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Evaluation of Sediment and Nutrient Loss during the Revegetation of Mississippi Roadsides

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Evaluation of sediment and nutrient loss during the revegetation of Mississippi roadsides

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Runoff during the revegetation of roadsides can transport sediment and nutrients offsite, leading to surface water quality reductions. Two field experiments were conducted near Starkville, MS in 2011 and 2012 to evaluate the influence of 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 on 10% and 15% slopes for Experiment I and Experiment II, respectively. A bahiagrass (*Paspalum notatum* Flugge), tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.], 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. Experiment I treatments 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 treatments consisted of wheat straw and six 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). Experiment I results suggest the greatest N and P runoff losses occurred during the first runoff event following fertilization. Splitting 147 kg N ha^{-1} into two equal applications increased nutrient losses compared to one application. Application of organic plus inorganic P increased PO_4^{3-}-P 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 nutrient runoff losses during dry conditions. The FGM, ET-FGM, and BFM mulch treatments were more effective than the paper, wood, and paper/wood fiber treatments in reducing solids and nutrients in runoff. It was apparent during both experiments that timing, intensity, and duration of rainfall events following fertilization have an influence on runoff losses. However, further research is needed to quantify the influence of those rainfall parameters.

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS ... ii

LIST OF TABLES ... v

LIST OF FIGURES ... vii

CHAPTER

I. INTRODUCTION ... 1

II. LITERATURE REVIEW ... 4

Plant Species Specified for Mississippi Roadside Plantings ... 4
Common Bermudagrass ... 4
Bahiagrass ... 6
Sericea Lespedeza ... 8
Tall Fescue ... 9
Crimson Clover ... 11
Sediment and Nutrient Runoff Losses ... 12
Sediment ... 12
Nitrogen ... 13
Phosphorus ... 17
Erosion Control Products ... 19
Mulches ... 19
Polyacrylamide ... 23
Summary ... 25

III. MATERIALS AND METHODS ... 26

Experiment I ... 26
Experiment II ... 33

IV. RESULTS AND DISCUSSION ... 45

Experiment I ... 45
Vegetative Coverage ... 45
Natural Rainfall ... 47
Rainfall and Runoff ... 47
Total Solids in Runoff ... 49

Total Nitrogen Runoff Losses....................50
Inorganic Nitrogen Runoff Losses....................51
Total Phosphorus Runoff Losses....................54
Inorganic Phosphorus Runoff Losses....................55
Simulated Rainfall....................57
Runoff Quantity and Total Nitrogen, Phosphorus, and Solids in Runoff....................57
Inorganic Nitrogen Runoff Losses....................59
Inorganic Phosphorus Runoff Losses....................60
Experiment II....................62
Vegetative Coverage....................62
Natural Rainfall....................64
Rainfall and Runoff....................64
Total Solids in Runoff....................65
Total Nitrogen Runoff Losses....................66
Inorganic Nitrogen Runoff Losses....................68
Total Phosphorus Runoff Losses....................69
Inorganic Phosphorus Runoff Losses....................70
Simulated Rainfall....................70
Soil Volumetric Water Content, Runoff Initiation Time, and Runoff....................70
Total Solids in Runoff....................72
Total Nitrogen Runoff Losses....................73
Inorganic Nitrogen Runoff Losses....................74
Total Phosphorus Runoff Losses....................76
Inorganic Phosphorus Runoff Losses....................76

V. SUMMARY AND CONCLUSIONS....................100

Experiment I....................100
Experiment II....................105

REFERENCES....................111

LIST OF TABLES

3.1 Initial chemical and physical properties of Marietta soil from Experiment I 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. 37

3.2 Fertilization treatment names, fertilizer sources, N, P, and K rates, and fertilizer application timings used during Experiment I conducted summer 2011 and 2012 on a roadside (lat: 33.485328 log: -88.850483) near Starkville, MS. 38

3.3 Analysis of the rainfall simulation water source used in Experiment I. 39

3.4 Initial chemical and physical properties of Marietta soil from Experiment II conducted fall 2011 and 2012 at Mississippi State University R.R. Foil Plant Research Facility (lat: 33.485328 log: -88.770875) Mississippi State, MS. Samples were taken from a depth of 0-to 15-cm. 40

3.5 Mulch type, composition, and application rates used in Experiment II conducted fall 2011 and 2012 at Mississippi State University R.R. Foil Plant Research Facility (lat: 33.485328 log: -88.770875) Mississippi State, MS..41

3.6 Analysis of the rainfall simulation water source used in Experiment II. 42

4.1 Experiment I NH_4^+ and NO_3^--N runoff losses produced by natural rainfall. All treatments except the Control received N fertilizer at seeding. The Split, Poultry, SU, and DAP treatments received additional N fertilizer at 15 days after seeding. 79

4.2 Experiment I PO_4^{3-}-P runoff losses produced by natural rainfall. All treatments except the Control received P fertilizer at seeding. The Split, Poultry, SU, and DAP treatments received additional P fertilizer at 15 days after seeding. 80

4.3 Experiment I runoff, TS, TP, and TN runoff losses for the 2011 and 2012 rainfall simulations. Data were pooled across fertilization treatments and means are presented by sampling times.........................81

4.4 Experiment II percent vegetative cover determined by visual evaluation in 2011 and 2012. 82

4.5 Experiment II NH_4^+ and NO_3^--N runoff losses for the 2011 and 2012 natural rainfall events. 83

4.6 Experiment II PO_4^{3-}-P runoff losses for the 2011 and 2012 natural rainfall events. 84

4.7 Experiment II antecedent soil volumetric water content (VWC), runoff initiation time (RIT), runoff, and TS, TN, and TP in runoff for the rainfall simulation conducted 14 DAS in 2011 and 2012. Simulated rainfall intensity was 66 mm ha^{-1}. Runoff, TS, TN, and TP data were pooled across sampling time and means are presented by mulch treatment. 85

4.8 Experiment II antecedent soil volumetric water content (VWC), runoff initiation time (RIT), runoff, and TS, TN, and TP in runoff for the rainfall simulation conducted 28 DAS in 2011 and 2012. Simulated rainfall intensity was 66 mm ha^{-1}. Runoff, TS, TN, and TP data were pooled across sampling time and means are presented by mulch treatment. 86

4.9 Experiment II antecedent soil volumetric water content (VWC), runoff initiation time (RIT), runoff, and TS, TN, and TP in runoff for the rainfall simulation conducted 56 DAS in 2011 and 2012. Simulated rainfall intensity was 66 mm ha^{-1}. Runoff, TS, TN, and TP data were pooled across sampling time and means are presented by mulch treatment. 87

LIST OF FIGURES

Figure 3.1 Runoff frame and collection container arrangement used for Experiment I and II. Experimental area locations differed between experiments and between years for each experiment..............43

Figure 3.2 The Tlaloc 3000 rainfall simulator (Joern's Inc., West Lafayette, IN) used during Experiment I and II in 2011 and 2012. 43

Figure 3.3 The light box used in conjunction with a digital camera to capture photographs for digital image analysis of percent vegetative coverage. 44

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 fertilization treatments and means presented by days after seeding for each year............................88

Figure 4.2 Experiment I rainfall and runoff amounts for the 2011 and 2012 natural rainfall events. Data were pooled across fertilization treatment and means are presented by days after seeding for each year. 89

Figure 4.3 Experiment I TS, TN, and TP runoff losses for the 2011 and 2012 natural rainfall. Total solid losses were pooled across fertilization treatment and means are presented by date for each year. An asterisk indicates a significant difference from all other fertilization treatments at that specific date according to Least Squared Means (α = 0.05). 90

Figure 4.4 Experiment I NH_4^+ and NO_3^--N runoff losses for the 2011 and 2012 simulated rainfall event 14 days after seeding (DAS). An asterisk indicates a significant difference from all other fertilization treatments at that specific sampling time according to Least Squared Means (α=0.05). 91

Figure 4.5 Experiment I NH_4^+ and NO_3^--N runoff losses for the 2011 simulated rainfall events at 30 and 56 days after seeding (DAS). An asterisk indicates a significant difference from all other fertilization treatments at that specific sample time according to Least Squared Means (α=0.05). 92

Figure 4.6 Experiment I PO_4^{3-}-P runoff losses for the 2011 simulated rainfall events at 14, 30, and 56 days after seeding (DAS) and 2012 simulated rainfall at 14 DAS. An asterisk indicates a significant difference from all other fertilization treatments at that specific sampling time according to Least Squared Means (α=0.05). 93

Figure 4.7 Natural rainfall that occurred during Experiment II in 2011 and 2012. An asterisk indicates a runoff producing natural rainfall event. 94

Figure 4.8 Experiment II runoff produced by natural rainfall in 2011 and 2012. 95

Figure 4.9 Experiment II TS, TN, and TP in runoff produced by natural rainfall events in 2011 and 2012. An asterisk indicates a significant difference from all other mulch treatments at that specific date according to Least Squared Means (α=0.05). 96

Figure 4.10 Experiment II NH_4^+ and NO_3^--N runoff losses for simulated rainfall events at 14, 28, and 56 days after seeding (DAS) in 2011. Ammonium and NO_3^--N losses were pooled across sampling times and means are presented by mulch treatment. Values with the same letter for each N species and simulated rainfall date are not statistically different according to Least Squares Means (α = 0.05). 97

Figure 4.11 Experiment II NH_4^+ and nitrate NO_3^--N runoff losses for simulated rainfall events at 14, 28, and 56 days after seeding (DAS) in 2012. Ammonium and NO_3^--N losses were pooled across sampling times and means are presented by mulch treatment. Values with the same letter for each N species and simulated rainfall date are not statistically different according to Least Squares Means (α = 0.05). 98

Figure 4.12 Experiment II PO_4^{3-}-P runoff losses for simulated rainfall events at 14, 28, and 56 days after seeding (DAS) in 2011 and 2012. Orthophosphate losses were pooled across sampling times and means are presented by mulch treatment. Values with the same letter for each year and simulated rainfall date are not statistically different according to Least Squares Means (α = 0.05)..99

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% 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 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 [*Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.], 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., 1991; 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 as well as to enhance vegetative establishment and growth. However, information concerning time to reach acceptable coverage and patterns of nutrient loss in runoff are needed to validate or improve current recommendations.

Fertilizer rates are often increased during propagation to enhance vegetative establishment (Rodriguez et al., 2001). Current Mississippi specifications require that 13-13-13 fertilizer be applied at a N rate of 147 kg ha^{-1}. The concern is that applying N along with P_2O_5 at the same rate 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 were to: 1) to evaluate the influence of various N and P sources and rates on vegetative establishment and sediment and nutrient loss during runoff; 2) evaluate the influence of fertilization timing on vegetative establishment and sediment and nutrient loss during runoff; and 3) to determine if mulch type has an effect on vegetative establishment and sediment and nutrient 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 centuries (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 using 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 less competition. Thus, increasing the upper limits of biomass production (power rule boundary) compared to higher seeding rates (Lush, 1990).

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} bi-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 Sept. 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 Sept.) 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 seedlings are sensitive to competition (Beaty and Powell, 1978). However, it tolerates a wide range of soil conditions and produces moderate yields with very low fertility maintenance (Chambliss and Sollenberger, 1991). Winterkill is problematic in some bahiagrass cultivars. The cultivar 'Wilmington' is considered to be cold hardy and is less prolific in seedhead production compared to Pensacola (Chambliss and Sollenberger, 1991). Burton (1946) indicated 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% established three weeks after planting, significantly different than the other two cultivars. Furthermore, the five-week post planting fertilization 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 should be considered 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 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°C 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 soon as possible before the onset of substantial weed pressure. Although rainfall and soil moisture are highly variable, 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 [*Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.] 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., 1985). ‘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 approximately 75% as the constant soil 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 increases (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 been shown to increase tall fescue establishment on soils with low soil test P. Establishment on soils with sand contents of 0 to 100% were examined (Summerford and Karcher, 2010). Results suggest P application had the greatest influence on tall fescue establishment in soils with 80 and 100% sand (5.6 and 4.1 $\mu g\ g^{-1}$ soil test P, respectively). However, fertilizer applications to the soils with at least 7 μg g^{-1} 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% 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 introduce biologically fixed N_2 into the system, ultimately benefiting non-legume 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 5.7, 11.8, and 13.4 MT ha^{-1} from bare soil plots across three locations. Montoro et al. (2000) indicated that TS lost 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 sandy loam soil sites. The variability in runoff contaminant loads is likely due to multiple 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% 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 P movement into surface waters can cause an increase in algal growth, leading to the depletion of dissolved O 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 timing of 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% (Carrow et al., 2001), meaning close to half is immobilized or lost to the environment.

Slow-release N sources were created to enhance uptake efficiency by the target species and reduce fertilizer N loss to the environment. These products regulate the release and transformation of N forms to 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 (Trenkel, 1997). Products such as sulfur-coated urea (SCU), polymer-coated urea (PCU), and isobutylidine urea (IBDU) vary in N content, N form, release times, and release characteristics. Thus, the development of a fertilizer program for roadside establishment must be based on soil and environmental conditions specific to the site.

Increasing fertilizer N 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 a 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 greater than the average dissolved NH_4^+-N concentrations of 0.10 mg L^{-1}. Faucette et al. (2005) evaluated N loss from bare soil across three rainfall simulations during a 1-y period. Total NO_3^--N loss from bare soil was 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 lost for 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 runoff from 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 indicated a total kjeldahl N (organic N + NH_4^+) loss of 18.2 mg L^{-1} for bare soil and 26.5 mg L^{-1} for hydroseeding. Concentrations were reduced to 11.0 (bare soil) and 4.3 mg L^{-1} (hydroseed) during rainfall simulations the following 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 fertilization.

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 greatest 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 fertilizer N solubility trends. When comparing N losses from manure to inorganic N sources, Gaudreau et al. (2002) found greatest 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 P during establishment or analyze runoff for forms of P. Mississippi DOT establishment specifications include the application of a complete and balanced fertilizer. Therefore, it is necessary to study P losses during runoff.

