. Reducing the fertilization rate may reduce inorganic-N runoff losses during the first event following fertilization.

Similar to TN loss results, 15 DAS fertilization to Spilt, Poultry, SU, and DAP increased ammonium and nitrate-N runoff losses relative to other programs. The delay of urea hydrolysis and subsequent nitrification by urease and nitrification inhibitors contained in SU may have increased ammonium and nitrate-N runoff losses during the second and third events. Nitrogen from readily soluble N sources such as ammonium nitrate was transported offsite or moved into the soil profile during the first event. Nitrogen in SU continued to be released, increasing runoff loss potential.

The results indicate applying a combination of poultry litter and inorganic P will significantly increase orthophosphate in runoff. The effects were more prominent in runoff produced by natural rainfall. Similar to N losses, 15 DAS fertilization also increased orthophosphate runoff losses.

Although N and P runoff loss differences did occur between fertilizer programs in both years, the total losses were minimal compared to applied N and P. The MDOT specified rate of 13-13-13 may increase the potential for N and P runoff losses compared to a half rate with little benefit to vegetative establishment of the spring-summer species.

Timing, intensity, and duration of the first rainfall event following fertilization are important in the offsite movement of nutrients and solids. Further research conducted to evaluate fertilization rates over a range of slopes is needed to verify these results.

Experiment II

A runoff experiment was conducted during the fall of 2011 and 2012 to evaluate the environmental impact of various mulches to be used for vegetative establishment and erosion mitigation following roadside construction. The Mississippi Department of Transportation (MDOT) vegetative establishment specifications are to apply 13-13-13 at 147 kg N ha^{-1} during seeding followed by straw mulch at 4490 kg ha^{-1}. Straw mulch applied at half and the MDOT standard rate and six hydromulches were selected for evaluation during the experiment. The MDOT fall-spring seed mixture and standard fertilizer rate was used for all mulch treatments. Straw mulched plots were seeded and fertilized prior to mulch application. Hydromulches were mixed separately with fertilizer and seed and applied at the label rate for a 15 percent slope.

Runoff produced by natural and simulated rainfall that occurred the first 56 days after seeding (DAS) was collected and analyzed for nutrient and solid content. Simulated rainfall events were conducted 14, 28, and 56 DAS in 2011 and 2012. There were four runoff producing natural rainfall events in each year. Vegetative coverage and runoff data were separated by year due to significant interactions between mulch and year.

Digital image analysis (DIA) and visual evaluations were used to determine percent vegetative coverage each week. Similar to Experiment I, DIA results were skewed by canopy shading near the end of the establishment period. Therefore, visual evaluations were used to make inferences about vegetative coverage differences that occurred between mulches. Yearly differences in vegetative cover may have been due to a five week earlier planting date and seed loss that occurred during the first runoff event in 2012.

The least amount of vegetation established in Paper plots during both years. Wood and Blend were applied at the same rate but produced greater vegetative cover than Paper. Of the hydromulches applied at 3368 kg ha^{-1} (FGM, ET-FGM, and BFM), vegetative cover in ET-FGM plots was greater across both years. The MDOT goal of 70 percent cover in 30 days was not achieved in either year. However, straw mulch (Half and Standard) reduced time to 70 percent coverage compared to hydromulches. The experiment was conducted on a 15 percent slope in which straw mulch application would be feasible. Vegetative establishment on steeper slopes may require the use of hydromulch. Therefore, further research is needed to compare vegetative establishment following straw and hydromulch application on a range of slope gradients.

Unlike vegetative coverage results, there were no significant differences in runoff produced by natural rainfall between mulch treatments. However, Standard was the most effective treatment for reducing runoff loss in 2011. The 2012 results differed due to rainfall events having greater intensity and duration. Runoff losses from Paper, Wood, Blend, and BFM were similar to each other and greater than from the other four mulches.

Similar results were observed during the three 66 mm hr^{-1} simulations in each year. However, it was evident percent vegetative coverage influenced runoff losses during the 56 DAS simulations. Generally, runoff losses from hydromulches were greater than from straw mulch treatments. Furthermore, greater losses were observed from Paper, Wood, and Blend than FGM, ET-FGM, and BFM. These and results from natural rainfall suggest straw mulch may be the most effective for use on a 15 percent slope. Reducing runoff may reduce solids and nutrients transported offsite. Results suggest solids and nutrients lost during runoff were positively correlated with runoff collected during the experiment.

