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Nutrient and sediment losses from surface runoff during bermudagrass (Cynodon dactylon L.) establishment on a levee embankment

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NUTRIENT AND SEDIMENT LOSSES FROM SURFACE RUNOFF DURING BERMUDAGRASS (*Cynodon dactylon* L.) ESTABLISHMENT ON A LEVEE EMBANKMENT

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ABSTRACT

Fertilizer applications to newly constructed levee embankments during soft armor establishment may pose an increased threat to water quality. Potential nutrient and sediment loading can impact human and aquatic organisms that rely on water resources. The objectives of this study were to 1) determine the effect of grass coverage on surface runoff 2) evaluate bermudagrass establishment between water-soluble and insoluble N sources and 3) quantify nutrient and sediment losses from surface runoff during grass establishment. In 2008, fertilizer treatments consisted of sulfur-coated urea (SCU) or urea applied at 50 kg ha^{-1} to runoff collection trays installed on a 30% sloped levee embankments planted with common bermudagrass (*Cynodon dactylon* L.). Simulated rainfall was applied at 96 mm h^{-1} 14, 28, 42, 56 and 70 days after seeding (DAS). In 2009, ammonium nitrate (NH_4-NO_3) and urea-formaldehyde (UF) were applied at 100 kg ha^{-1}. Simulated rainfall was applied for 30 minutes after the onset of continuous runoff every 14 days during bermudagrass establishment. Runoff collected from storm and simulated precipitation events was analyzed for volume, NO_3-N, NH_4-N, total dissolved phosphorus (TDP), and total phosphorus (TP). Other measurements included time until runoff, sediment loss, percent vegetative groundcover, and soil volumetric water content. Nitrogen applications accelerated bermudagrass growth compared to unfertilized controls for both years of the study. In 2008 and 2009, nutrient losses from initial precipitation events were 40% to 87% greater from fertilized bermudagrass than unfertilized controls. Sediment, volume, time until runoff, and nutrient losses declined as bermudagrass coverage increased, but fertilized bermudagrass did not decrease total sediment losses and runoff volumes compared to unfertilized controls for either year. In 2008, total N losses were similar between fertilizer sources (SCU and Urea) with the greatest losses of 5 mg L^{-1} during initial rainfall events following application. In 2009, total N losses from unfertilized grass and UF-fertilized grass were 0.49 kg ha^{-1} while

losses from NH_4-NO_3 fertilized grass were 1.73 kg ha^{-1}. Water-soluble N sources and SCU resulted in the highest N losses. Application of the slow-release N fertilizer, UF, accelerated bermudagrass establishment and limited N losses.

CHAPTER 1: LITERATURE REVIEW

Levee Design and Construction

Designed to provide floodwater protection, a levee is typically constructed of heavy soils compacted into an embankment of approximately 30% slope (USACE, 2000). Compactable clay soils are preferred because their textural, hydraulic, and cohesive properties yield the capacity to withstand high stress loads while being relatively impermeable to flood water (USACE, 1992). Furthermore, during flood events, compacted clays are the least erodible soil material in regards to flood water erosion.

Surface erosion has been identified as a known cause of levee failure (USACE, 2000). Grass systems, also known as soft armoring, are utilized to mitigate the impacts of erosive forces on constructed levees. Grass ensures safety, functionality of levees, and retains accessibility for inspection and flood fighting without compromising structural integrity (USACE, 2000). For most levees, the USACE has found grass protection to be adequate in its maintenance of slopes that do not experience prolonged exposure to waves or currents (USACE, 2000).

Reduction of Sediment and Nutrient Runoff Losses

United States Department of Agriculture (USDA) Soil Conservation Service (SCS) soil and water conservation practices commonly utilizes forage and turfgrass systems to reduce soil erosion (Anderson et al. 1989; Bennett 1979). Grasses are considered conservation systems because of their relatively low volumes of surface runoff thereby reducing offsite sediment and nutrient transport (USEPA, 1983; Gross et al., 1990; Hayes et al., 1978; Welterlen et al. 1989). Bermudagrass (*Cynodon dactylon*) has been utilized as an effective conservation practice (Barnhisel et al., 1990). Because grasses are recognized as effective vegetative filter strips for erosion control, mature grass systems are considered a best management practice (BMP) for the protection of surface water quality (Anderson et al. 1989).

Grasses reduce sediment and nutrient runoff losses because of their capacity to retain large quantities of precipitation, dissipate rain drop impact forces, decrease the rate and volume of runoff water, adsorb nitrogen and phosphorous into vegetative tissue, enhance soil stability through rooting, and increase soil infiltration capacity. Grasses with dense growth habits and thatch-forming sods provide a torturous pathway for runoff water flow that reduce runoff velocities, sediment losses, and increased infiltration (Linde et al., 1995, 1998). Krenitsky et al. (1998) reported grass canopies dissipate rain drop impact energy thereby reducing sediment detachment and subsequent erosion. In addition, dense, established grass swards are capable of reducing soil-water through evapotranspiration (Ebdon et al., 1999), thus increasing infiltration capacity while absorbing soil nutrients. Petrovic (1990) reports that evapotranspiration is the largest nutrient sink in turfgrass ecosystems. Vietor et al. (2002) observed the sequestration of 50% of applied N and 88% of applied P in Kentucky bluegrass.

In a study comparing nutrient and sediment runoff losses of established tall fescue (*Festuca arundinacea* Schreb.) at various densities, runoff and sediment losses were significantly reduced compared to bare soil (Gross et al. 1991). Seeding rates of 0, 98, 244, 390, and 488 kg ha^{-1} were used to establish plots and plots were allowed to mature for 9 months before the application of simulated rainfall. The seeding rate of 0 kg ha^{-1} was the only rate significantly different in runoff initiation time from all others. There were no statistical differences in sediment loss rates between the 98, 244, 390, and 488 kg ha^{-1} seeding rates at low, medium, or high rainfall intensities (76, 94, and 120 mm h^{-1}). During the high rainfall intensity (120 mm h^{-1}), more than a six fold reduction in sediment losses was observed when comparing the 0 kg ha^{-1} rate to the 98 kg ha^{-1} seeding rate. From these results, it is evident that even lower tiller density turfgrass systems can significantly reduce sediment loss. Reduction of sediment and nutrient runoff losses observed in this study were accredited with increasing infiltration, hydraulic resistance, and enhanced surface storage capacity.

Another study evaluating the effectiveness of orchardgrass (*Dactylis glomerata*) as a conservation turfgrass, Dillaha and coworkers (1989) applied conventional fertilizer and simulated rainfall to experimental plots. This study found orchardgrass to be an effective vegetative filter strip in its reduction of incoming P in plots 4.6 m and 9.1 m wide by 61% and 79%, respectively. Reductions of 70% to 80% of incoming suspended solids were also observed.

In an effort to correlate vegetative filter strip length and quality of runoff from tall fescue (*Festuca arundinacea* Schreb.), Chaubey et al. (1994) applied poultry litter (5Mg/ha) to experimental plots and used simulated rainfall to produce surface runoff. Tall fescue was found to be an effective filter-strip vegetation in its reduction of mass transport of ammonia-nitrogen (NH_4-N), total Kjeldahl nitrogen (TKN), ortho-phosphorus (PO_4-P), total phosphorus (TP), and total suspended solids (TSS). The 3.1 m filter strip reduced TKN, NH_4-N, PO_4-P, and TP mass transport by averages of 39, 47, 40, and 39%, respectively. Reduction of TKN, NH_4-N, PO_4-P, and TP mass transport was observed in 21.4 m filter strips by averages of 81, 98, 91, and 90%, respectively.