Phosphorus

Although N is often indicated 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 greatest P growth requirement is for 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. Organic P must be mineralized to inorganic orthophosphate ($H_2PO_4^-$) or (HPO_4^{-2}) for transportation in the soil solution by diffusion and mass flow and plant uptake (Carrow et al., 2001). 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 (Havlin et al., 2005). The ion $H_2PO_4^-$ is primarily taken up by plants when the soil pH is below 7.2. Furthermore, inorganic fertilizer P sources can have a slight influence on soil pH (Young et al., 1984).

Rock phosphate (RP) is the most common raw material used in the manufacturing of inorganic 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 a slight liming effect on acid soils (Varco and Sartain, 1986). 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% greater 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 soil test P (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 4.1 and 4.3 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% 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. 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% 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 straw mulch reduced total runoff 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 total runoff 1.8 cm when soil moisture was 10% and 0.3 cm when soil moisture was 20%. Therefore, antecedent soil moisture content 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 indicated 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% 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 reducing sediment loss compared to bare soil (Benik et al., 2003).

Hydromulches are more expensive to apply but provide an alternative to loose mulches. Benik et al. (2003) found less total runoff from plots treated with a fiber-bonded matrix compared to straw mulch across two soil moisture contents. Furthermore, the flexible growth medium Flexterra® (PROFILE Prodcuts, LLC., Buffalo Grove, IL) has been shown to reduce sediment loss 91% 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 loss from Flexterra® mulched 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.

Similar to bare soil runoff loss results, there is an apparent relationship between sediment and nutrient losses following loose and hydromulch application. Soupir et al. (2004) observed the greatest total P (TP) and total N (TN) reductions 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) indicated no significant difference in TN and TP between hydromulch and straw mulch treatments.

Nitrogen and P fertilizer in the 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% of TN applied was lost from hydromulch treatments across three 78 mm hr^{-1} simulated rainfalls. This was compared to 0.7% for yard waste and poultry litter treatments. The researchers attributed their results to the inorganic N fertilizer applied with hydromulch treatments.

Polyacrylamide

Polyacrylamide (PAM) refers to a class of polymers that are composed of acrylamide and acrylate chains (Lee et al., 2010). It is often added to loose and hydromulches as a tackifier to further reduce the potential of nutrient and sediment losses during runoff. 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 TS loss from hydroseeding and hydroseeding + PAM treatments were significantly less 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. It was concluded that 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 indicated 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% compared to the control; whereas, reductions from PAM applied in solution were 19 to 30% (Soupir et al., 2004).

Dry PAM produced the greatest reductions in TP concentration in runoff, whereas, 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 N and P as granular fertilizer is specified to promote establishment following seeding. However, sediment and nutrient losses due to runoff readily occur on disturbed sloped sites during establishment. Previous research has indicated sediment and nutrient runoff losses from disturbed 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, 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 vegetating 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 Sept. 2011 and June through Aug. 2012. Lack of active roadside construction near Mississippi State University required the creation of an experimental area on a previously established roadside. The roadside selected was completed in 2006. In 2011, three applications of glyphosate [N-(phosphonomethyl) glycine] at 5.6 kg ai ha^{-1} were made, resulting in 100% 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 P (MSTP) level from high to medium and to reduce the weed seedbank.

The soil at both sites is mapped as a Marietta fine sandy loam (fine-loamy, siliceous, active, thermic Fluvaquentic Eutrudepts) (USDA-NRCS Soil Survey Division, 2010). However, the site was likely highly disturbed and may contain fill soil from a different location. A particle size analysis was conducted using the hydrometer method (Bouyoucos, 1962). 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% slope following seedbed preparation. Alleys (0.3 m) were left between each frame. Rubber hoses (1.9 cm diameter, 3 m length) were attached to the ports of each flume and inserted into individual 68 L collection containers downhill from the runoff frames (Fig. 3.1).

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 K using Mississippi Soil Test Methods (Cox, 2001). Samples were analyzed for NH_4^+-N and NO_3^--N 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^--N 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 either 73.5 kg N ha^{-1} 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 (PCU), diammonium phosphate (DAP), ammonium nitrate (AN), and triple super phosphate (TSP).

Poultry litter (4-2-2) 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 and nitrification to highly mobile NO_3^--N. Polymer coated urea was chosen for its slow release properties. A PCU application at seeding should provide N at a more controlled rate during the 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 chosen as a readily available, soluble N source and applied 15 DAS to supplement the poultry litter and diammonium phosphate programs. Fifteen DAS was chosen as the second fertilizer application date because MDOT aims to reach 70% vegetative cover within 30 days of planting (David 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 at seeding. Fertilizer was broadcast across the soil surface at 15 DAS.

The MDOT spring-summer seed mixture of common bermudagrass [*Cynodon dactylon* (L.) Pers.], bahiagrass (*Paspalum notatum* Flugge), tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort., nom. cons.], 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 ha^{-1}. Common bermudagrass was seeded at 22.5 kg ha^{-1}. Seeding rates were not based on percent pure live seed. 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 a natural rainfall event. In 2012, the only simulation was conducted 14 DAS. This was due to runoff producing natural rainfall events occurring five of seven 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 on 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 (Fig. 3.2). 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. Nitrate analysis was performed by Cd-reduction of NO_3^--N to NO_2^--N followed by color development with sulfanilamide and N-(1-naphthyl)-ethylenediamine dihydrochloride. The ascorbic acid reduction method was used to analyze PO_4^{3-}-P (Fiore and O'Brien, 1962a; Fiore and O'Brien 1962b; Murphy and Riley, 1962; USEPA, 1979; Greenberg et al., 1992).

The dimensions of the rainfall simulator (2.3 m x 2.8 m) 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). 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. Time from simulation initiation to runoff initiation was recorded and runoff events lasted 30 minutes following runoff initiation. During each simulation, runoff volume (L) was determined on a weight basis. Runoff samples were collected every five minutes after runoff initiation and continued for 30 minutes (i.e. sample 1 = 0-5 min., sample 2 = 5-10 min, etc.). One-L subsamples were taken from each five-minute sampling 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 downslope from the runoff frames. Following runoff collection, containers were weighed to determine total 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). Collection containers, hoses, and flumes attached to runoff frames were wiped clean and rinsed following every runoff event.

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) (Fig. 3.3). The area of each plot photographed was selected by visual evaluation in order to provide a representative sample of vegetative coverage. 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 treatment and year. Furthermore, data were separated by DAS if there was an interaction between fertilizer treatment 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. Sampling time was specified as the repeated measure and fertilizer treatment 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 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 was mapped 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, 1962). 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 on a 15% slope 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% wood/paper fiber blend (FINN TRU-Blend Wood/Paper, FINN Corp., Fairfield, OH), 75% wood fiber flexible growth medium (FGM) (Flexterra® FGM, PROFILE Products, LLC, Buffalo Grove, IL), 50/20% wood/coconut fiber extended term-FGM (ET-FGM) (CocoFlex™ ET-FGM, PROFILE Products, LLC, Buffalo Grove, IL), and 68% 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. The MDOT fall-winter seed mixture was used in both years. 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% 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 labeled amount of mulch was applied using two passes across each plot. During application, adjacent plots were covered 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 mulch treatment and year. Furthermore, data were separated by DAS if there was an interaction between mulch treatment and DAS. Fisher's Protected Least Significant Difference ($LSD_{0.05}$) was used to separate mulch treatment 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. Sampling time was specified as the repeated measure and mulch treatment 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 relationships between runoff parameters for both simulated and natural rainfall.

Table 3.1 Initial chemical and physical properties of Marietta soil from Experiment I 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†, $cmol_c\ kg^{-1}$	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
OM§, %	2.4	1.4
Sand, %	58.7	56.1
Silt, %	18.9	21.7
Clay, %	22.4	22.2
Texture	Sandy clay loam	Sandy clay loam

†CEC, estimated cation exchange capacity from Mississippi Soil Test extracted cations
‡ MSTP, Mississippi Soil Test P
§OM, organic matter

Table 3.2 Fertilization treatment names, fertilizer sources, N, P, and K rates, and fertilizer application timings used during Experiment I conducted summer 2011 and 2012 on a roadside (lat: 33.485328 log: -88.850483) near Starkville, MS.

Experiment 1					
Fertilizer Trt. Names	Fertilizer Sources	N rate (kg ha^{-1})	P rate (kg ha^{-1})	K rate (kg ha^{-1})	Timing (DAS†)
Control	untreated	0.0	0.0	0.0	n/a
Standard	13-13-13	147.0	64.0	121.0	0
Split	13-13-13	73.5	32.0	60.5	0
	13-13-13	73.5	32.0	60.5	15
Poultry	poultry litter 4-2-2	98.0	21.3	40.5	0
	triple super phosphate 0-46-0	0.0	10.7	0.0	0
	KCl 0-0-60	0.0	0.0	20.0	0
	ammonium nitrate 34-0-0	49.0	0.0	0.0	15
	triple super phosphate	0.0	32.0	0.0	15
	KCl	0.0	0.0	60.5	15
	Total	147.0	64.0	121.0	n/a
SU‡	stabilized urea 46-0-0	73.5	0.0	0.0	0
	triple super phosphate	0.0	32.0	0.0	0
	KCl	0.0	0.0	60.5	0
	stabilized urea	73.5	0.0	0.0	15
	triple super phosphate	0.0	32.0	0.0	15
	KCl	0.0	0.0	60.5	15
	Total	147.0	64.0	121.0	n/a
Half	13-13-13	73.5	32.0	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	0
	KCl	0.0	0.0	60.5	0
DAP¶	diammonium phosphate 18-46-0	29.4	32.0	0.0	0
	ammonium nitrate	44.1	0.0	0.0	15
	KCl	0.0	0.0	60.5	15
	Total	73.5	32.0	60.5	n/a

† DAS, days after seeding
‡SU, stabilized urea
§PCU, polymer coated urea
¶DAP, diammonium phosphate

Table 3.3 Analysis of the rainfall simulation water source used in Experiment I.

Parameter	Year	
	2011	2012
pH	8.75	8.96
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 Experiment II conducted fall 2011 and 2012 at Mississippi State University R.R. Foil Plant Research Facility (lat: 33.485328 log: -88.770875) Mississippi State, MS. 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
OM§, %	1.6	1.1
Sand, %	63.6	48.6
Silt, %	25.7	36.2
Clay, %	10.8	15.3
Texture	Sandy loam	Loam

†CEC, estimated cation exchange capacity from Mississippi Soil Test extracted cations
‡ MSTP, Mississippi Soil Test P
§OM, organic matter

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

Mulch Treatment Name	Mulch Source	Mulch Composition	Application Rate (kg ha^{-1})
Half	wheat straw	100% wheat straw	2245
Standard	wheat straw	100% wheat straw	4490
Paper	paper fiber	100% paper fiber	2245
Wood	wood fiber	100% wood fiber	2245
Blend	70/30 wood/paper fiber	70% wood fiber 30% paper fiber	2245
FGM	flexible growth medium (FGM)	80% wood fiber 10% tackifier 5% interlocking fibers 5% mineral activator	3368
ET-FGM	extended term-FGM (ET-FGM)	52% wood fiber 21% coconut fiber 10% tackifier 7% interlocking fibers	3368
BFM	bonded fiber matrix (BFM)	78% wheat straw 12% natural fiber 10% tackifier	3368

Table 3.6 Analysis of the rainfall simulation water source used in Experiment II.

Parameter	Year	
	2011	2012
pH	9.14	8.73
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

Figure 3.1 Runoff frame and collection container arrangement used for Experiment I and II. Experimental area locations differed between experiments and between years for each experiment.

Figure 3.2 The Tlaloc 3000 rainfall simulator (Joern's Inc., West Lafayette, IN) used during Experiment I and II in 2011 and 2012.

Figure 3.3 The light box used in conjunction with a digital camera to capture photographs for digital image analysis of percent vegetative coverage.

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 42 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 for the final 28 days of the establishment period. Days after seeding was significant in both years, but there was not a fertilization treatment by DAS interaction in either year. Data were pooled across fertilization treatments and presented by DAS (Fig. 4.1).

Seedling emergence began between 10 and 14 DAS 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 weed seedbank, leading to fewer weeds during the establishment period. The results suggest 15 DAS fertilization of Split, Poultry, SU, and DAP treatments did not influence establishment. This may be due to a lack of vegetation, and nutrient loss vulnerability following fertilization. Vegetative coverage was less than 10% in both years at the 15 DAS fertilization. Furthermore, fertilizer was not soil incorporated following application. 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% 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% coverage 30 DAS may be difficult to achieve under non-irrigated conditions. Although the target coverage was not achieved, vegetation that did grow the first 30 DAS likely reduced runoff losses. Data from the 30 DAS indicated approximately 40% coverage in 2011 and 20% coverage in 2012. Gross et al. (1991) found that low density vegetation significantly reduced sediment loss compared to bare soil. Coverage reached 70%, 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 non-mowed vegetation. Canopy shadowing late in the establishment period likely influenced DIA 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% in both years.

Slow germination of warm-season species in the MDOT spring-summer seed mixture increased the time needed to reach 70% coverage in both years. Furthermore, results suggest fertilization treatments did not influence vegetative growth compared to the untreated Control treatment. 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

Approximately the same number 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 fertilization treatments. This is not a surprising result considering there were no significant vegetative coverage differences between treatments. There was significant positive correlation between rainfall and runoff quantities in both years. However, when data were pooled across fertilization treatments and dates 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 quantities was strong. This may be due to the variability in runoff quantity collected during each event.

Mulching and rainfall intensity influenced runoff. Maximum rainfall (~100 mm) for one event was approximately the same in both years, and occurred at 54 DAS in 2011 and 28 DAS in 2012. 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% vegetative cover at 54 DAS. This is compared to mulched plots in 2012 with 17% cover at 28 DAS. Thus, straw mulch applied in 2012 may have 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) showed a 55 and 10% loss of simulated rainfall when bermudagrass cover was 20 and 90%, respectively. Our 2011 results were similar, with 50% runoff loss at 32% coverage and 20% loss at 80% coverage. Burwell et al. (2011) did not apply mulch, but the experimental site consisted of clay soil and a 30% 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 in our experiments lasted 5 h (29 DAS) in 2011 and 15 h (54 DAS) in 2012 at varying intensities. The influence of rainfall intensity and duration was also evident in our 2012 experiment.