Straw mulch was the most effective in limiting erosion during runoff events. Furthermore, straw applied at the MDOT standard rate reduced TS losses compared to the half rate during natural rainfall in 2011. Greater vegetative cover in Half, Standard, and ET-FGM plots may have reduced TS losses compared to other mulches during 2012. Total solids in runoff produced by natural and simulated rainfall were the greatest from Paper, Wood, and Blend during both years. Similar to runoff depth results, greater TS losses may be due to the low application rate of Paper, Wood, and Blend. However, results across natural and simulated rainfall suggest straw application at the 2245 kg ha^{-1} rate will be more effective than Paper, Wood, and Blend in reducing TS losses on a 15 percent slope.

Experiment I results suggest the greatest N and P losses occur during the first runoff event following fertilization. Similar results were observed during Experiment II. However, results suggest timing of non-runoff producing natural rainfall and the first runoff event influence N and P loss from straw mulch plots. In 2011, the first runoff event was produced by simulated rainfall 14 DAS, whereas the first event in 2012 was produced by natural rainfall 8 DAS. Furthermore, there were 3 and 0 non-runoff producing natural rainfall event in 2011 and 2012, respectively. Non-runoff producing natural rainfall in 2011 likely dissolved fertilizer prills applied to Half and Standard. In 2012, Half and Standard losses were generally greater during the first runoff event.

Therefore, granular fertilization during dry conditions may increase the potential for nutrient transport offsite if runoff occurs prior to non-runoff producing rainfall. A benefit of applying hydromulch in this situation is that the fertilizer is dissolved in the hydroseeder prior to application. Furthermore, the water applied with the hydromulch mixture will increase soil moisture, creating favorable germination conditions.

Nutrients loss differences between mulches during simulated and natural rainfall following the first runoff event in each year were similar to previously discussed TS differences. Half and Standard were the most effective and Paper, Blend, and Wood were the least effective in reducing TN and TP losses in both years. Losses from FGM, ET-FGM, and BFM were similar in 2011. Mulch loss from BFM during the first runoff event in 2012 may have lead to increased TN and TP losses later in the establishment period. This may be a result of organic N and P lost with sediment. Therefore, limiting sediment losses may also limit TN and TP losses.

Ammonium and nitrate-N runoff losses from FGM, ET-FGM, and BFM were less than from Paper, Blend, and Wood. However, Half and Standard were the most effective in limiting ammonium and nitrate-N losses during both years. Orthophosphate runoff losses were generally less than inorganic N losses. Straw mulch was the most effective in limiting orthophosphate losses in 2011. There were few significant differences between mulches in 2012. Half and Standard losses were greater than from all other mulches four of the seven runoff events. However, Half and Standard total orthophosphate losses across the seven events were 1.1 and 0.9 percent of applied P, respectively.

The use of mulches that will persist during the establishment period is necessary to establish vegetation and limit sediment and nutrient runoff losses. Straw was generally the most effective mulch used to increase vegetative establishment and limit solids and nutrients in runoff. Few differences occurred between half and the MDOT standard application rate of straw. Greater differences may be observed on slopes greater than 15 percent. Caution should be used when applying granular fertilizer to the soil surface during dry conditions. Fertilizer incorporation into the soil may reduce nutrient loss potential when rainfall and soil moisture are limited. Fertilizer dissolution prior to hydromulch application may also reduce nutrient runoff loss potential.

FGM, ET-FGM and BFM hydromulches preformed similarly to each other in terms of limiting runoff losses. Differences that occurred between the three were due to mulch failure during a long duration, high intensity natural rainfall event. The least affected by the event was ET-FGM. Paper fiber and paper/wood fiber blend hydromulches were the least effective in limiting runoff losses. However, further research is needed to evaluate the influence of mulch application rate and rainfall timing on solid and nutrient losses from the mulches used in our experiment.

CHAPTER VI

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