Lee et al. (1999) evaluated the effectiveness of sediment and nutrient removal between native switchgrass (*Panicum vigatum*) and a filter strip consisting of a mixture of cool season grasses. The cool season grass mixture consisted of bromegrass (Bromus inermis), timothy (Phleum pretense) and fescue (*Festuca arundinacea* Schreb.). Incoming sediment and TP were reduced by 69% and 39%, respectively, in the 3 m switchgrass plot while the 6 m switchgrass plot removed 78% and 55%, respectively. The 3 m and 6 m cool season grass plots removed 62% and 78% of incoming sediment, respectively, and reduced TP by 35% and 49%, respectively. As for an evaluation of effectiveness, Lee et al. (1999) did not find significant differences between the two vegetative filter strip types. However, results describe the ability of grass to effectively reduce runoff losses.

Another study examining the feasibility of employing turfgrass systems to effectively control nutrient losses from swine waste effluent concluded that a bermudagrass (*Cynodon dactylon*) and ryegrass (*Lolium perenne*) filter strip was an exceptional treatment system for liquid lagoon effluents (Hawkins et al., 1998). Vegetative filter strips in this experiment were located on slopes of 5 and 11%. Swine waste effluent was applied to vegetative filter strip plots, and subsequent surface runoff water analyzed for TKN, NH_4-N, NO_3-N, and TP. Mass balances of the previous parameters were calculated to evaluate the effectiveness of the turfgrass systems. Hawkins et al. (1998) observed mass reductions greater than 34% for all parameters on both slopes except NO_3-N. NO_3-N showed an increase on the 11% slope.

McFarland and Hauck (2004) conducted an experiment to evaluate practices to reduce P runoff losses from dairy waste fields high in soil extractable P. This study compared Bermudagrass (*Cynodon dactylon*) and sorghum (*Sorghum bicolor*) plots of approximately 0.4 ha in their ability to effectively reduce edge-of-field P runoff. Following Texas permit guidelines, P and N were applied to all plots during the pretreatment period. Reductions of 51% of incoming PO_4-P and 61% of incoming TP were observed in bermudagrass plots. Consistency in either PO_4-P or TP reductions was not observed in sorghum plots.

Impacts of Nutrient Loading from Fertilized Turfgrass Ecosystems

Common turfgrass management practices incorporate fertilizer applications to enhance turfgrass establishment and growth. In addition, substantial inputs of fertilizers are necessary to maintain healthy turfgrass (Balogh and Watson, 1992; Witteveen and Bavier, 1999; Branham et al., 2005). Intensive management practices of turfgrass systems, especially on golf courses, has promoted the perception that nutrient losses to surface waters from these systems are detrimental to surface water quality (Shuman, 2002; Kohler et al., 2004; Schmidt, 2006). However, in current research, many studies report findings of negligible nutrient losses in surface runoff from mature turfgrass systems (Morton et al., 1988; Gross et al. 1990; Harrison et al., 1993; Linde et al., 1994). For instance, Gross et al. (1990) reported findings of significant nutrient losses above control from turf plots, but much less relative to agronomic fields.

Well-established turfgrass swards have been the primary focus for the majority of research concerning runoff losses from turfgrass. The experimental scenarios of these research projects do not represent a wide range of soil conditions or management scenarios. For instance, many research efforts are concerned with nutrient losses from previously established and fully developed turfgrass systems, leading others to question how data from these studies compare with losses observed during turfgrass establishment on a recently constructed golf course with exposed soil surfaces? The collective findings from the above research efforts do not definitively answer the question of whether or not fully describe the potential or times turfgrass systems nutrient losses are most detrimental to aquatic habitats. Additional research is necessary on a broader range of soil, management, and establishment phase scenarios to further evaluate the potential of nutrient losses from grass systems.

Many studies evaluate the potential detriment of nutrient losses based on USEPA's maximum contaminant levels of 10 mg L^{-1} NO_3-N for human drinking water or the USEPA's maximum limit of 0.1 mg L^{-1} for PO_4-P (USEPA, 1976). Mallin and Wheeler (2000) reported that NO_3-N concentrations as low as 0.1 mg L^{-1} can cause eutrophication. Owens et al. (1998) reported PO_4-P concentrations above 0.024 mg L^{-1} favor eutrophication. Additionally, total N and P concentrations of 1 mg L^{-1} and 25 μg L^{-1}, respectively, have been reported to increase algal growth to levels detrimental to water quality (Walker and Branham, 1992; Koehler et al., 1982; Mallin and Wheeler, 2000). Based on these findings, several researchers believe there is a need to reevaluation of the USEPA maximum contaminant concentrations of PO_4-P and NO_3-N rather than rely on USEPA drinking water standards. Aquatic toxicities may be more appropriate references for determining maximum contaminant concentrations (Easton and Petrovic, 2004).

Nitrogen and phosphorous contamination of surface waters accelerates the eutrophication and subsequent deterioration of surface water quality (Sharpley et al., 1994; Uttormark et al., 1974). Eutrophication impairs surface waters restricting their use for aesthetics, fisheries, habitats, recreation, industry, and drinking. Serious local and regional economic impacts from eutrophication are unquestionable (Sharpley, 1994).

Numerous studies have reported significant losses of N and P in surface runoff water. Gross et al. (1990) reported significant concentrations of N and P above control in runoff water from turfgrass fertilized with 220 kg N ha^{-1}. Runoff losses in this study were found to be significantly higher from fertilized turf than from unfertilized turf. In a study designed to examine the influence of overwatering and fertilization on N losses in runoff from Kentucky bluegrass (*Poa pratensis*), Morton et al. (1988) found mean concentrations of NH_4-N and NO_3-N to range from 0.36 mg L^{-1} on over-watered unfertilized turf to 4.02 mg L^{-1} on over-watered, fertilized turf.

Shuman (2002) conducted an experiment to evaluate nitrate and phosphate losses from simulated golf course fairways of bermudagrass (*Cynodon dactylon*). To further evaluate runoff losses, the roles of fertilizer application rate, antecedent soil moisture, and interval between application and rainfall event were examined. Turf plots were amended with 10-10-10 granular fertilizer with nitrogen and phosphorus source as mono-ammonium phosphate. Even at zero applied fertilizer, Shuman found dissolved phosphorus concentrations of 0.5 to 1 mg L^{-1} in runoff water. In reference to the USEPA phosphorous threshold of 0.1 mg L^{-1}, these concentrations could lead to eutrophication of surface waters. Nitrate concentrations in runoff water from all plots were well below the USEPA's 10 mg L^{-1} drinking water standard (USEPA, 1976). The low levels of nitrate found in runoff water were attributed to application of ammoniacal nitrogen. For the two fertilizer application rates, 13.8 and 15.6% of the applied phosphorous was lost in runoff water. Major flushes of fertilizer P coincided with early rainfall events. Only small amounts of P loss were observed in later rainfall events.

In an effort to limit runoff losses from established bermudagrass fairways, Cole et al. (1997) examined the potential of various buffer treatments to reduce runoff losses of pesticides and nutrients. Buffer treatments consisted of varying buffer length, mowing height, and solid-tine aerification. Buffer treatments were not found to significantly alter pesticide or nutrient runoff. Runoff losses were evaluated from heavy simulated rainfall events on bermudagrass fairway plots. Although buffers were found to be effective in reducing runoff losses, Cole et al. reported observations of nutrient concentrations from all treatments that exceeded minimum concentrations found to enhance eutrophication. Averaged losses of nutrients were 11% of the amount applied. From the treatment containing no buffer, phosphate concentrations in runoff from fertilized bermudagrass turf were as high as 9.57 mg L^{-1} and 8.14 mg L^{-1} in July and August precipitation simulations, respectively. Cole et al. also found greater nutrient losses from plots receiving urea fertilizer compared with plots receiving a sulfur-coated urea fertilizer. Sulfur-coated urea based fertilizers contain less soluble N than urea fertilizers and thus have less N that is readily available to dissolve into runoff water. Cole et al. conclude by recommending the use of fertilizers, such as sulfur-coated urea, with lower water solubility and stronger absorption to reduce potential of nutrient runoff.