In 2012, runoff occurring 24 and 28 DAS was similar. However, rainfall was 42 mm greater on 28 DAS. This appears to be due to differences in rainfall intensity as the 24 DAS rain fell in a 2 h period, whereas, the 28 DAS rain 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. This hypothesis is supported by Huang et al. (2013) who found runoff intensity increased with increased rainfall intensity and duration. Results from our experiments also indicate TS, TN, and TP lost during runoff produced by natural rainfall were correlated with runoff quantity collected.

Total Solids in Runoff

Statistical analyses for TS runoff losses indicated there was not a significant interaction between fertilization treatment and DAS in either year. Furthermore, fertilization treatment was not significant in either year. These results follow the same trend as previously discussed runoff results. Thus, data were pooled across fertilization treatments and presented by DAS (Fig. 4.3). Results suggest TS runoff losses were influenced by runoff quantity collected. 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 solids in runoff 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% greater in 2011 than 2012, but TS losses were 60% 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 (*Oryza sativa* L.) straw at 3600 kg ha^{-1} reduced TS runoff losses 91% compared to bare soil. Therefore, MDOT specified mulching may significantly reduce TS loss in runoff. 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 fertilization treatment by DAS interaction for TN losses. However, it was necessary to separate data by fertilization treatments and DAS to explain losses from those treatments receiving N fertilizer 15 DAS (Fig. 4.3).

In 2011, TN runoff losses and runoff quantity collected 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 quantity collected in 2012 resulted in similar results as in 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. The coefficient of variation at 21 DAS was 28% greater than any other event. This may be due to the 21 DAS event being the first following 15 DAS fertilization of the Split, Poultry, SU, and DAP treatments. The results indicate TN runoff losses for the Split, Poultry, SU, and DAP treatments were 750 to 1600 g N ha^{-1} greater than losses from all other treatments. 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 showed differences ranging from 70 to 570 kg N ha^{-1}. Furthermore, TN loss in runoff was significantly greater for the SU fertilization treatment than any other treatment. This was the only runoff event in which TN loss from one treatment was significantly greater than losses from all other treatments. This is an interesting result considering the greatest amount of N was applied to the Standard treatment at seeding.

Total N lost with the Standard treatment was not significantly different from that of the Half and Spilt treatments 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 with the untreated Control treatment was 70% of TN lost with the Standard treatment. Similarly, Mostaghimi et al. (1994) found kjeldahl N (organic-N + NH_4^+-N) runoff concentrations from bare soil to be 89% 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 to organic-N. However, NH_4^+ and NO_3^--N are often used as a measure of water quality.

Inorganic Nitrogen Runoff Losses

A significant interaction occurred between fertilizer treatment and DAS in both years for NH_4^+-N runoff losses. Fertilization treatment and DAS were significant for NO_3^--N but the interaction was not. Data were separated by fertilizer treatments 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 of the Spilt, Poultry, SU, and DAP treatments occurred 15 DAS of both years.

There were two runoff events prior to the 14 DAS rainfall simulation event in 2011. The increase in NO_3^--N runoff losses from the first to second event indicates applied N fertilizer had not completely nitrified prior to the event at 7 DAS. Therefore, most N was lost as NH_4^+, leading to significant NH_4^+-N loss differences. Ammonium-N loss in runoff 7 DAS for the Standard treatment was significantly greater than for the Split and Half treatments. However, there were no significant NH_4^+-N runoff loss differences between the three fertilization treatments 11 DAS. These results suggest applying the MDOT specified 13-13-13 at a half rate during seeding may reduce potential NH_4^+-N runoff losses during the first runoff event. It has been well documented that the greatest nutrient runoff losses occur during the first runoff event following fertilization on sites ranging from bare soil (Faucette et al., 2005) to low density (Burwell et al. 2011) and high density (Shuman, 2002; Vietor et al., 2004) turfgrass. Therefore, practices such as fertilizer incorporation may reduce runoff losses following fertilization.

Polymer coated urea was selected as an inorganic slow-release N source and was applied at half the MDOT specified N rate at seeding. Ammonium-N loss indicates urea contained within the polymer-coat was hydrolyzed and partially released during the 7 DAS event. The greatest PCU treatment loss 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 nutrient rate into two applications also appears to be an unacceptable practice to limit N runoff losses. Split and SU treatments received a half rate (73.5 kg N ha^{-1}) at 15 DAS, whereas Poultry and DAP treatments received 49 and 44.1 kg N ha^{-1}, respectively. Therefore, total N applied during the establishment period was 147 kg ha^{-1} to the Split, SU, and Poultry treatments and 73.5 kg ha^{-1} to the DAP treatment. Ammonium and NO_3^--N runoff losses for the Split, SU, Poultry and DAP treatments the first event following 15 DAS fertilization of both years were greater than for all other treatments. 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 on sloping soils. However, Nichols et al. (1994) suggested fertilizer incorporation of 2-3 cm was too shallow to reduce nutrient loss in runoff. They found no significant differences between surface application and 2-3 cm incorporation of poultry litter and inorganic fertilizer. Therefore, an incorporation depth greater than 2-3 cm may be necessary to reduce nutrient loss in runoff.

Ammonium-N losses with the Split, Poultry, and SU treatments were significantly greater than all other treatments 22 DAS in 2011. Furthermore, NH_4^+ and NO_3^--N losses from the Poultry fertilization treatment were significantly greater than from all other treatments 29 DAS in 2011. Overall, NH_4^+ plus NO_3^--N runoff losses during the 56 d establishment period were greater with the Split, Poultry, SU, and DAP fertilization treatments than the Standard treatment.

The greatest total NH_4^+ plus NO_3^--N runoff losses during natural rainfall were 3% of applied N (2012 DAP). The majority (76%) was lost during the first runoff event. Ammonium plus NO_3^--N runoff losses for the Standard treatment were 0.6 and 0.7% of applied N in 2011 and 2012, respectively. This indicated that 48% of the fraction in 2011 and 55% in 2012 was lost in the first runoff event. These results are similar to Edwards and Daniel (1994) who concluded the greatest nutrient loss in runoff occurred during the first event after fertilizing a tall fescue pasture with poultry litter or inorganic fertilizer. Runoff losses during natural rainfall were minimal compared to the applied N rate for each fertilization treatment. 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 during roadside establishment.

Total Phosphorus Runoff Losses

Similar to TN results, there was not a significant interaction between fertilization treatment and DAS in either year for TP. However, it was necessary to separate data by treatment and DAS to highlight variability that existed each year (Fig. 4.3). Total P losses were not as strongly correlated with runoff quantity 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 variability in both years.

The runoff event 7 DAS in 2011 resulted in the greatest TP losses from the Split and DAP treatments. The Standard treated plots, which were fertilized with the greatest P rate at seeding, lost less TP than the untreated Control plots. There were no significant TP differences between fertilization treatments or between fertilization treatments and the untreated Control treatment during that event. Potentially, the variation in sediment bound P lost during runoff overshadowed any differences that may have occurred between P sources and rates. Daniel et al. (1979) found that 90% of TP lost during runoff was associated with sediment load. Soil test P across our plots prior to fertilization was 91 kg ha^{-1} in 2011 and 52 kg ha^{-1} in 2012. Therefore, variability in TS losses between fertilization treatments may have led to variability in TP losses.

Mulch application in 2012 may have reduced TS in runoff compared to 2011. Total P loss in runoff for the SU treatment was significantly greater than for all other treatments during the first runoff event. The Split and Poultry treatments were fertilized with the same amount of P as SU at 15 DAS. However, TS losses were 40 (Split) 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 fertilization treatments, TP runoff losses for the Split, Poultry, and SU treatments were the greatest from the second and fourth runoff events 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 variability. Similarly, Vietor et al. (2004) found TP 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. In our experiment, significant relationships did not occur between P (PO_4^{3-}-P or TP) in runoff and soil test P in either year.

Inorganic Phosphorus Runoff Losses

A significant interaction between fertilization treatment and DAS occurred for PO_4^{3-}-P runoff losses. Data were separated by fertilization treatments and DAS (Table 4.2). The Poultry treatment 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 PO_4^{3-}-P runoff losses during the first event of 2011. Losses were at least 1.7 times greater than any other single treatment loss. Furthermore, losses were significantly greater than from all fertilization treatments except DAP the second runoff event of 2011. The application and subsequent runoff loss of P from organic sources has been well documented (Edwards and Daniel 1994; Nichols et al. 1994; Sharpley, 1997; Gaudreau et al. 2002; Schroeder et al. 2004; Vietor et al. 2004). The applied P rate to the Poultry treatment was half of the Standard treatment at seeding. However, the combination of organic-P and inorganic-P applied with the Poultry treatment may have caused greater PO_4^{3-}-P runoff losses.

The Standard treatment losses were not significantly different than the Half treatment losses 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 PO_4^{3-}-P concentration in runoff the first two events after application. Mass PO_4^{3-}-P loss was not presented. The researcher did indicate mass loss results were nearly identical to concentration in terms of the pattern of transport. It also must be noted Shuman (2002) simulated rainfall on a 5% slope and the first two runoff events occurred 4 and 24 h after fertilization. Therefore, slope and runoff frequency differences between our and Shuman (2002) experiments may have resulted in differences between the two experiments.

Orthophosphate runoff losses from the Standard treatment were not significantly different from the Split treatment 7 and 11 DAS in 2011. However, losses were significantly less than Split the first two events following fertilization at 15 DAS in 2011. Similar to inorganic N results, fertilization at 15 DAS to the Split, Poultry, and SU treatments significantly increased PO_4^{3-}-P runoff losses compared to all other fertilization treatments. Results indicate PO_4^{3-}-P lost from the SU treatment was significantly greater than from all other treatments except Split the first runoff event of 2012. Furthermore, losses for the Split, Poultry, and SU treatments were approximately 10 times greater than from all other treatments 22 DAS is both years. The greatest total loss was 1.4% of applied P (2011 Poultry). Therefore, total losses from all fertilization treatments were minimal compared applied P. This may be a result of conducting the experiments on only a 10% slope. Additional research on slopes with varying gradients is necessary to confirm these results.

Simulated Rainfall

Runoff Quantity 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 fertilization treatment and sampling time for any rainfall simulation in either year. Furthermore, fertilization treatment was not significant for any simulation in either year. Sampling time was significant for all simulations so data were pooled across fertilization treatments and presented by sampling time (Table 4.3). Similar to natural rainfall results, significant correlations existed between runoff quantities collected, 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 sampling time except 20 min at 14 DAS in 2011. Total P losses were not significantly correlated with any other parameter during the 14 and 30 DAS simulations in 2011. Similar to natural rainfall results, this may be due to variability. As previously mentioned, it is possible the variability in sediment bound P loss led to the variability in TP loss. Therefore, TP loss does not have a distinct trend across the six sampling times in the first two simulations of 2011. However, TP losses increased for each sampling time during the 56 DAS simulation in 2011 and the 14 DAS simulation in 2012. Runoff, TN and TS losses generally increased or decreased during all simulations.

Simulated rainfall lost as runoff increased across sampling times during every simulation. Runoff quantity collected the first two simulations of 2011 was similar although vegetative cover was 27% greater at the 30 DAS simulation. However, antecedent soil moisture 30 DAS was 4% 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 the 14 and 30 DAS simulations may be a function of both soil moisture and vegetative cover. At the 56 DAS simulation there was approximately 60% more vegetative coverage (visual), resulting in 2.7 mm less runoff per sampling time compared to the simulation at 14 DAS. Vegetative cover may have also had an influence on TS, TN, and TP runoff 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 solid 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 at seeding may have still been near the soil surface due to lack of precipitation prior to the 2012 simulation. Ammonium plus NO_3^--N runoff losses were 69% of TN losses during the 14 DAS simulation in 2012. This compares to 18% during the 56 DAS simulation in 2011. Overall, trends of inorganic N runoff losses were similar to TN losses across sampling periods.

Inorganic Nitrogen Runoff Losses

Sampling time was significant for every simulation, and fertilization treatment was significant for two of the four simulations for both NH_4^+ and NO_3^--N. Data were separated by fertilization treatments and sampling times in order to effectively explain significant differences for each simulation (Fig. 4.4 and 4.5).

Nitrate-N runoff losses generally decreased across sampling times for every simulation in 2011 and increased across sampling times in 2012. Mulch cover in 2012 may have delayed the transport of applied N, leading to greater losses later in the simulation. Although greater, NO_3^--N losses from the Standard treatment were not significantly different than from Split and Half treatments 14 DAS in either year. These results are consistent with NH_4^+-N losses during the same simulations. However, PCU applied in 2011 significantly increased NH_4^+-N in runoff.

Ammonium-N runoff losses for the PCU treatment were significantly greater than all other fertilization treatments across all sampling times 14 DAS in 2011. It must be noted NH_4^+-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 NO_3^--N, which were never greater than 100 g ha^{-1} and totaled 198 g ha^{-1}. Ammonium plus NO_3^--N losses from the PCU treatment during the 14 DAS simulation were 0.4% of applied N.

Burwell et al. (2011) simulated rainfall at 96 mm hr^{-1} on a 30% slope 14 DAS (following two runoff producing natural rainfall events). They found NH_4^+ plus NO_3^--N runoff losses from 50 kg N ha^{-1} applied as S-coated urea to be 0.9% of applied N. Compared to the PCU treatment in our experiment, less N was applied at seeding during Burwell et al. (2011). However, the slope and rainfall intensity Burwell et al. (2011) used was greater, potentially leading to greater NH_4^+ plus NO_3^--N runoff losses than our experiment.

Ammonium and NO_3^--N runoff losses were significantly greater for the SU treatment than from any other fertilization treatment during the 30 DAS simulation in 2011. Significant differences occurred for every sampling period except 5 min. NO_3^--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 were delayed. This may have reduced N lost by NH_3 volatilization and NO_3^--N leaching compared to applied NH_4NO_3. Therefore, a greater amount of NH_4 and NO_3^--N may have been present (compared to other treatments) near the soil surface.