Using sloped plots of creeping bentgrass (*Agrostis palustris* Huds.) and perennial ryegrass (*Lolium perenne* L.), Linde and Watschke (1997) assessed nutrient and sediment runoff losses from turf while investigating the influence of vertical mowing on sediment transport.

Treatments consisted of plots of perennial ryegrass and creeping bentgrass. This experiment consisted of 8 runoff events each approximately 2 weeks apart. Four of these forced runoff events were preceded by fertilizer application while vertical mowing preceded the other four runoff events. Linde and Watschke (1997) reported significant increases of phosphate and TKN concentrations and losses from all forced runoff events preceded by fertilizer application. During these events, 11 and 2% of applied P and N were lost in surface runoff water. Nutrient losses were reported as consistently lower from all other runoff events and were observed to be less than the USEPA drinking water standard of 10 mg L^{-1}. However, many of these observations were above the value of 1 mg L^{-1} reported by Walker and Branham (1992) and Koehler et al. (1982) to be potential detrimental to water quality. Linde and Watshke (1997) comment that turf systems are vulnerable to significant losses of nutrients when surface runoff occurs soon after fertilizer application.

Easton and Petrovic (2004) conducted a mass balance, 2 year field study to investigate the impacts of fertilizer nutrient source on runoff and leachate losses from mixed plots of Kentucky bluegrass (*Poa pratensis*) and perennial ryegrass (*Lolium perenne*). Turf plots were also used to examine nutrient and sediment losses through time during establishment. Easton and Petrovic (2004) define establishment in this study as the first 20 weeks after seeding. Nutrient sources included three organic sources (dairy, swine, and biosolid) and two synthetic sources (readily available urea and a sulfur-coated urea, slow-release formula). Treatments consisted of five fertilizer sources with two application rates and an unfertilized control. Volumes of runoff water were collected from 33 natural precipitation events, and composite leachate samples were collected monthly. High antecedent moisture conditions, greater than 40% of total soil pore space, contributed to the highest volumes of surface runoff water. The first of these precipitation events occurred approximately one month after the seeding date. Sediment losses were observed from all runoff plots during the establishment phase. After turf establishment, approximately 20 weeks, sediment losses were only reported from unfertilized controls. Averaged runoff volumes were also found to be higher during initial 20 weeks of the study with the first runoff event producing the highest percent of precipitation as runoff and some of the highest N and P runoff concentrations. Easton and Petrovic (2004) attributed these losses to inadequate turfgrass shoot density. Although turfgrass was found to reduce concentrations of NO_3-N in runoff and leachate with time, NO_3-N levels observed in this study could be detrimental to the health of aquatic organisms. Easton and Petrovic regard that fertilizer applications during the establishment phase of turfgrass pose the highest threat to water quality. However, enhancement of grass establishment speed and growth with fertilizer application was found to reduce overall losses. Total N and P losses were observed to be equal or higher on many occasions from the unfertilized control. After the establishment phase, fertilizer applications can effectively reduce N and P loading of surface waters.

Nutrient Cycles

Nitrogen

Forms of N found in soil systems include the following: organic N, NH_4-N/$NH_{3(g)}$-N, nitrite N (NO_2-N), NO_3-N, nitrous oxide (N_20-N), and dinitrogen gas ($N_{2(g)}$). Atmospheric and industrial fixation of $N_{2(g)}$ reduces $N_{2(g)}$ to a biologically available from, NH_3-N. Industrial fixation, or the "Haber-Bosch process", reduces $N_{2(g)}$ to NH_3-N ($N_2 + 3H_2 \rightarrow NH_3$). Ammonia is a common source of fertilizer and is applied to soils by direct injection of anhydrous ammonia or by the addition of ammonium salts such as ammonium nitrate or ammonium sulfate. Fertilizers also add some organic N to soils. Urea-N is a common constituent of N in fertilizer. Organic N, commonly urea, applied to soils is subject to ammonification, and organic N is oxidized to NH_3-N. In upland soils, ammonium can be assimilated into microbial biomass and immobilized, fixed onto soil particles, volatilize as $NH_{3(g)}$ (in higher pH soils), or be subject to mineralization/nitrification. Once applied to upland/aerobic soils, most ammonium is rapidly oxidized by nitrification to nitrate. In upland soils, fates of nitrate include plant uptake, immobilization by the microbial biomass, denitrification, and transport by leaching or surface runoff water. Under anaerobic conditions, denitrification reduces NO_3-N to $N_{2(g)}$ which can move by diffusion in the gas phase back into the atmosphere (Reddy and DeLaune, 2002; Evangelou, 1998)

Phosphorus

General forms of P found in soils include organic P, inorganic/solution P, and inorganic sediment bound P (labile and non-labile P) found as specific compounds. A high concentration of organic P is stabilized in humic compounds and becomes available through mineralization of organic matter. Solution P is soluble, mobile, and biologically available and chemical species include phosphates such as PO_4^{-3}-P, HPO_4^{-2}-P, and $H_2PO_4^{-1}$-P. Inorganic sediment bound P is not immediately biologically available and includes the general categories of aluminum phosphates (Al-PO_4), iron phosphates (Fe-PO_4), and calcium phosphates (Ca-PO_4). Labile sediment bound P is not strongly sorbed to the soil and is in ready equilibrium with solution P. Non-labile sediment bound P constitutes the greatest fraction of soil P. Although non-labile can react chemically to become labile and solution P, most will remain in the non-labile form indefinitely. As dictated by the equilibrium between organic P, solution P, and inorganic bound P, only a small amount of P is in the soluble and biologically available inorganic form.

Phosphorus inputs to the soil are primarily from fertilizer application of inorganic soluble P or application of organic P such as manures. Fertilizer P, inorganic soluble P, is produced from treating phosphate bearing minerals with acid to produce. Lesser amounts may be added to soil by atmospheric deposition (particulate deposition and sea spray deposition) or sedimentation.

Microbial processes involved in weathering of phosphate minerals to make original P sources available are not important P additions to soil. Fates of soluble P in the soil include plant uptake, sorption to particulate surfaces, immobilization by microbial biomass, and transportation. Following fertilizer P addition to soil, water dissolves P, and soil solution P is increased. Most of the P now in solution will subsequently react with soil minerals (sorption processes) and move into the labile P pool where it can later become available as solution P decreases and the equilibrium allows labile P to move into solution (Evangelou, 1998). Phosphorus transport (labile, non-labile and soluble P) is primarily due to surface water runoff and erosion but may also occur via leaching and subsequent subsurface flow. Phosphorus has no significant transformation and transport through a gas phase (Reddy and DeLaune, 2002).

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CHAPTER 2: NUTRIENT AND SEDIMENT LOSSES FROM SURFACE RUNOFF DURING BERMUDAGRASS (*Cynodon dactylon* L.) ESTABLISHMENT ON A LEVEE EMBANKMENT

Introduction

The United States Army Corps of Engineers (USACE) defines a levee as "an embankment whose primary purpose is to furnish flood protection from seasonal high water and which is therefore subject to water loading for periods of only a few days or weeks a year (USACE, 2000)." Designed to provide floodwater protection, a levee is typically constructed of heavy soils compacted into an embankment of approximately 30% slope. Although compacted soils are excellent materials for structural integrity that limit water infiltration, heavy soils compacted into slopes with extreme gradients are prone to sediment and nutrient transport via surface runoff during precipitation events.

Reduction in sediment losses are currently mitigated through the use of soft armoring otherwise known as vegetative cover. Several studies have reported mature vegetation greatly reduces surface runoff occurrence, severity and pollution (Easton and Petrovic, 2004; Linde and Watschke, 1996; Gross et al., 1990; Daniel et al., 1979). To develop erosion resistance rapidly, fertilizers are applied to accelerate vegetation establishment. Current USACE grass establishment specifications require a broadcast surface application of soluble N-P-K in excess of 50 kg N-P-K ha^{-1} during planting when insufficient grass coverage/protection of the levee surfaces exists.

The use of fertilizers to enhance grass growth increases the potential for nutrient losses into surface waters. Construction sites have been identified as significant non-point sources of pollution (Balogh et al., 1992; Daniel et al., 1979; Kuo et al., 1988; Schuler, 1987). Fertilizer applications to newly constructed levee embankments could have adverse environmental impacts. Easton and Petrovic (2004) identified the establishment phase as the period that poses the greatest threat for nutrient movement. Most nutrient movement occurs within the initial runoff events with patterns of decreasing losses (Gaudreau et al., 2002; Vietor et al., 2004). Implementation of best management practices, such as application of water-insoluble fertilizer sources, has been shown to reduce potential nutrient losses (Easton and Petrovic, 2004).

Nitrogen and phosphorous contamination of surface waters accelerates the eutrophication and subsequent deterioration of surface water quality (Sharpley et al., 1994; Uttormark et al., 1974). Nutrient concentrations of 1 mg N L^{-1} and 25 µg P L^{-1} have been shown to increase algal growth and reduce water quality (Walker and Branham, 1992; Koehler et al., 1982; Mallin and Wheeler, 2000). Eutrophication impairs surface waters restricting their use for aesthetics, fisheries, habitats, recreation, industry, and drinking. Therefore, preservation of water quality has become a high priority issue for the USEPA.

The purpose of this research is to establish best management practices concerning bermudagrass establishment on levee embankments. The objectives were to 1) determine the duration of bermudagrass establishment necessary to effectively reduce runoff losses of sediment, N, and P from levee embankments and 2) determine if nutrient losses in runoff water from levee embankments can be reduced through the application of a slow-release fertilizer.

Materials and Methods

Site Characterization

Field plots were installed on the western slope of the Bonnet Carré Spillway levee near LaPlace, LA on 2008 July 5 (latitude = 30°, 2.4 minutes North; longitude = 90°, 25.8 minutes West). The 30% sloped embankment was constructed from a sandy loam consisting of 55.4% sand, 29.9% silt, and 14.7% clay. Water bodies adjacent to the levee included the Bonnet Carré Spillway that empties into Lake Pontchartrain located on the flood side (East) and a bayou on the protected side (West). Long-term precipitation data (30 yr) recorded for the months of August through October averages 532 mm of total precipitation (LA Office of State Climatology, 2009). Environmental conditions during the runoff monitoring period are described in Figure A.1.

Runoff Collection Plot Construction

Runoff was collected using stainless steel trays (15.25 cm x 208.5 cm x 75 cm) with an internal area of 1.5 m^2. At the base of each tray, runoff collection troughs (8.5 cm x 75 cm x 5 cm) were located on the down slope side. A stainless steel bar bent at a 90° angle was placed inside the down-slope of the tray to ensure runoff movement into the collection trough. The right side of each collection gutter contained a runoff water exit port 6.3 cm in length with a diameter of 2.5 cm. Trays were installed using a level to ensure proper water flow through gutter exit ports. To prevent rainfall from collecting directly in the troughs, sheet metal was secured over each trough. Runoff trays were installed at a depth of 8 cm below the soil surface and plastic tubing (2.5 cm diameter) connected the trays' exit ports to 3 meters of polyvinyl chloride (PVC) tubing running down slope into covered collection reservoirs. Collection reservoirs (117 L) were installed below ground level to allow gravity induced water flow during natural and simulated runoff events.

Vegetation Establishment and Fertilizer Treatments

Common bermudagrass (*Cynodon dactylon* L.) seed was sown at 195.3 kg PLS ha^{-1} (4 lbs 1000 ft^{-2}) on 2008 August 8 within each tray. Treatments were applied at seeding and consisted of 50 kg N ha^{-1} from either water soluble urea or sulfur-coated urea, a slow- release fertilizer, and unfertilized control.

Rainfall Simulation

Experimental rainfall simulation followed the methods outlined by the United States Department of Agriculture's (USDA) National Phosphorous Research Project's (NPRP) protocol for rain simulation (USDA, 2008). Simulated rainfall was applied to plots using a Tlaloc 3000

Rainfall Simulator (Joern's Inc. in West Lafayette, IN), a field mobile unit based on the designs of Miller (1987) and Humphry et al. (2002). The Tlaloc 3000 was fitted with a Spraying Systems Co. Fulljet ½HH SS 50WSQ nozzle with a spray angle of 104° (±5%) and delivered 16.25 L per minute at 7 psi (USDA, 2008). The nozzle and associated plumbing assemblies are mounted to a cubed shaped aluminum frame (3m x 3m x3m) that elevated the nozzle 3 m above the soil surface. Two leg extensions were installed on the down-slope corners of the simulator to level the apparatus for more uniform raindrop distribution.

Water applied during rainfall simulation was obtained from a municipal water supply and transported to the research site in a 300 gal polycarbonate tank. Water was supplied to the rainfall simulator via a utility pump (Water Ace® Portable Utility Pump rated at 151 L min^{-1}). Water temperature was monitored during calibration and simulations (27°±1° C).

To approximate local conditions, a rainfall intensity for a ten-year, one-hour precipitation extreme of 96 mm h^{-1}, was applied during all rainfall simulations (LA Office of State Climatology, 2009). The simulator was calibrated to deliver 2406.7 mL min^{-1} at 9 psi. Rainfall simulations commenced 14 DAS with subsequent simulations at 42 and 70 DAS.

Simulated runoff events consisted of 30 minutes of continuous runoff from plots. Initiation of surface runoff was marked at the start of a continuous trickle of water into collection reservoirs with runoff water collected *in toto* for 30 minutes.

Data Collection

Environmental and Plot Data

On 2008 August 8, soil samples were collected outside and adjacent to each runoff collection tray. Soil samples were analyzed by the Louisiana State University (LSU) AgCenter Soil Testing and Plant Analysis Lab (LSU STPAL) for N, P, K and pH (Table 2.1). After completing the final simulation 70 DAS, soil samples were collected within each tray and analyzed.

Table 2.1. Soil analysis from samples taken at seeding and after final simulation, 70 DAS.

	AUGUST 6, 2008 (0 DAS)				OCTOBER 22, 2008 (70 DAS)			
Treatment	**N**	**P**	**K**	**pH**	**N**	**P**	**K**	**pH**
	%	**mg kg^{-1}**	**mg kg^{-1}**	**1:1 Water**	**%**	**mg kg^{-1}**	**mg kg^{-1}**	**1:1 Water**
CONTROL	**0.34**	**60.8**	**396.4**	**8.2**	**0.26**	**29.3**	**392.6**	**7.9**
SCU	**0.35**	**71.4**	**492.8**	**8.1**	**0.28**	**52.6**	**414.7**	**8.2**
UREA	**0.33**	**64.4**	**438.3**	**8.3**	**0.27**	**52.0**	**419.9**	**8.2**

Source water for each simulation was collected and analyzed for conductivity, pH, ammonium (NH_4-N) and nitrate (NO_3-N), total dissolved phosphorous (TDP), total phosphorous (TP), and concentrations of cations that could potentially react with phosphate and/or nitrate ions. Water source analysis data were used to correct nutrient loss data from plots.