Inorganic Phosphorus Runoff Losses

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

The combination of poultry litter and CSP applied at seeding to the Poultry treatment resulted in the greatest PO_4^{3-}-P runoff losses at the 14 DAS simulation in both years. Furthermore, losses were significantly greater than from all fertilization treatments during the 15 and 30 minute sampling times in 2011. Orthophosphate losses for the Standard fertilization treatment were greater than for the Split and Half treatments during every sampling time in 2011 (14 DAS). Due to variability, differences were not statistically significant except between Standard and Split treatments the final three sampling times. These results indicate that both P source and rate may have an influence on PO_4^{3-}-P runoff losses.

Edwards and Daniel (1994) fertilized a tall fescue pasture 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) found that increasing P rate applied as CSP and manure to established bermudagrass significantly increased dissolved P concentration in runoff. Both of these studies were conducted on established turfgrass. Therefore, P surface applied to turfgrass maybe more likely to be transported offsite during runoff.

Inorganic P applied to the soil surface at 15 DAS increased PO_4^{3-}-P runoff losses during the 30 DAS simulation in 2011. Losses for the Split, Poultry, and SU treatments were greater than for all other treatments for each sampling time. Total PO_4^{3-}-P runoff loss with the Split, Poultry, and SU treatments ranged from 89 to 116 g ha^{-1} during the 30 DAS simulation. This was 0.13 to 0.18% of total applied P. Shuman (2002) found rainfall simulations of 4, 24, 72, and 168 hours after P application resulted in 9.7% (4 h) to 0.2% (168 h) 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 should reduce nutrient movement due to runoff.

Experiment II

Vegetative Coverage

Visual evaluations and 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 treatment and 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 treatments 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 for the Half, Standard, and ET-FGM treatments in 2012 than 2011. This 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 likely due to a 70 mm natural rainfall event that occurred 8 DAS. Although it occurred over a 15-h period, there were two high intensity, short duration periods that caused significant mulch loss from the Paper, Wood, Blend, FGM, and BFM treatments (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. The ET-FGM treatment 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 for 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 at 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}. A rate difference between the two groups was due to mulches being applied at labeled rates based on slope gradients. Our results for both years suggest the slowest establishment occurred with Paper mulch application. Application of Wood and Blend mulches resulted in greater vegetative cover than Paper mulch during the establishment period both years. Cover ratings of the FGM, ET-FGM, and BFM treatments were similar for every date in 2011. However, seed loss due to runoff from FGM and BFM treated plots early in the 2012 establishment period may have reduced cover compared to ET-FGM.

The MDOT goal of 70% vegetative coverage in 30 days was not achieved in either year. Cover in straw mulched plots reached 70% at 77 DAS in 2011 and at 56 DAS in 2012. The difference between 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% cover. Further research should evaluate seeding rates and alternative species for use during fall-winter plantings.

Natural Rainfall

Rainfall and Runoff

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 4.8). There was not a significant interaction between mulch treatment and DAS in either year. Treatment and DAS were significant in 2011, whereas only DAS was significant in 2012. Data were separated by mulch treatments and DAS in order to explain runoff variation and mulch treatment differences.

Rainfall and runoff collected were positively correlated 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 for Standard treated plots in 2011 were less than from all other mulch treatments 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 runoff quantity collected. 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).

Rainfall and subsequent runoff quantities 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. However, the greatest percent of rainfall lost as runoff occurred 35 DAS in 2012. An average of 47% 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 the Half, Standard, FGM, and ET-FGM treatments 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 treatment and DAS during both years. Data were separated by mulch treatments 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 quantity collected 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 non-significant correlations at various other dates.

In 2011, TS runoff losses from the Half and Standard treatments were less than from all other treatments. Applying the MDOT Standard rate of straw reduced TS losses 32% compared to the Half rate of straw across the four runoff events in 2011. However, the only significant difference between the Half and Standard treatments occurred 33

DAS. Maximum TS runoff losses never exceeded 25 kg ha^{-1} for a single event (Paper, 37 DAS). Furthermore, TS in runoff for the Paper treatment at 37 DAS was significantly greater than from all other mulch treatments. There were no significant differences in TS runoff losses between the Wood, Paper, and Blend treatments or between the FGM, ET-FGM, and BFM treatments for the other three runoff events.

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

Total Nitrogen Runoff Losses

Similar to TS results, there was a significant interaction between mulch treatment and DAS when TN data were analyzed. Therefore, data were separated by mulch treatments and DAS (Fig. 4.9). Significant positive correlations existed between TS and TN at 26, 33, and 47 DAS in 2011 and at 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 coincided with the 14 DAS rainfall simulation. The second event occurred 26 DAS as a result of natural rainfall. Results from Experiment I indicated the largest percent fertilizer nutrient losses occurred during the first runoff event following fertilization. This may partially explain the differences between 2011 and 2012 TN runoff losses during the first event produced by natural rainfall.

Results indicate TN runoff losses for the Half treatment were not significantly different than the Standard treatment in either year. Losses for Half and Standard treated plots were less than all other treatments at 26 DAS in 2011, whereas they were greater than for all other treatments at 8 DAS in 2012. This may be a result of fertilizer application method and non-runoff producing rainfall events. Granular fertilizer was applied to the soil surface to both the Half and Standard treatments 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 a runoff event occurs prior to non-runoff producing rainfall events. These events may aid in dissolving fertilizer and allow time for the fertilizer nutrients to react with the soil. 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 of using hydromulch rather than straw mulch during dry conditions.

Although TN runoff losses were the greatest for the Half and Standard treatments during the first runoff event of 2012, across all other events (2011 and 2012) the greatest losses were generally for the Paper, Wood, or Blend treatments. Applying Paper, Wood, and Blend mulches above the recommended label rate on a 15% slope may be necessary to reduce losses. Of the hydromulches applied at 3368 kg ha^{-1}, TN runoff losses for the BFM treatment were significantly greater than for the FGM and ET-FGM treatments at 21 DAS in 2012. This may be a result of greater TS losses for the BFM treatment than the FGM and ET-FGM treatments. The observed mulch loss in 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 treatment and DAS for NH_4^+ and NO_3^--N runoff losses in both years. Results were separated by mulch treatments and DAS (Table 4.5). The Half, Standard, and BFM treatments were the most effective in reducing inorganic N runoff losses 26 DAS in 2011. Ammonium and NO_3^--N losses for the Half, Standard, and BFM treatments were significantly lower than for the Wood and Blend treatments during the event.

The 26 DAS event was the second runoff event of 2011. Therefore, NH_4^+ and NO_3^--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 the Half and Standard treatments had not been completely dissolved and moved into the soil profile prior to runoff. Ammonium plus NO_3^--N lost with the Half and Standard treatments during event at 8 DAS was 1.5 and 2% of applied N, respectively. The BFM application resulted in NH_4^+ plus NO_3^--N runoff losses of 0.5% of applied N during the same event. This was less than all other mulches. The other three runoff events in 2012 did not produce NH_4^+ and NO_3^--N losses greater than 0.4% of applied N (Blend, 21 DAS). The reduced losses in the last three runoff events are supported by Edwards and Daniel (1994) who reported nutrient concentrations in runoff can reach background levels following 2-5 runoff events. 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 loss at 26 and 47 DAS in 2011 and at 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. These results are supported by Daniel et al. (1979) who found 90% of TP runoff losses were associated with sediment loss. Furthermore, it was 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 the Half and Standard treatments in either year except at 38 DAS in 2012. Total P loss for the fourth replication of the Half treatment 38 DAS was approximately three times greater than for the other plots treated the same. Therefore, it is possible sediment contamination of the fourth replication sample lead to the increased TP loss.

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

Inorganic Phosphorus Runoff Losses

In general, PO_4^{3-}-P 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 PO_4^{3-}-P were the same in both years. There were no significant PO_4^{3-}-P loss differences between the Half and Standard treatments for any event in either year (Table 4.6). In 2011, losses from all hydromulched treatments were greater than from the Half and Standard treatments. An evaluation of the hydromulches indicated the BFM treatment had the least amount of PO_4^{3-}-P loss in runoff. In 2012, the greatest losses were generally for the Half and Standard mulch treatments. However, the Half and Standard treatment total losses across the four events were 0.7 and 0.6% of applied P, respectively. The lowest total loss was 0.3% of applied P (FGM). Therefore, PO_4^{3-}-P runoff losses during natural rainfall from all mulches were minimal compared to the applied rate.

Simulated Rainfall

Soil Volumetric Water Content, Runoff Initiation Time, and Runoff

Soil volumetric water content (VWC) and runoff initiation time (RIT) data were collected once for each plot during each simulation, whereas runoff quantity was collected six times, once for each sampling time. Therefore, VWC and RIT results are averaged across four replications and runoff quantity results are averaged across sampling times and replications. Data were separated by mulch treatment and rainfall simulation events due to a significant interaction between mulch treatments and DAS for each year (Table 4.7, 4.8, and 4.9).

In general, 14 DAS antecedent VWC, RIT, and runoff quantity were less in 2011 than 2012. Results indicate there were no significant differences between the Half and Standard treatments for the 14 DAS simulation in either year. Although not significant, the Half and Standard treatments 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-y storm, these results suggest use of straw mulches may be more appropriate than hydromulches on a 15% slope. Mostaghimi et al. (1994) made similar conclusions after comparing runoff mitigation of straw mulch to hydromulch on a 10% slope. Runoff losses for the Paper, Wood, and Blend treatments were generally greater than for the FGM, ET-FGM, and BFM treatments at 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 with the Paper, Wood, and Blend treatments was greater than with all other mulch treatments during the 28 DAS simulation in 2011. The results differed in 2012, with the greatest runoff collected from the FGM treatment. In total, 93% of rainfall applied to FGM was lost as runoff. This is compared to the Half and Standard treatments which lost 69 and 64% of rainfall as runoff, respectively. However, vegetative cover in Half and Standard plots was 20% greater than in FGM plots during the simulation.

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

Total Solids in Runoff

Similar to runoff results, TS in runoff was less in 2011 than in 2012 (Table 4.7, 4.8, and 4.9). Total solids in runoff for the Paper, Wood, and Blend treatments were significantly greater than from all other mulch treatments during the 14 DAS simulation in 2011. Erosion resulted in total losses of 51.6 kg TS ha^{-1} from the Blend mulch treatment for the 30-min simulation. This is compared to total losses of 2.2 and 3.2 kg ha^{-1} for the Half and Standard treatments, respectively. Furthermore, there were no significant loss differences between the mulch treatments applied at 3368 kg ha^{-1} (FGM, ET-FGM, and BFM) and the straw mulch treatments (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% 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 for the Paper treatment were not significantly different than for the Wood or Blend treatments.

However, differences did occur in 2012. Blend and Wood treatments reduced TS loading by 21 and 26% compared to the Paper treatment, respectively. During the same event, losses for the Half, Standard, and ET-FGM treatments were significantly less than from all other treatments. In 2011, 56 DAS losses for the Paper treatment were significantly greater than from all other mulches. There were no other significant differences between mulch treatments. 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% slope.

Total Nitrogen Runoff Losses

As previously mentioned, the first 2011 runoff event coincided with the 14 DAS rainfall simulation. Similar to TS results, TN losses were the greatest for the Paper, Wood, and Blend treatments the first event (Table 4.7, 4.8. and 4.9). The greatest total loss was 2.5 kg ha^{-1} (Blend), which was significantly greater than losses from all other treatments except Wood. Comparatively, losses were 99% less for the Standard treatment than for the Blend treatment. There were no significant differences between the Half, Standard, FGM, ET-FGM, or BFM treatments at the 14 DAS simulation in 2011.

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

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

Inorganic Nitrogen Runoff Losses

Results indicate the Paper, Wood, and Blend mulch treatments were the least effective at reducing NH_4^+ and NO_3^--N runoff losses during 2011 (Fig. 4.10). Nitrate-N losses from these three mulch treatments were greater than from all other mulch treatments across all three simulations. The greatest total NO_3^--N loss for one simulation was 738 g ha^{-1} (Blend, 14 DAS). Comparatively, 5.7 g ha^{-1} was lost with the Standard mulch treatment for the same simulation.

Ammonium-N runoff losses during the 14 DAS event in 2011 were generally greater than NO_3^--N losses. The greatest NH_4^+-N runoff loss of 1380 g ha^{-1} was with the Blend treatment. 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 NH_4^+ plus NO_3^--N lost during the first runoff event. Ammonium plus NO_3^--N runoff loss 14 DAS in 2011 was 2118 g ha^{-1} for the Blend treatment. This event attributed to 64% of the total losses of NH_4^+ plus NO_3^--N for the Blend treatment across the establishment period (natural and simulated rainfall). Although losses with the Blend treatment were greater at

14 DAS, a NH_4^+ plus NO_3^--N runoff loss of 930 g ha^{-1} was 67% of the total loss for the Paper treatment. In comparison, NH_4^+ plus NO_3^--N losses were 5 and 16% of the total loss for the Half and Standard treatments, respectively. It must be noted that the Half treatment losses at the 28 DAS simulation were 76% of the total loss. However, total loss was 0.1% of applied N for Half treated plots, whereas the greatest loss of applied N was 2.2% with the Blend treatment. Results indicate there were no NH_4^+ or NO_3^--N loss differences between FGM, ET-FGM, and BFM mulch treatments in either year.

Ammonium plus NO_3^--N runoff losses for the 2012 rainfall simulations were generally greater than for 2011 simulations. During the 14 DAS simulation, NH_4^+-N losses with the Half treatment were significantly greater than all other mulch treatments. Nitrate-N losses for the Standard treatment were significantly greater than for all other treatments except Half. The 14 DAS simulation was the second runoff event of 2012. However, NH_4^+ plus NO_3^--N losses for the Half and Standard treatments were approximately 10% 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% of the total losses for both Half and Standard treatments. Ammonium plus NO_3^--N losses were significantly greater for the ET-FGM than the FGM and BFM treatments at the 14 and 28 DAS simulation. Paper, Wood, and Blend mulch applications lead to the greatest NH_4^+ plus NO_3^--N loss in runoff at the 56 DAS simulation. However, total loss across sampling times for the three mulch treatments did not exceed 240 g ha^{-1} (Wood).