For each simulated runoff event the following data were collected: volumetric water content (m^3 m^{-3}) (data not shown) (EC-5 soil moisture sensors, Decagon Devices Inc., Pullman, WA); visual percent vegetative ground coverage; time for runoff to occur; total runoff volume; temperature; and previous rainfall. Percent coverage was assessed using a scale of 0 to 100% with 0% = bare ground and 100% = no soil visible. Total runoff volume was determined after 30 min runoff and composite samples collected.

In addition to the simulated runoff events, six natural runoff events occurred during the 70 day monitoring period. For each naturally occurring runoff, percent vegetative ground cover, total runoff volume, and total rainfall were collected and recorded.

Runoff Water Data Analysis

Runoff water samples obtained from simulated and naturally occurring runoff events were analyzed for TDP, TP, and NH_4-N and NO_3-N concentrations and sediment. Water samples were stored at 4°C with analysis occurring within 48 hr after collection. Samples were prepared for TDP analysis by filtering runoff samples through a 0.45 μm filter. Potassium persulfate digestions as described by Pierzynski (2000) in *Methods of P Analysis for Water and Soil* were used to prepare samples for TP analysis. Both TDP and TP were analyzed by the Louisiana State University STPAL using Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES). Nitrogen (NH_4-N and NO_3-N) analysis was performed by the LSU's Ag Chemistry Department using a modified version of Environmental Protection Agency's (EPA) Method 351.2 (prepared by Bran Luebbe). Nutrient runoff data is presented as concentration (mg L^{-1}) and as a mass loss. Sediment analysis was performed through oven drying 40 mL runoff water samples with weight recorded.

Data Treatment and Statistics

The three fertilizer treatments were arranged in a randomized complete block design (RCBD) with four replications for a total of 12 plots. Data were analyzed according to the Analysis of Variance (ANOVA; α=0.05) using the mixed procedure in the statistical software SAS (SAS Institute, 2000). Post-hoc testing was performed using a Fisher's protected least significant difference (Fisher's LSD; α=0.05). Data for DTP, TP, and Total N are reported not only as concentration but mass loss to account for discrepancies in total runoff volume over time. Simple linear regressions (SLR; α=0.05) were used to evaluate correlations between percent vegetative groundcover and runoff data (sediment, time until runoff, runoff volume and infiltration rate) for each fertilizer treatment. Raw data for sediment, time until runoff and infiltration rate were transformed using the natural log to normalize and homogenize residuals before regression analyses were performed.

Results and Discussion

Effects of Bermudagrass Cover on Surface Runoff

Bermudagrass vegetative cover affected surface runoff occurrence and severity. Parameters such as time for runoff to occur and infiltration capacity prior to runoff were positively correlated with vegetative ground cover (Figures 2.1 and 2.2). At 50% to 60% ground cover, time until runoff increased over 4x from 60 sec for <10% ground cover. Infiltration capacity increased from 0.19 cm to 0.68 cm for 10% and 60% ground cover, respectively. Runoff volume, expressed as a percent of simulated rainfall over the thirty minute simulation, decreased linearly with increasing bermudagrass ground cover (Figure 2.2). Volume losses decreased from 44 L and 55% of applied rain at <20% ground cover to 7 L and <10% of applied rain at 90% ground cover (Table 2.2).

Bermudagrass cover in excess of 50% delayed the onset of runoff and subsequently reduced runoff volumes through disrupted water flow, increased infiltration and higher evapotranspiration rates (Ebdon et al., 1999; Linde et al., 1998). Higher grass shoot densities provide greater physical barriers to runoff that slow runoff velocity to allow greater infiltration (Linde et al., 1995, 1998; Easton and Petrovic, 2004; Gross et al., 1990, 1991; Krenitsky et al., 1998). Ebdon et al. (1999) reported efficient reduction in soil moisture from grass evapotranspiration. Decreased antecedent soil moisture directly affects sward infiltration capacity.

Although runoff water is not directly detrimental to water quality, surface runoff is a major mode for dissolved nutrients and sediment bound nutrient transport (Petrovic, 1990). Brown et al. (1997) found nitrate concentration in runoff water to be related to runoff volume. Therefore, cultural practices that would accelerate vegetative establishment should result in faster runoff resistance and reduced pollutant transport.

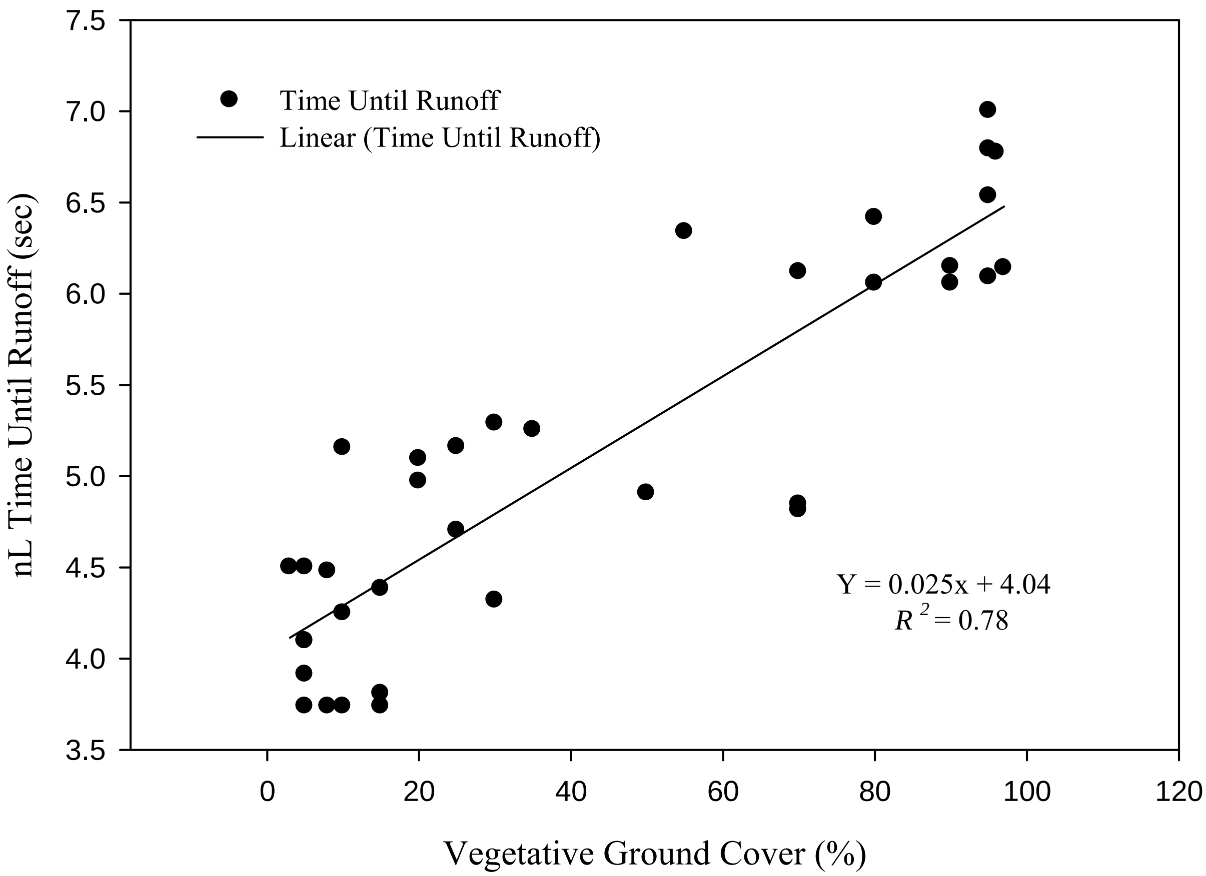

Figure 2.1. Time until runoff as a function of percent vegetative ground cover. Significant at α = 0.05. Separate regression lines for individual treatments are not shown as slopes were not different (α = 0.05) (Table 2.2).

Table 2.2. Volume and sediment losses during bermudagrass establishment (August 6 - October 22, 2008).

DAS	Rainfall	Sediment			Volume		
		Control	Urea	SCU	Control	Urea	SCU
	mm	———— kg ha^{-1} ————			————— L —————		
8	110	2404a	2222a	2261a	31a	31a	31a
12	50	488a	493a	961a	22a	21a	20a
14 §	49 - 51	1840a	1650a	1875a	45a	42a	47a
19	54	109a	122a	80a	10a	9a	8a
28	24	1585a	1484a	1740a	104a	99ab	94b
37	60	2232a	3868b	2001a	39a	35a	38a
42 §	50 - 54	1386a	1214a	841a	37a	35a	35a
45	17	200a	226a	150a	23a	24a	25a
70 §	59 - 78	154a	48a	49a	23a	24a	25a
Totals		10397a	11325a	9958a	333a	320ab	323b

§ Simulated rainfall event.

‡ Numbers followed by the same letter within a row are not significantly different according to Fisher's LSD at α = 0.05.

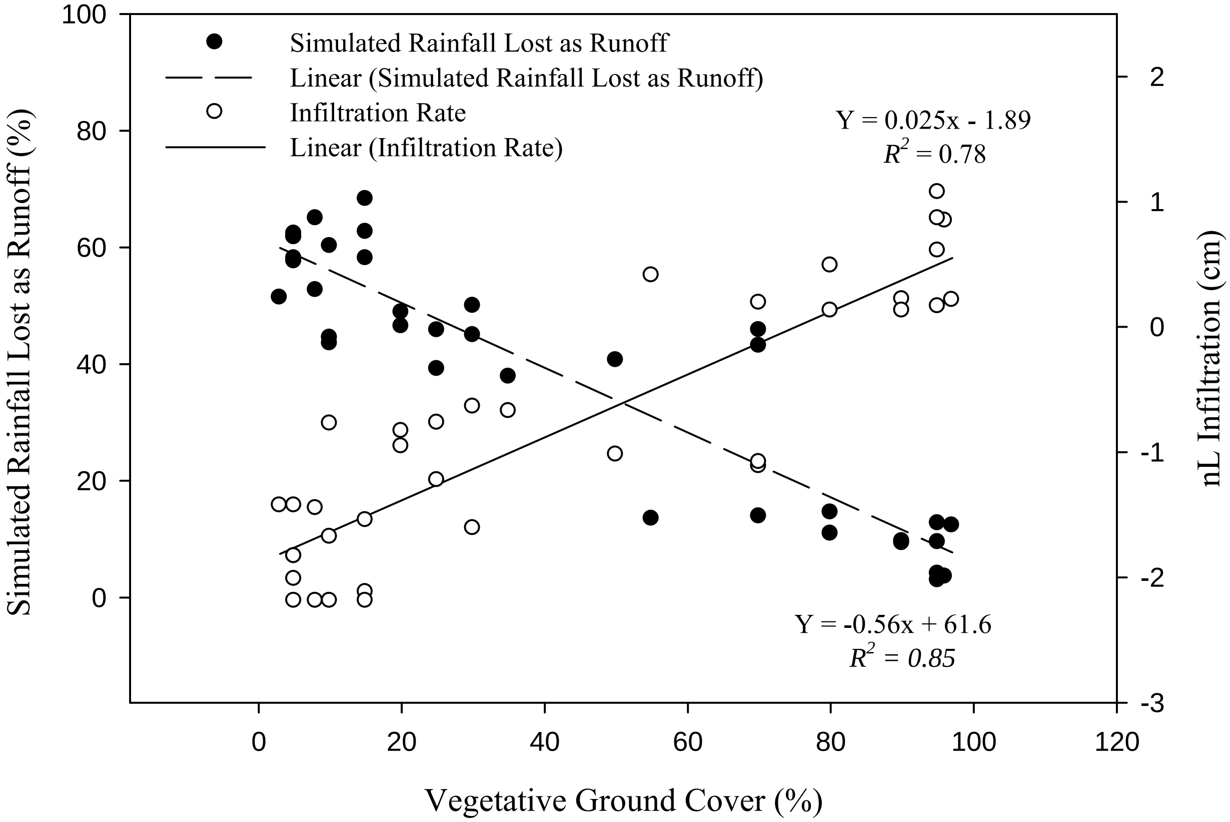

Figure 2.2. Soil infiltration and percent of simulated rainfall lost as runoff water as a function of percent vegetative ground cover. Significant at α = 0.05. Separate regression lines for individual treatments are not shown as slopes were not different (α = 0.05) (Tables 2.3 and 2.4).

Sediment Losses

Sediment losses (natural log losses) decreased linearly with increasing bermudagrass ground cover (Figure 2.3). Similar relationships have been reported by Elwell and Stocking (1976), Hussein and Laflen (1982), and Foster et al. (1981). Sediment losses were reduced from 1746 kg ha^{-1} from bare ground (14 DAS) to 262 kg ha^{-1} from 50% ground cover (45 DAS). At 95% bermudagrass ground cover, losses were reduced to only 5% of initial, 86.6 kg ha^{-1}. Sediment losses from bare ground (1746 kg ha^{-1}) were ~10x greater than data reported by Gross et al. (1991) and Vietor et al. (2004) from similar rainfall volumes. In contrast, rainfall intensity of these studies was 20% lower with 8% slopes. Total sediment losses and sediment losses per event were similar between fertilizer treatments (Table 2.2).