Total Phosphorus Runoff Losses

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

During the 28 DAS simulation in 2011, TP runoff losses were significantly greater for the Paper and Wood treatments than for the Standard and FGM treatments. However, during this 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 for the Standard and ET-FGM treatments.

In 2011 at 56 DAS, TP losses with Paper were significantly greater than for all other mulch treatments. Losses were 7 times greater than the next greatest loss (Blend). As previously discussed, this may be a result of significantly greater TS in runoff with the Paper treatment. The Half, Standard, and ET-FGM treatments reduced TP losses 60 to 67% from the greatest loss (Blend) at 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 PO_4^{3-}-P runoff losses for the Blend treatment were greater than from all other mulch treatments for the 14 and 28 DAS rainfall simulations in 2011 (Fig. 4.12). Combined losses from those two simulations accounted for 69% of total losses during the establishment period. However, this was only 0.4% of applied P. The Half, Standard, FGM, ET-FGM, and BFM treatments were generally more effective in reducing PO_4^{3-}-P runoff losses than the Paper, Wood, and Blend mulch treatments for all rainfall simulations. During the 56 DAS simulation, total losses (79.4 g ha^{-1}) with the Paper treatment were greater than for all other mulch treatments. Comparatively, losses with the Half treatment were 65% less than with the Paper treatment for this simulation.

Overall, PO_4^{3-}-P runoff losses were greater in 2012 than 2011. Furthermore, losses for the Half and Standard mulch treatments were greater than all other mulches across the three simulations. However, the only significant difference between the straw mulch treatments (Half and Standard) and the other mulch treatments occurred at the 28 DAS simulation. There were no significant differences between mulches at the 56 DAS simulation.

Results suggest that straw mulch applied at Half and the Standard MDOT recommended rates can reduce inorganic N and P runoff losses on a 15% slope during vegetative establishment. However, there are situations in which hydromulches may be more appropriate for vegetative establishment of sloped terrain. Specifically, losses for the Half and Standard treatments in 2012 are concerning. It is apparent that 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 for the Paper, Wood, and Blend mulches were too low to effectively mitigate runoff on a 15%

slope. Performances of the FGM, ET-FGM, and BFM mulch treatments were similar and more effective than the Paper, Wood, or Blend treatments.

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 only simulated rainfall. Our experiment utilized natural and simulated rainfall events, 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 NH_4^+ and NO_3^--N runoff losses produced by natural rainfall. All treatments except the Control received N fertilizer at seeding. The Split, Poultry, SU, and DAP treatments received additional N fertilizer at 15 days after seeding.

	Year†									
	2011					2012				
	Days After Seeding									
Fertilization Treatment‡	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

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

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

Table 4.2 Experiment I PO_4^{3-}-P runoff losses produced by natural rainfall. All treatments except the Control received P fertilizer at seeding. The Split, Poultry, SU, and DAP treatments received additional P fertilizer at 15 days after seeding.

Fertilization Treatment‡	Year†									
	2011					2012				
	Days After Seeding									
	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 Squares means (α = 0.05)

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

Table 4.3 Experiment I runoff, TS, TP, and TN runoff losses for the 2011 and 2012 rainfall simulations. Data were pooled across fertilization treatments and means are presented by sampling times.

Sampling Time (min)	Runoff (mm)	TS ($kg\ ha^{-1}$)	TP ($g\ ha^{-1}$)	TN ($g\ ha^{-1}$)
	Year – Simulation Date			
	2011 – 14 DAS†			
5	2.9	67.6	326.6	286.5
10	4.0	95.7	450.9	301.5
15	4.3	101.2	435.1	316.1
20	4.6	142.2	388.0	306.7
25	4.7	104.2	326.5	306.6
30	4.9	111.2	608.9	305.6
	2011 – 30 DAS			
5	3.5	67.3	411.8	251.9
10	4.2	66.6	385.5	197.9
15	4.3	64.7	444.1	179.4
20	4.5	63.6	348.5	166.6
25	4.5	62.3	389.1	161.2
30	4.6	63.4	467.0	161.6
	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

Runoff Parameter columns: Runoff, TS, TP, TN.

†DAS: days after seeding

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

DAS	Mulch Treatment†							
	Half	Standard	Paper	Wood	Blend	FGM	ET-FGM	BFM
2011								
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 $\alpha = 0.05$

Table 4.5 Experiment II NH_4^+ and NO_3^--N runoff losses for the 2011 and 2012 natural rainfall events.

	Year†							
	2011				2012			
Mulch Treatment‡	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 PO_4^{3-}-P runoff losses for the 2011 and 2012 natural rainfall events.

	Year†							
	2011				2012			
Mulch Treatment‡	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, and TS, TN, and TP in runoff for the rainfall simulation conducted 14 DAS in 2011 and 2012. Simulated rainfall intensity was 66 mm ha^{-1}. Runoff, TS, TN, and TP data were pooled across sampling time and means are presented by mulch treatment.

	14 Days After Seeding†											
	2011						2012					
Mulch Trt‡	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, and TS, TN, and TP in runoff for the rainfall simulation conducted 28 DAS in 2011 and 2012. Simulated rainfall intensity was 66 mm ha^{-1}. Runoff, TS, TN, and TP data were pooled across sampling time and means are presented by mulch treatment.

	28 Days After Seeding†											
	2011						2012					
Mulch Trt‡	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, and TS, TN, and TP in runoff for the rainfall simulation conducted 56 DAS in 2011 and 2012. Simulated rainfall intensity was 66 mm ha^{-1}. Runoff, TS, TN, and TP data were pooled across sampling time and means are presented by mulch treatment.

Mulch Trt‡	56 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	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

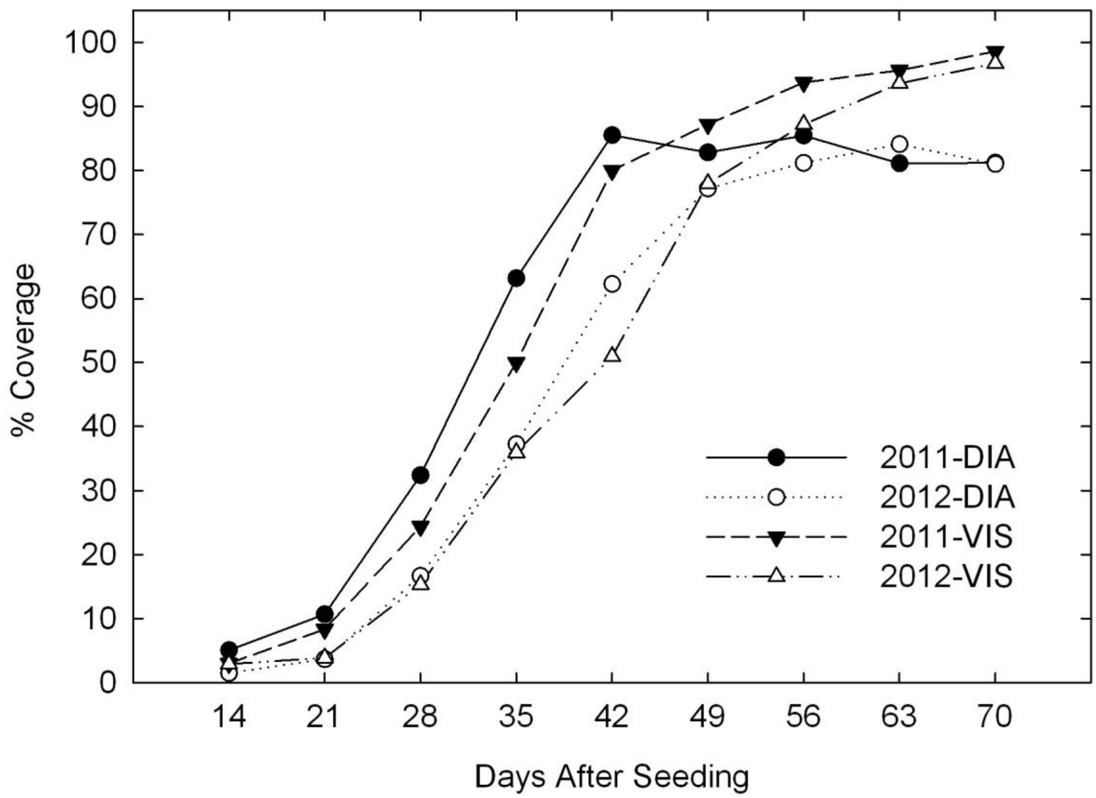

Figure 4.1 Experiment I percent vegetative coverage determined by visual evaluation (VIS) and digital image analysis (DIA) during 2011 and 2012. Data were pooled across fertilization treatments and means presented by days after seeding for each year.

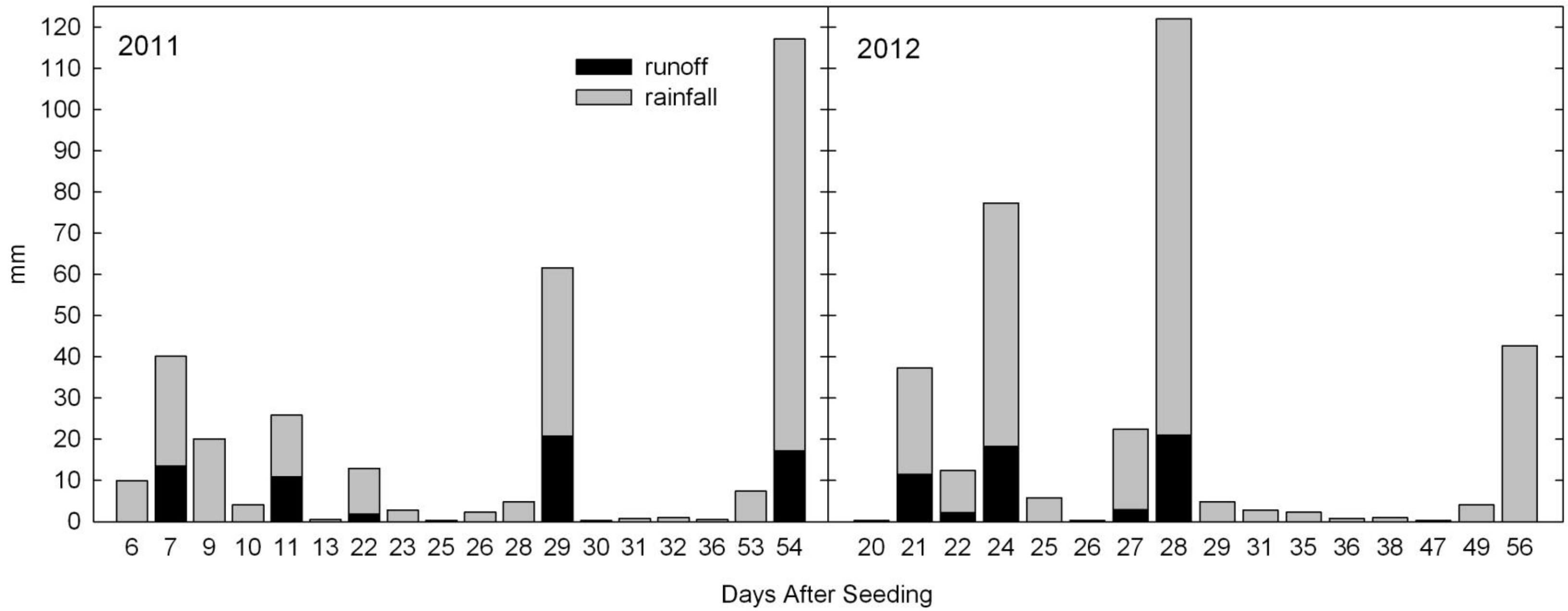

Figure 4.2 Experiment I rainfall and runoff amounts for the 2011 and 2012 natural rainfall events. Data were pooled across fertilization treatment and means are presented by days after seeding for each year.

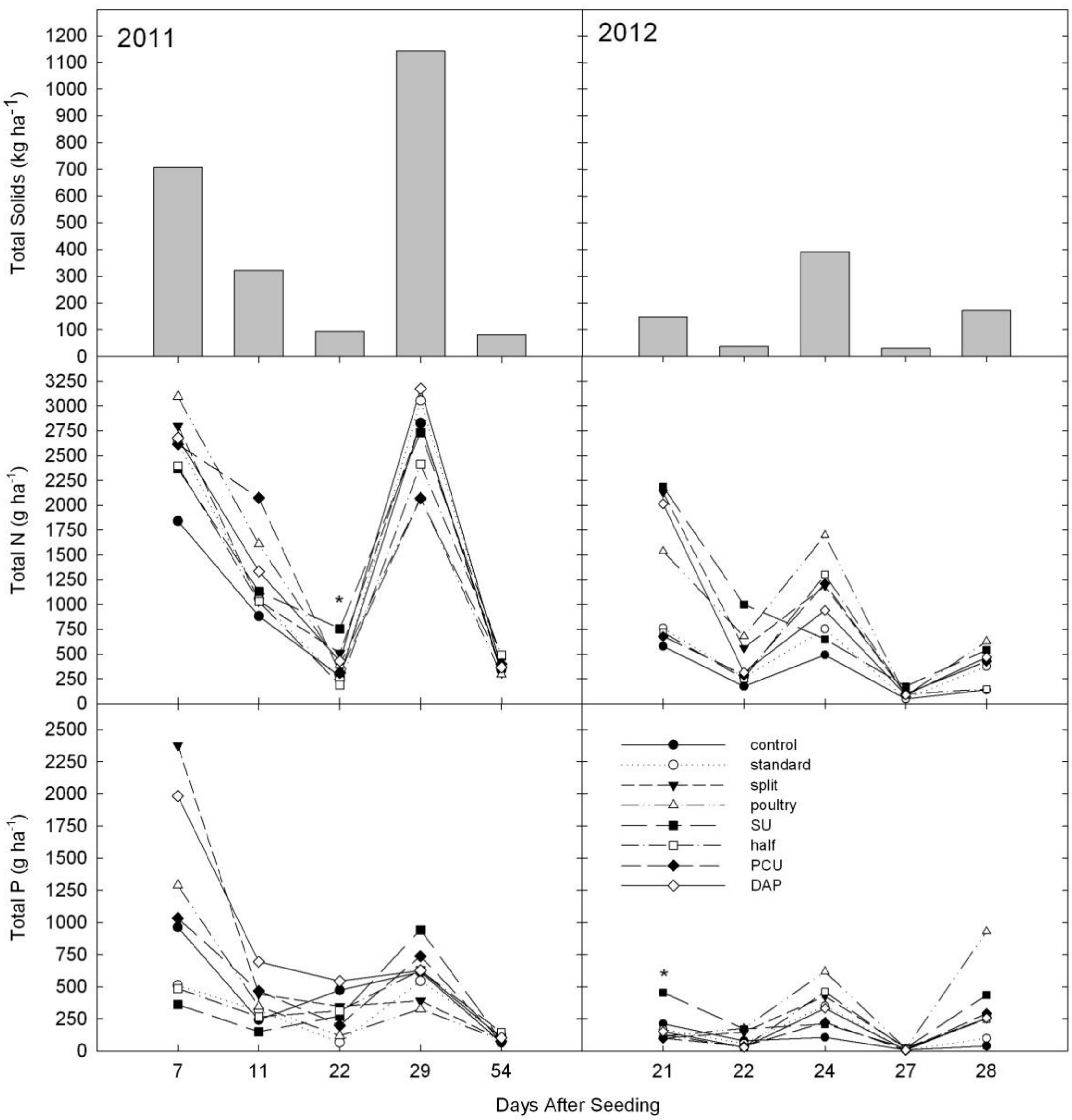

Figure 4.3 Experiment I TS, TN, and TP runoff losses for the 2011 and 2012 natural rainfall. Total solid losses were pooled across fertilization treatment and means are presented by date for each year. An asterisk indicates a significant difference from all other fertilization treatments at that specific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