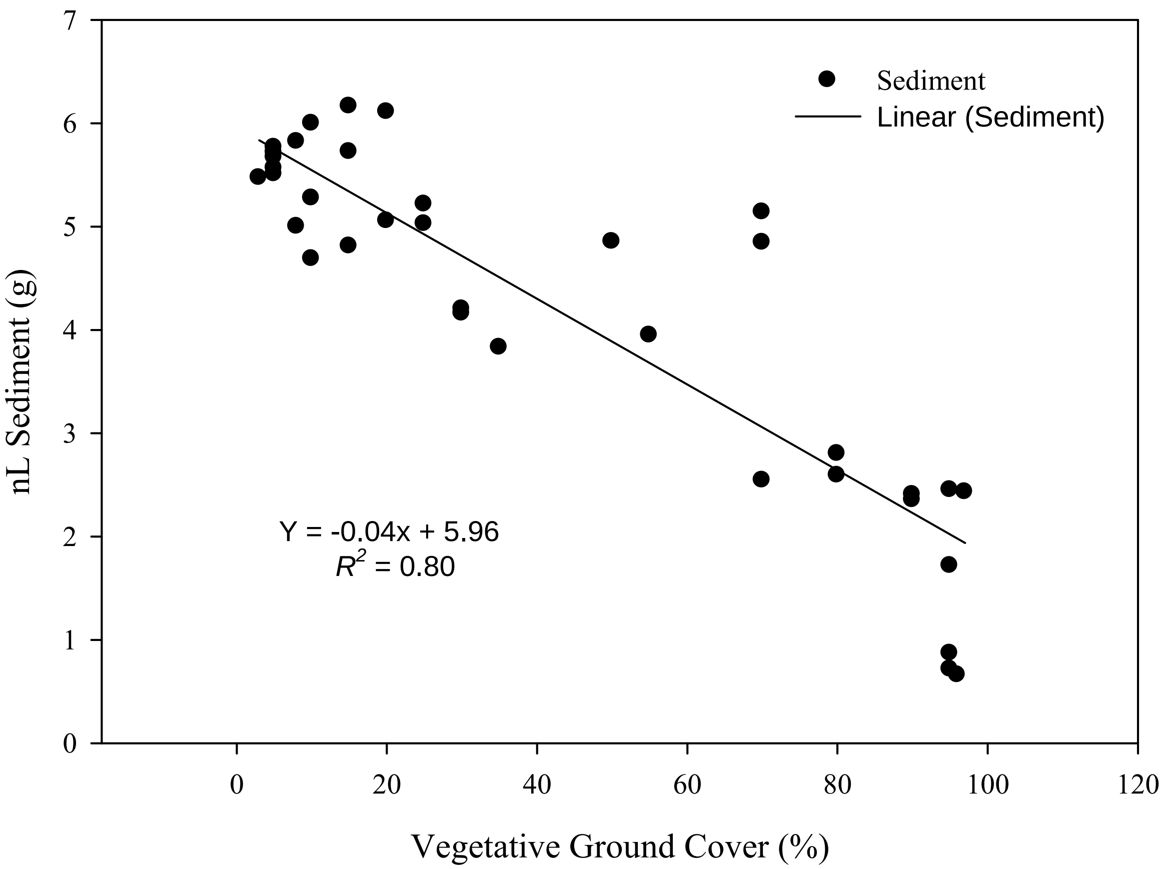

Figure 2.3. Sediment loss as a function of percent vegetative ground cover. Significant at α = 0.05. Separate regression lines for individual treatments are not shown as slopes were not different (α = 0.05) (Table 2.6).

Increased vegetative growth has been shown to reduce sediment losses in several ways. Grass shoots and leaves intercept rainfall and abate raindrop impact energy, reducing soil particle dislodgement from the soil surface (Elwell and Stocking, 1976). Increased shoot densities reduce runoff velocity, thereby reducing the erosive impact of runoff (Linde et al., 1995, 1998). Grass evapotranspiration can reduce soil moisture and thus, increase infiltration capacity and reduce runoff and erosion (Ebdon et al., 1999). Increased grass height reduces impact of soil splash, decreasing sediment detachment (Baver, 1956).

Bermudagrass Establishment

Fertilizer treatments accelerated bermudagrass establishment (Figure 2.3). Johnson (1973) reported a similar result with a 17% increase in bermudgrass coverage fertilized during establishment. Fertilized bermudagrass attained >50% groundcover 50 DAS compared to ~62 DAS for unfertilized bermudagrass. Vegetative groundcover of unfertilized bermudagrass consistently lagged fertilized bermudagrass beginning 18 DAS until the end of the study. At 70 DAS, bermudagrass ground covers were 92%, 93% and 75% for urea-fertilized, SCU-fertilized, and unfertilized bermudagrass, respectively.

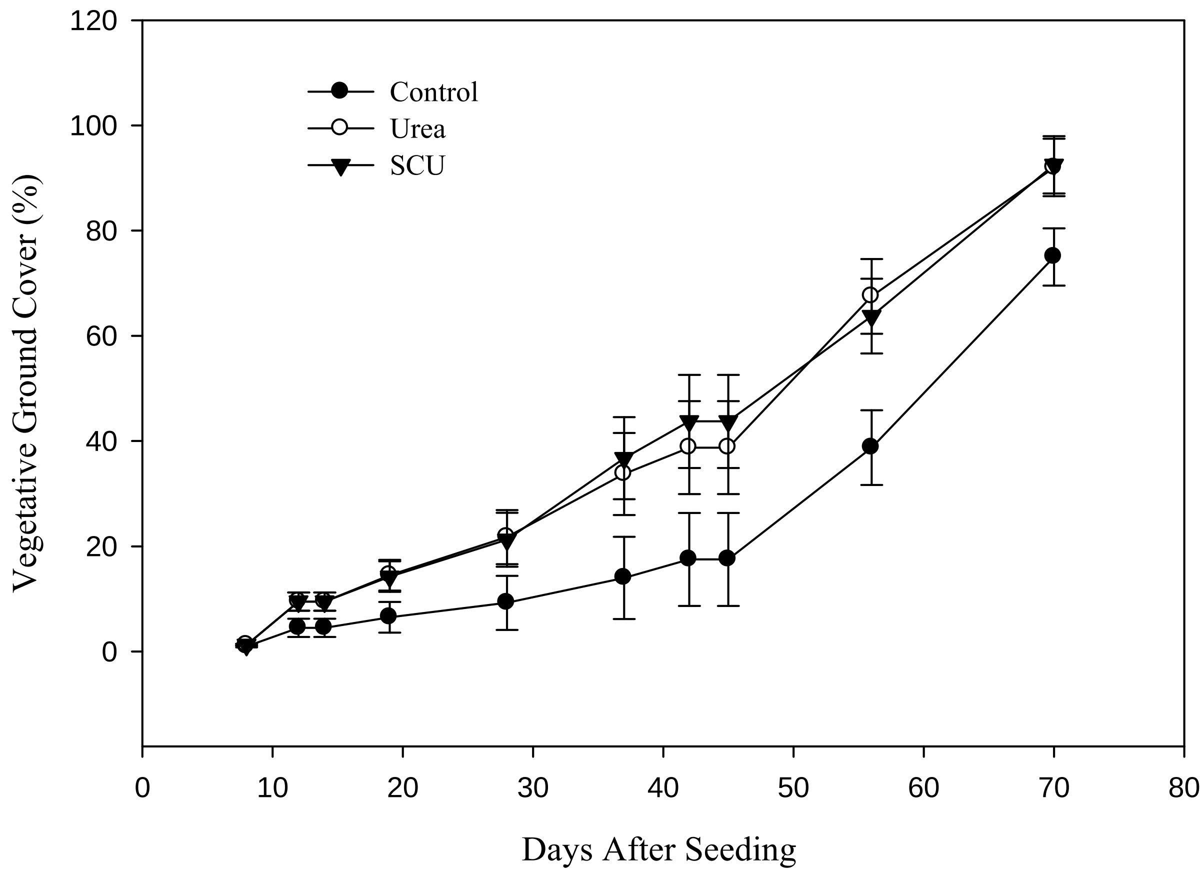

Figure 2.4. Bermudagrass vegetative ground cover as a function of time. Each point represents a mean of four replicates.

Fertilizers are commonly applied to accelerate bermudagrass growth to achieve canopy closure (Dudley, 1969; McCarty and Miller, 2002; Parkins et al., 1993). Nitrogen has been shown to effect sward characteristics including density, shoot growth, root growth, and plant environmental stress tolerance (Parkins et al., 1993). In this study, no differences in grass establishment patterns were observed between urea and SCU. Parkins et al. (1993) reported grass response between SCU and water-soluble N to be similar; most likely as a result of environmental conditions coupled with the release characteristics of SCU. According to Volk and Horn (1975) several grass species exhibited faster growth when fertilized with SCU compared to other slow-release N formulations. Higher temperatures and rainfall during the monitoring period affected N availability of SCU (Figure A.1).

Nutrient Losses

Phosphorus Losses

Nutrient losses are reported on a mass basis to account for variable runoff volume losses during establishment (Table 2.3). Total DP and TP losses were higher from fertilized grass for multiple runoff events but similar between fertilizer sources. In the first three runoff events after fertilizer application, TDP and TP were 93% and 26% greater from fertilized grass than unfertilized grass, respectively. Gaudreau et al. (2002) and Vietor et al. (2004) also reported high DP losses from initial runoff events with DP losses 95% greater from fertilized grass (P at 50 kg ha^{-1}). Phosphorus losses per runoff event decreased throughout the monitoring period.

Table 2.3. Nutrient masses (N, TDP, and TP) lost in runoff during bermudagrass establishment (August 6 - October 22, 2008).