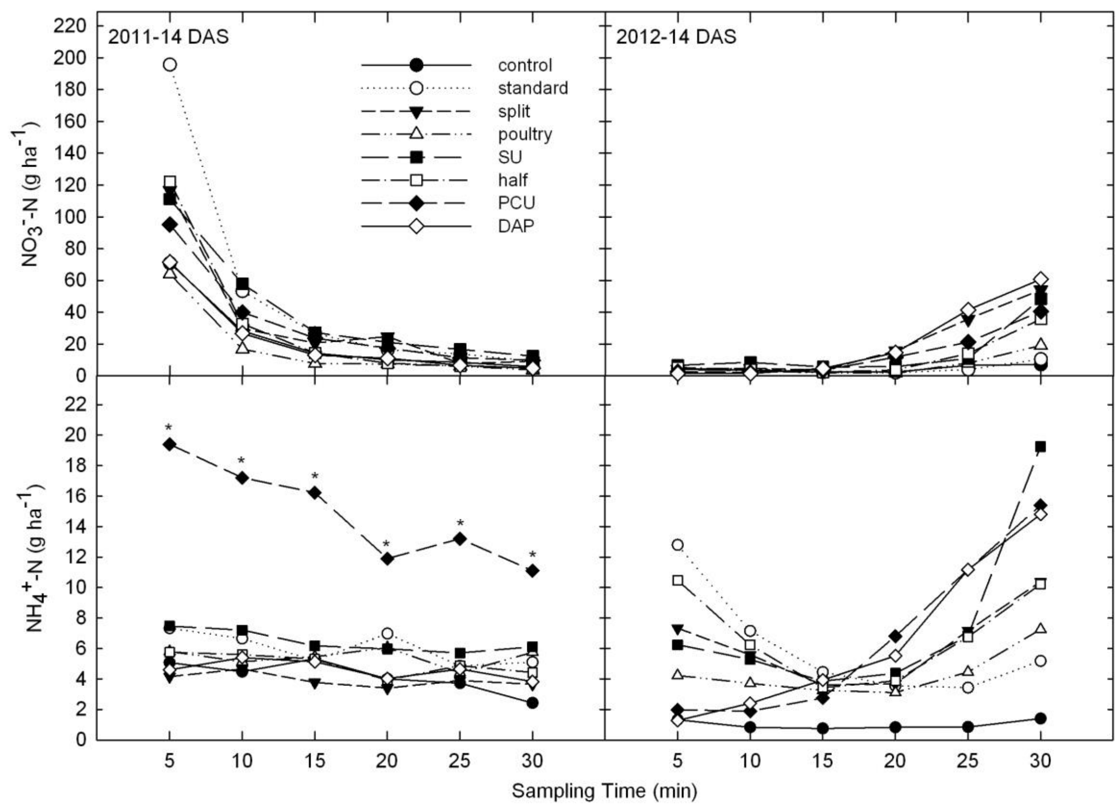

Figure 4.4 Experiment I NH_4^+ and NO_3^--N runoff losses for the 2011 and 2012 simulated rainfall event 14 days after seeding (DAS). An asterisk indicates a significant difference from all other fertilization treatments at that specific sampling time according to Least Squared Means (α=0.05).

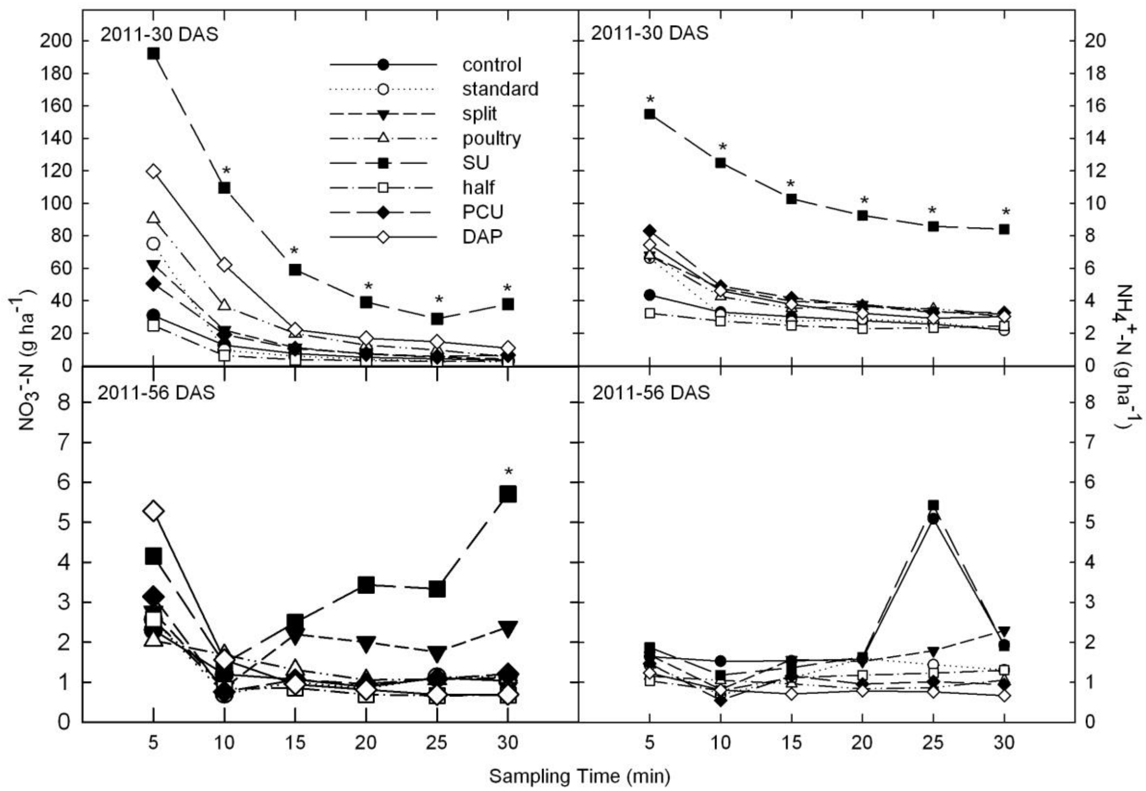

Figure 4.5 Experiment I NH_4^+ and NO_3^--N runoff losses for the 2011 simulated rainfall events at 30 and 56 days after seeding (DAS). An asterisk indicates a significant difference from all other fertilization treatments at that specific sample time according to Least Squared Means (α=0.05).

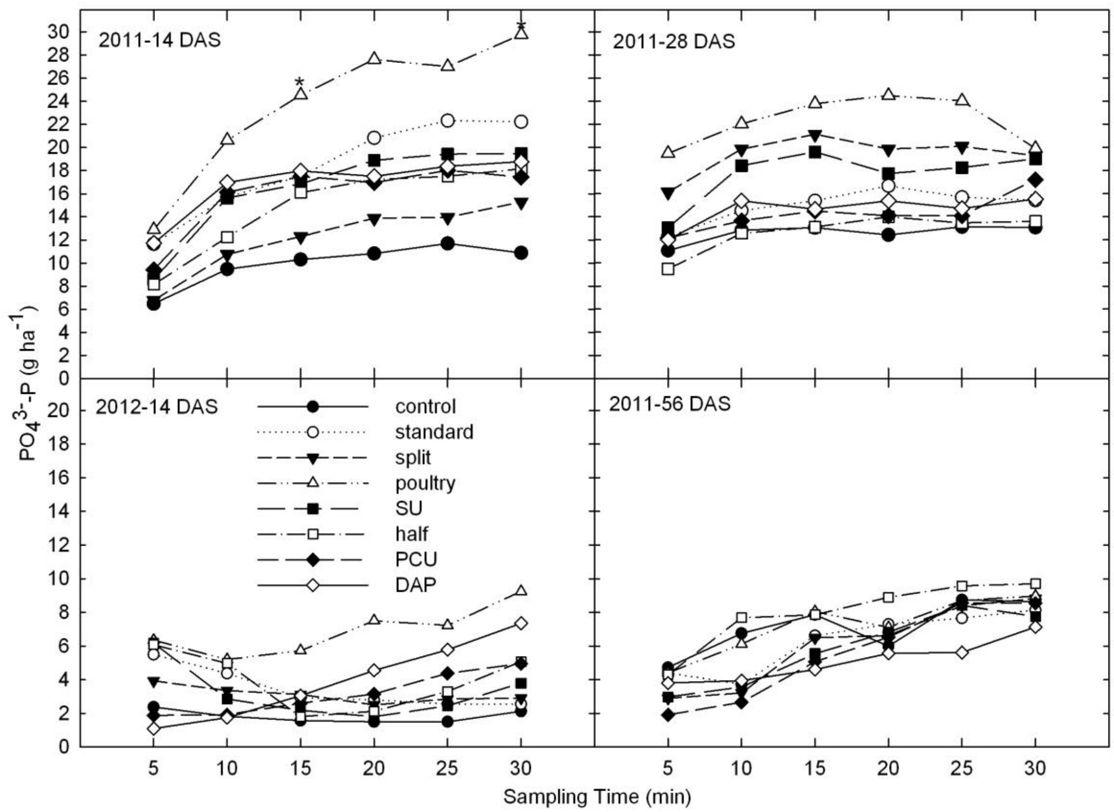

Figure 4.6 Experiment I PO_4^{3-}-P runoff losses for the 2011 simulated rainfall events at 14, 30, and 56 days after seeding (DAS) and 2012 simulated rainfall at 14 DAS. An asterisk indicates a significant difference from all other fertilization treatments at that specific sampling time according to Least Squared Means (α=0.05).

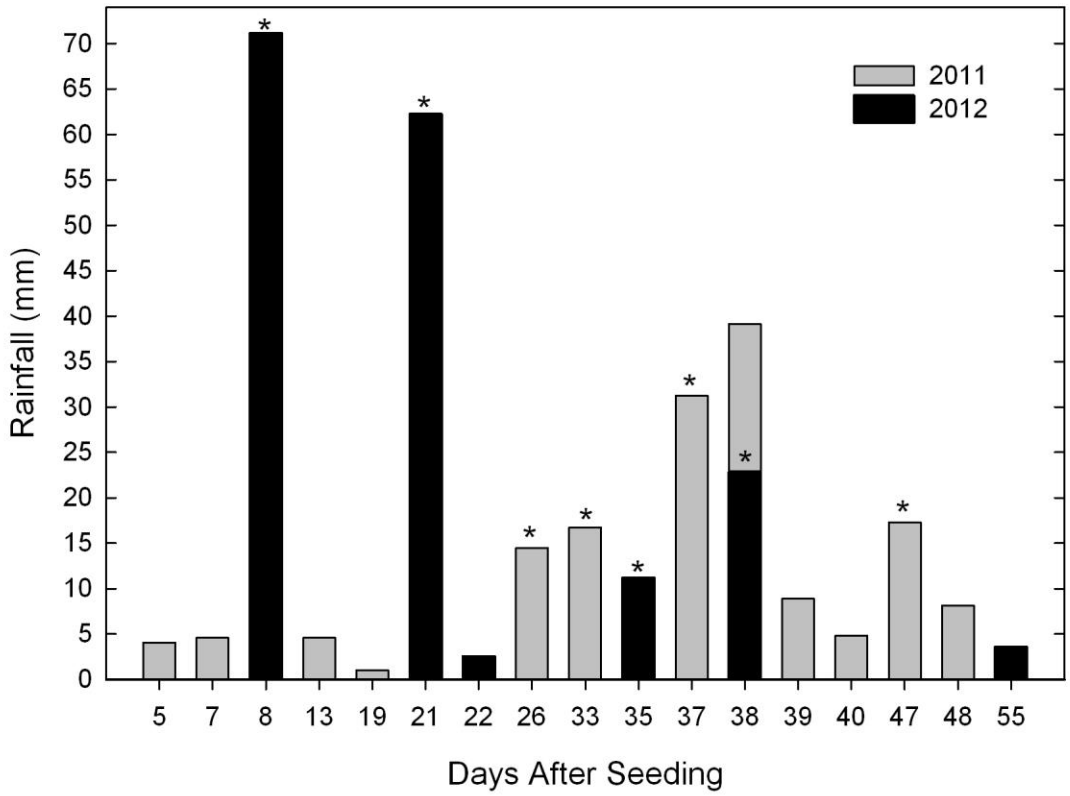

Figure 4.7 Natural rainfall that occurred during Experiment II in 2011 and 2012. An asterisk indicates a runoff producing natural rainfall event.

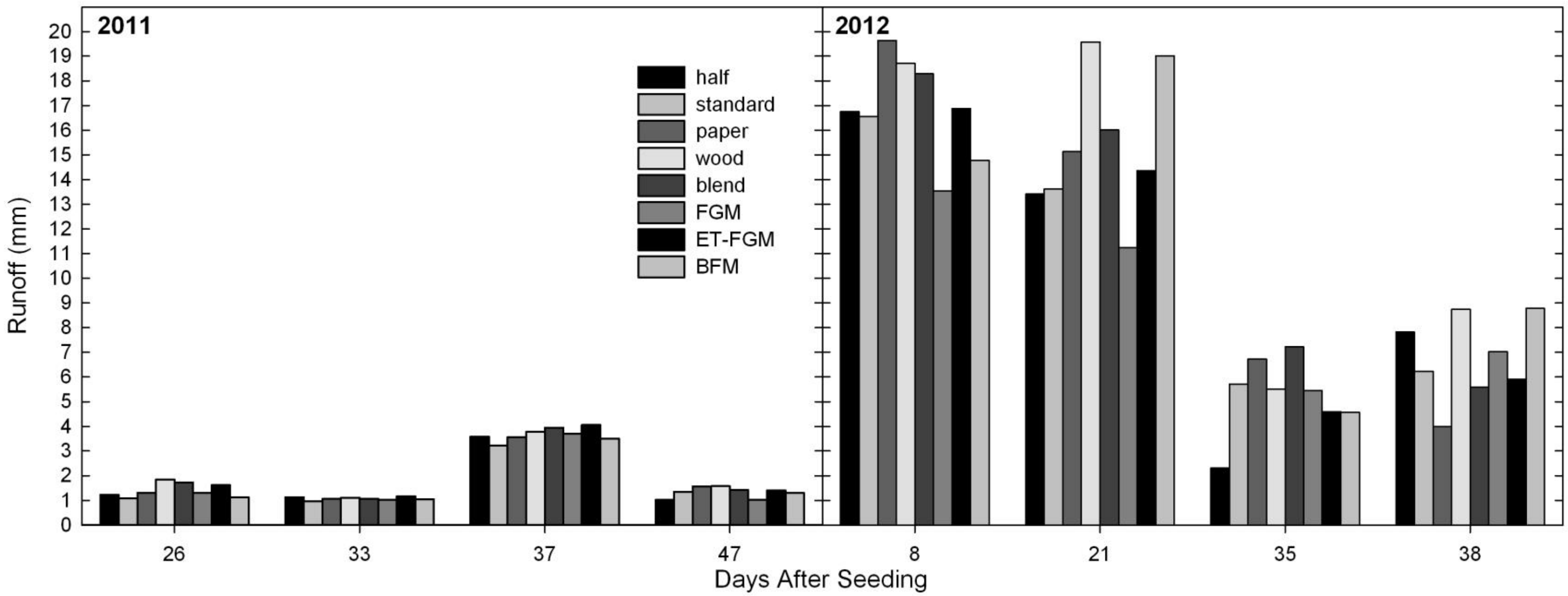

Figure 4.8 Experiment II runoff produced by natural rainfall in 2011 and 2012.

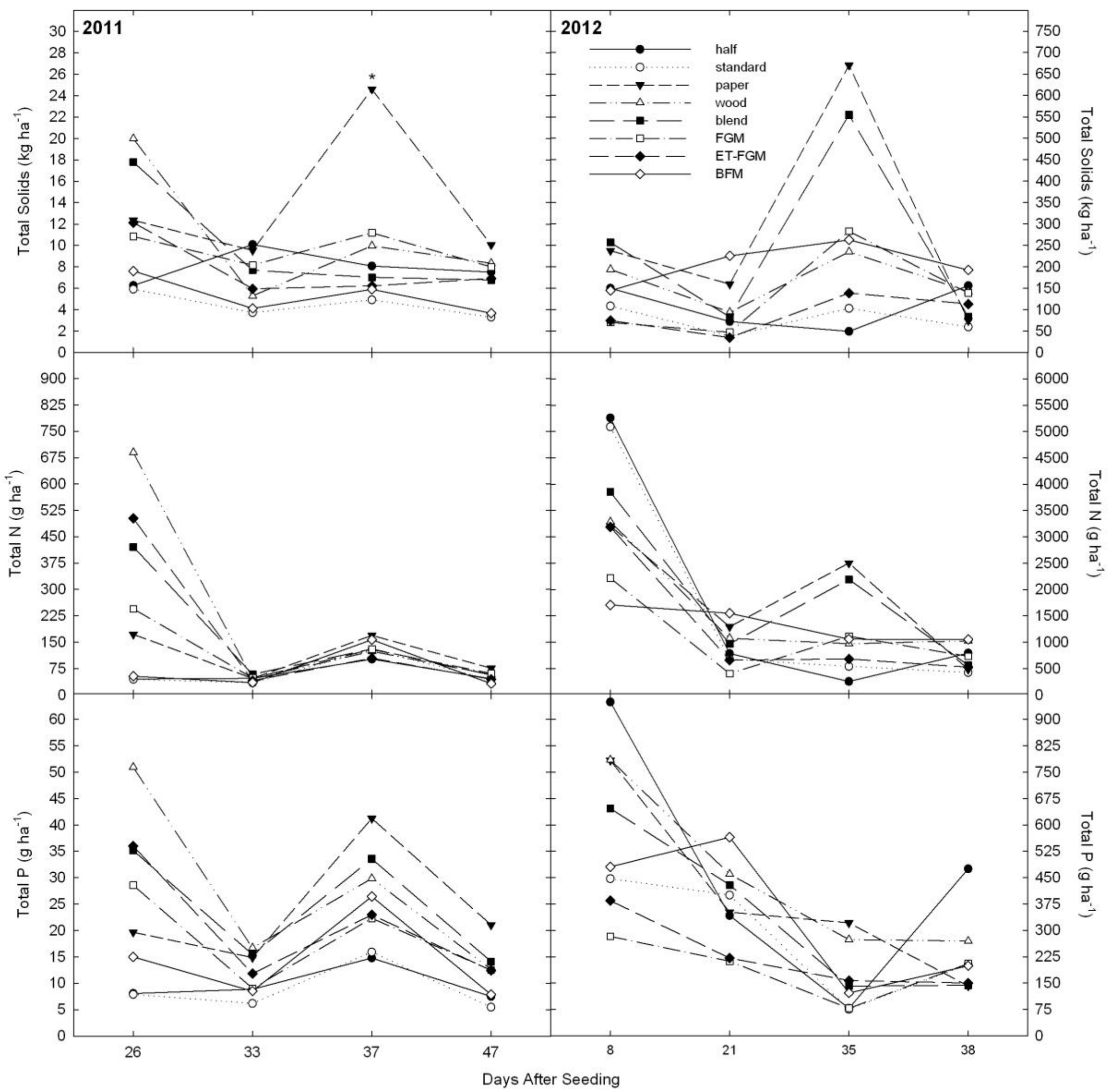

Figure 4.9 Experiment II TS, TN, and TP in runoff produced by natural rainfall events in 2011 and 2012. An asterisk indicates a significant difference from all other mulch treatments at that specific date according to Least Squared Means (α=0.05).

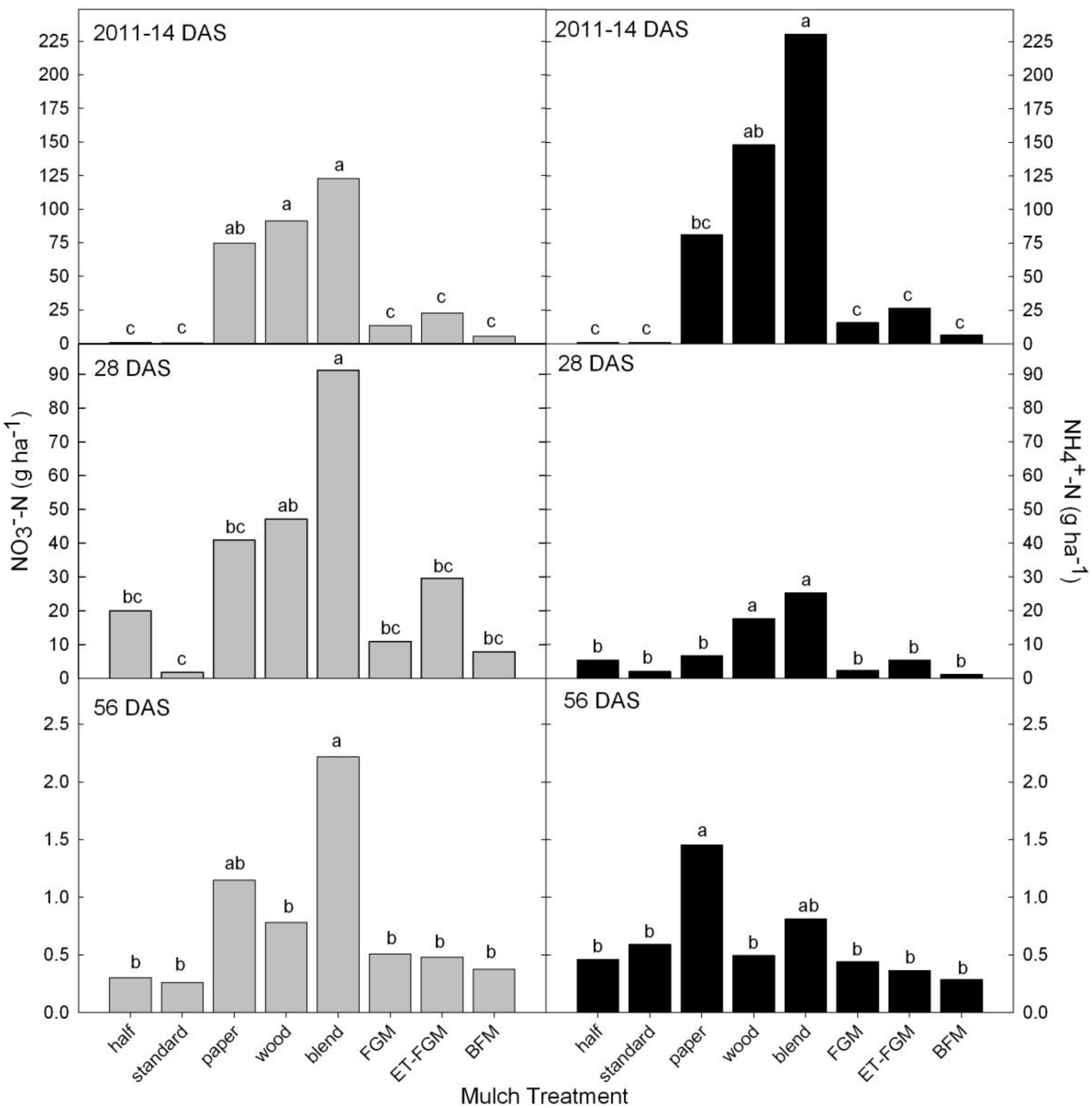

Figure 4.10 Experiment II NH_4^+ and NO_3^--N runoff losses for simulated rainfall events at 14, 28, and 56 days after seeding (DAS) in 2011. Ammonium and NO_3^--N losses were pooled across sampling times and means are presented by mulch treatment. Values with the same letter for each N species and simulated rainfall date are not statistically different according to Least Squares Means (α = 0.05).

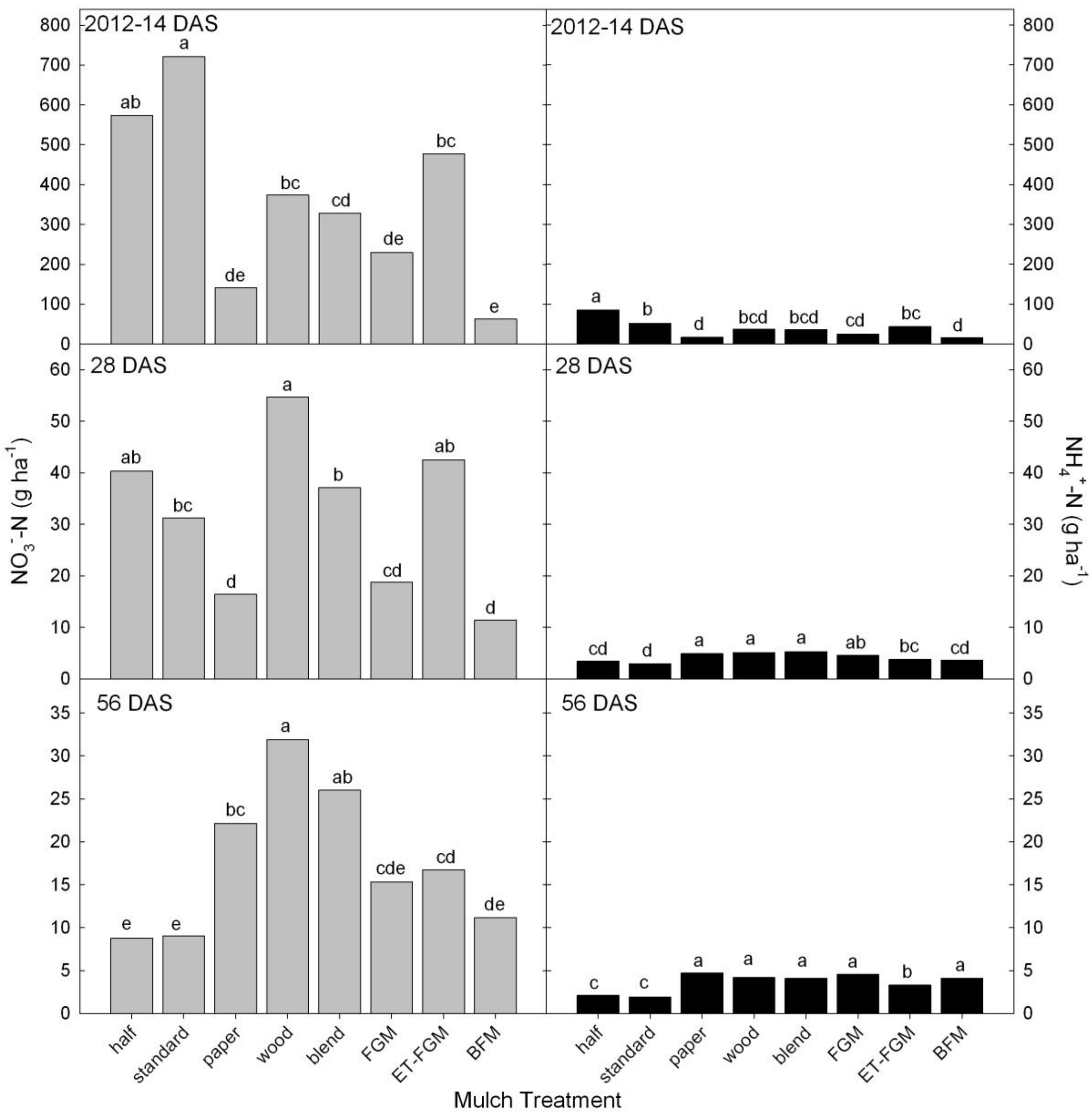

Figure 4.11 Experiment II NH_4^+ and nitrate NO_3^--N runoff losses for simulated rainfall events at 14, 28, and 56 days after seeding (DAS) in 2012. Ammonium and NO_3^--N losses were pooled across sampling times and means are presented by mulch treatment. Values with the same letter for each N species and simulated rainfall date are not statistically different according to Least Squares Means ($\alpha = 0.05$).

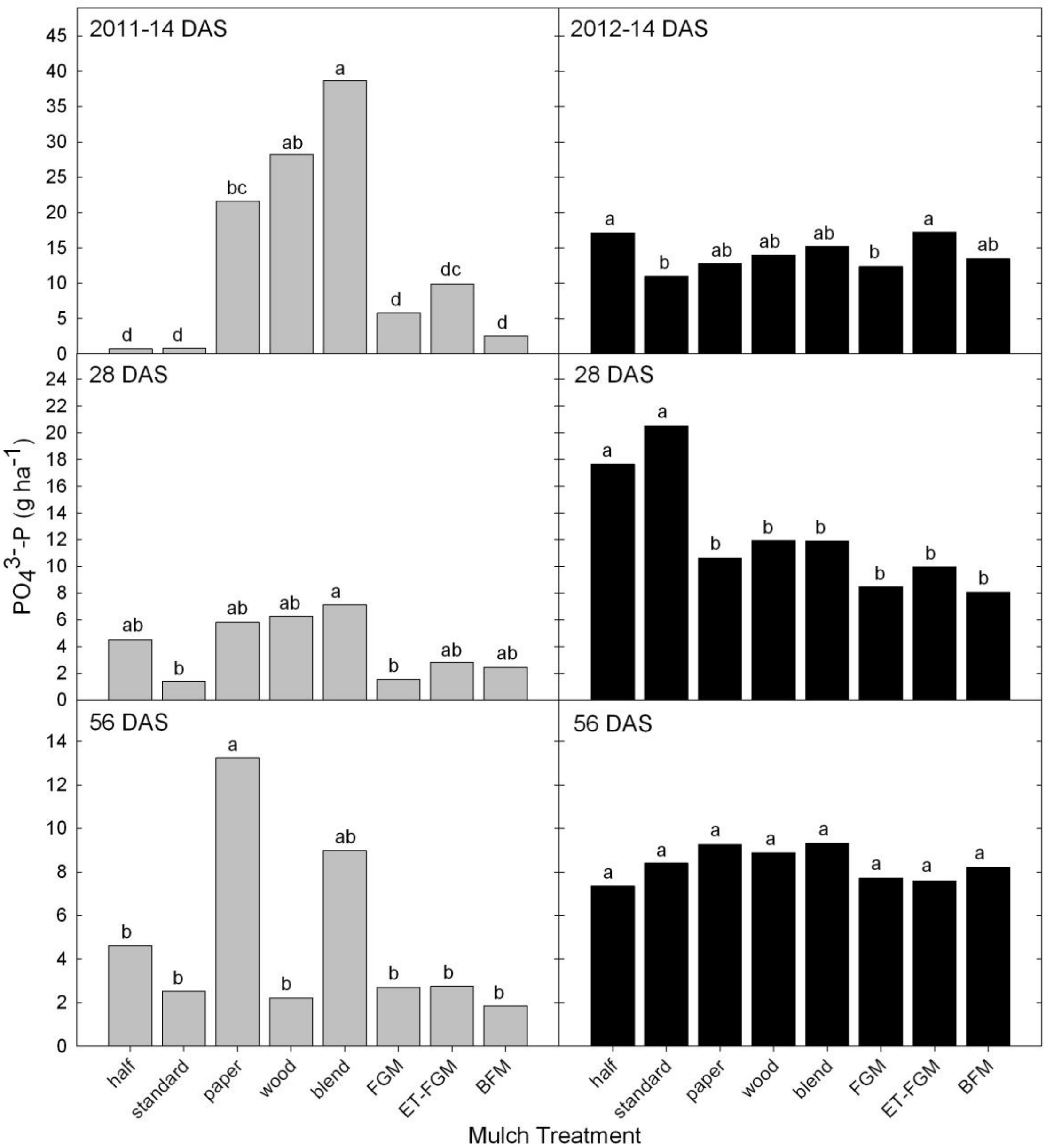

Figure 4.12 Experiment II PO_4^{3-}-P runoff losses for simulated rainfall events at 14, 28, and 56 days after seeding (DAS) in 2011 and 2012. Orthophosphate losses were pooled across sampling times and means are presented by mulch treatment. Values with the same letter for each year and simulated rainfall date are not statistically different according to Least Squares Means (α = 0.05).

CHAPTER V

SUMMARY AND CONCLUSIONS

Experiment I

A runoff experiment was conducted during the summers of 2011 and 2012 to determine the environmental impact of granular fertilization management strategies 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 fertilization 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%. 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 fertilization treatments and year.

Digital image analysis (DIA) was used in conjunction with visual evaluation to determine percent vegetative 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 fertilization treatments or between fertilization treatments and the untreated 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 bank. Therefore, there was less coverage but a greater percent of desired species in 2012. Fertilization for the Spilt, Poultry, SU, and DAP treatments 15 DAS did not have a significant influence on vegetative coverage in either year.

The MDOT goal of 70% 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. Research on species evaluation, seeding rates, and cultural practices for summer plantings with a goal of achieving 70% coverage in 30-day is warranted. The lack of significant differences between fertilization treatments makes it difficult to evaluate each strategy. However, results do indicate that the MDOT standard rate of 13-13-13 may not increase vegetative establishment compared to a half rate. Using the Half rate fertilization strategy may also reduce the potential of nutrient loss in runoff while saving on establishment costs.

Similar to vegetative coverage results, there were no significant differences in runoff collected during natural or simulated rainfall between fertilization treatments. 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% greater in 2011 than 2012 when the respective events occurred. Therefore, the straw mulch that was applied following seeding in 2012 may have reduced runoff. 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 at 28 DAS. The lack of runoff differences may have been partially due to rainfall intensity and duration between the two events. Rainfall on 24 DAS fell in a 2 h period compared to a 24 h period for the 28 DAS event. 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 and sediment and nutrients loss in 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 quantity collected increased across sampling times for all simulations. Lack of runoff quantity differences between fertilization treatments may be due to a lack of vegetative coverage differences. Losses of TS, TN, and TP during runoff were positively correlated with runoff quantity collected.

Total solid losses in runoff from both simulated and natural rainfall events were greater in 2011 than 2012. Similar to runoff quantity results, this may be partially due to the inclusion of straw mulch at seeding in 2012. Losses during simulated rainfall events 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 largest dose of N applied at seeding was to Standard treatment plots. Total N losses in runoff for the Standard treatment were not significantly greater than from any other fertilization treatment during the first runoff event in 2011. The lack of any difference was potentially due to small irrigations applied the first 14 DAS to promote germination and the amount of organic-N in collected runoff. Therefore, rainfall event(s) following fertilization that do not produce runoff may be beneficial to promoting fertilizer reactions with the soil that aid in nutrient retention. Furthermore, reducing TS in runoff may reduce TN.

Nitrogen fertilization 15 DAS to the Split, Poultry, SU, and DAP treatments increased TN losses the first runoff event following this application. These results were apparent in both years. Lack of vegetative coverage and fertilizer incorporation 15 DAS likely increased the vulnerability of nutrient loss. 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 events were not as strongly correlated to runoff quantity or TS as was TN. The variability that existed likely overshadowed any P source or rate response that occurred between fertilization treatments. However, results indicated there were significant NH_4^+ and NO_3^--N and PO_4^{3-}-P runoff loss differences during natural and simulated rainfall events between fertilization treatments in both years.

In 2011, NH_4^+-N loss in runoff was the greatest during the first event following seeding. Furthermore, losses from the Standard treatment were significantly greater than from the Split or Half treatments during that event. This was the only significant NH_4^+ and NO_3^--N difference that occurred between the Standard and Half rates 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, fertilization at 15 DAS for the Spilt, Poultry, SU, and DAP treatments increased NH_4^+ and NO_3^--N runoff losses relative to other fertilization treatments. The delay of urea hydrolysis and subsequent nitrification by urease and nitrification inhibitors contained in SU may have increased NH_4^+ and NO_3^--N runoff losses during the second and third events. Nitrogen from readily soluble N sources such as NH_4NO_3 was transported offsite or moved into the soil profile during the first precipitation event. Nitrogen in SU continued to be released, thus, increasing runoff loss potential. Therefore, SU surface applications may increase N runoff loss potential during the establishment period.

Similar to N losses, fertilization at 15 DAS also increased PO_4^{3-}-P runoff losses. Furthermore, applying a combination of poultry litter and inorganic P may significantly increase orthophosphate in runoff during the establishment period. The effects were more prominent in runoff produced by natural rainfall. Although N and P runoff loss differences did occur between fertilization treatments in both years, total losses were minimal compared to the applied rates of 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. Soil fertility varies across locations. Therefore, soil testing should be used to develop fertilization recommendations for each site which vegetation is needed. Furthermore, 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 across a range of slopes is needed to verify these results.

Experiment II

A runoff experiment was conducted during the falls of 2011 and 2012 to evaluate the environmental impact of various mulches 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-winter 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 labeled rate for a 15% 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 treatment 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 was observed following the Paper mulch application during both years. The Wood and Blend mulch treatments were applied at the same rate, but produced greater vegetative cover than the Paper treatment. Of the hydromulches applied at 3368 kg ha^{-1} (FGM, ET-FGM, and BFM), vegetative cover for the ET-FGM treated plots was greater across both years. The MDOT goal of 70% cover in 30 days was not achieved in either year. However, straw mulch (Half and Standard) reduced time to 70% coverage compared to hydromulches. The experiment was conducted on a 15% 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 quantity produced by natural rainfall events between mulch treatments. However, the Standard mulch treatment was the most effective for reducing runoff loss in 2011. The 2012 results differed due to rainfall events having greater intensity and duration. Runoff losses with the Paper, Wood, Blend, and BFM treatments were similar to each other and greater than for the other four mulches.

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

Straw mulch was the most effective in limiting soil 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 mulch and vegetative cover for the Half, Standard, and ET-FGM treatments may have reduced TS losses compared to other mulches during 2012. Total solids in runoff produced by natural and simulated rainfall events were the greatest for the Paper, Wood, and Blend mulch treatments during both years. Similar to runoff quantity results, greater TS losses may be due to the low application rate of Paper, Wood, and Blend mulches. However, results across natural and simulated rainfall events suggest straw application at a rate of 2245 kg ha^{-1} is more effective than Paper, Wood, and Blend mulch treatments in reducing TS losses on a 15% slope.

Experiment I results suggest the greatest N and P losses occurred during the first runoff event following fertilization. Similar results were observed during Experiment II. However, results indicate timing of non-runoff producing natural rainfall and the first runoff event influence N and P loss from straw mulched 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 non-runoff producing natural rainfall events in 2011 and none in 2012. Non-runoff producing natural rainfall in 2011 likely dissolved fertilizer prills applied to the Half and Standard treatments. In 2012, losses for the Half and Standard treatments were generally greater during the first runoff event. Therefore, a broadcast application of granular fertilizer 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.

Nutrient loss differences between mulches during simulated and natural rainfall events following the first runoff event each year were similar to previously discussed TS differences. Half and Standard treatments were the most effective while Paper, Blend, and Wood treatments were the least effective in reducing TN and TP losses both years. Losses for the FGM, ET-FGM, and BFM treatments were similar in 2011. Mulch loss for the BFM treatment 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 transported with detached sediments. Therefore, limiting sediment losses may also limit TN and TP losses.

Ammonium and NO_3^--N runoff losses for the FGM, ET-FGM, and BFM treatments were less than for the Paper, Blend, and Wood treatments. However, half and standard MDOT rates of straw mulch were the most effective in limiting NH_4^+ and NO_3^--N losses in 2011. Orthophosphate runoff losses were generally less than inorganic N losses. Straw mulch was the most effective in limiting PO_4^{3-}-P losses in 2011. There were few significant differences between mulches in 2012. Losses for the Half and Standard treatments were greater than for all other treatments four of the seven runoff events. However, total PO_4^{3-}-P losses across the seven events were only 1.1 and 0.9% of applied P for the Half and Standard treatments, respectively. Therefore, losses were minimal compared to applied P across all mulch treatments.

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 sediment and nutrients in runoff. Few differences occurred between the half and standard MDOT application rates of straw. Greater differences may be observed on slopes greater than 15%. 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.

Flexible Growth Medium, ET-FGM and BFM hydromulches performed 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 in 2012. The least affected treatment by the event was ET-FGM. Generally, paper fiber and paper/wood fiber blend hydromulches were the least effective in limiting runoff losses in both years. However, further research is needed to evaluate the mulches used in this research. The influence of mulch application rate and rainfall timing on sediment and nutrient loss in runoff would provide vegetation coordinators with more comprehensive information to use when creating vegetative establishment plans.

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