DAS	Rainfall	Total NO_3-N + NH_4-N			Total TDP			Total TP		
		Control	Urea†	SCU†	Control	Urea†	SCU†	Control	Urea†	SCU†
	mm	kg ha^{-1}								
8	110	0.317a	0.987b	1.130b	0.042a	0.577b	0.577b	2.115a	3.030b	2.734ab
12	50	0.330a	0.633b	0.771b	0.041a	0.183b	0.205b	0.508a	0.820a	0.730a
14 §	49 - 51	0.291a	0.391a	0.466a	0.007a	0.016a	0.037a	1.977a	2.279ab	2.559b
19	54	0.003a	0.021a	0.013a	0.007a	0.034a	0.029a	0.108a	0.128a	0.107a
28	24	0.245a	0.155a	0.249a	0.253a	0.378b	0.371b	1.120a	2.264b	2.166b
37	60	0.175a	0.113a	0.266a	0.108a	0.134a	0.170a	1.405a	1.140a	1.226a
42 §	50 - 54	0.039a	0.021a	0.083a	0.007a	0.024a	0.024a	1.234a	1.048a	1.225a
45	17	0.051a	0.047a	0.045a	0.132a	0.182b	0.176b	0.476a	0.553a	0.539a
70 §	59 - 78	0.134a	0.086a	0.109a	0.0004a	0.005a	0.005a	0.129a	0.056a	0.056a
TOTALS		1.585a	2.453ab	3.132b	0.596a	1.532b	1.591b	9.073a	11.318a	11.341a

§ Simulated rainfall event.

‡ Numbers followed by the same letter within a row are not significantly different according to Fisher's LSD at α = 0.05.

† All treatments except the unfertilized control consisted of single N applications of 50 kg ha^{-1}.

Phosphorus transport during runoff events reduced labile and solution P reducing the amount of soil P available for transport in runoff. During bermudagrass establishment, increases in vegetative ground cover and secondary growth factors such as shoot and root densities, biomass, height, and leaf area require plant uptake of P and thus, reduced soil P.

Total TDP losses were greatest from fertilized grass while differences in TP were not significant. Similar total TP losses can be attributed to large initial sediment losses from insufficient bermudagrass ground. Differences in TDP losses appear to be directly related to the availability of larger amounts of soluble P from fertilizer applications.

With only one exception, TP concentrations were equal to or above the USEPA's maximum contaminant level of 0.1 mg L^{-1}, and TDP concentrations were above 0.024 mg L^{-1} reported to favor eutrophication (Owens et al., 1998; USEPA, 1976).

Nitrogen Losses

Similar to P losses, the greatest N losses occurred during the initial runoff events. Fertilized grass lost up to 72% more N than unfertilized grass (Table 2.3). Within 14 DAS, N losses from fertilized grass were 82% (2.37 kg ha^{-1}) and 75% (2.01 kg ha^{-1}) of total N lost from SCU and urea-fertilized grass, respectively. Large N losses following fertilizer application have been reported by Easton and Petrovic (2004), Gaudreau et al. (2002), and Linde and Watschke (1997). Vietor et al. (2004) similarly reported differences in nutrient losses between fertilizer sources following the first runoff event. Total N losses were highest for SCU-fertilized grass, 3.13 kg ha^{-1}, compared to 2.45 kg ha^{-1} and1.59 kg ha^{-1} for SCU-fertilized grass and unfertilized grass, respectively. Total N losses never exceeded 5.5% of applied N.

Decreases in N losses throughout grass establishment occurred with decreased runoff volumes as result of increased vegetative cover. Decreases in N losses can be attributed to reductions in soil N concentrations from plant uptake, microbial biomass immobilization, leaching, surface runoff, denitrification, and volatilization (Reddy and DeLaune, 2008; Johnson et al., 1995). All N concentrations in surface runoff were ≥0.1 mg N L^{-1} reported by Mallin and Wheeler (2000) to accelerate eutrophication, and losses within 14 DAS were >1 mg L^{-1} reported to favor detrimental algal growth (Walker and Branham, 1992; Koehler et al., 1982).

Nitrogen losses did not differ between SCU and urea-fertilized grass. Parkins et al. (1993) reported N release from SCU to be well above other slow release products and water soluble N. Quiroga-Garza et al. (2001) reported similar N recovery in plant tissues and leachate NO_3-N losses between SCU and urea fertilizers.

Fertilization with SCU provided no benefit in reducing nutrient transport via surface runoff. In contrast, Easton and Petrovic (2004) reported slow-release N (synthetic or organic) such as SCU ultimately decreased water contamination. However, in this study, the total N and TDP losses from unfertilized grass were significantly less compared to fertilized grass. Under our experimental conditions and those of Quiroga-Garza et al. (2001) and Parkins et al. (1993), N availability from SCU was similar to urea, thus, the slow release properties of SCU did not reduce nutrient transport.

Easton and Petrovic (2004) suggest fertilization during establishment preserves water quality without mentioning alternate solutions such as mulches or fertilizer application timing. If Easton and Petrovic (2004) found a correlation between infiltration capacity and shoot density, then fertilization after sufficient grass growth could reduce nutrient transport due to increased plant nutrient uptake potential. Parkins et al. (1993) found SCU to be the most soluble out of nine slow-release N fertilizers tested. Linde and Watschke (1997) concluded that timing of fertilizer application in relation to rain events could be critical in reducing N losses. Mostaghimi et al. (1994) reported reductions in runoff volume, sediment, N, and P from mulch applications.

Conclusions

Levee embankments are prone to surface runoff and nutrient and sediment loading into adjacent water bodies. Unlike, previous research which commonly concludes pollutant mitigation by buffer zones is likely before runoff can reach surface waters (Easton and Petrovic, 2004); levees typically border water features with little to no buffer zones. Therefore, the hypothesis of increasing grass growth through fertilizer application in order to attain faster surface protection from runoff may have unintended consequences.

Although trends of increasing time for runoff to occur, higher infiltration rates, decreased runoff volumes and reduced sediment losses corresponded with increasing bermudagrass cover, urea and SCU did not accelerate bermudagrass growth sufficiently to compensate for large initial sediment losses or offset increased total N and P lost to runoff compared to unfertilized controls. Data provided no indication of decreased solubility of SCU when compared to urea.

Current protocols to seed and fertilize levees in a single application represent a threat to the environment. Best Management Practices concerning grass establishment on levee embankments should focus on planning fertilizer applications according to soil testing (P) and rainfall as well as applying fertilizers after the existence of vegetative ground cover (≥50%) sufficient to reduce the severity of runoff losses. Further testing is needed to evaluate combinations of slow-release N sources, mulches, and application timings.

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CHAPTER 3: FERTILIZER SOURCE EFFECT ON SURFACE RUNOFF LOSSES DURING BERMUDAGRASS (*Cynodon dactylon* L.) ESTABLISHMENT ON A LEVEE EMBANKMENT

Introduction

Past hurricane and flooding events have resulted in governmental mandates to increase flood protection within the New Orleans Levee District. Construction of levee embankments, consisting of soil compacted into slopes designed to minimize water penetration, have become the major focus for floodwater protection (USACE 2000). Construction sites have been identified as major sources of non-point pollution (Daniel et al., 1979; Kuo et al., 1988; Schuler, 1987). In the case of levees, these man-made structures directly border major water bodies with little to no buffer zones to reduce nutrient and sediment movement. As a result, large tracts of land post-construction will be susceptible to severe pollution from surface runoff.

Soft armoring or vegetation establishment on the levee surfaces to maintain embankment structural integrity has become the standard practice post-levee construction (USACE 2000). Numerous studies have reported mature grass systems reduce surface runoff occurrence, severity and pollution compared to fallow soils (Morton et al., 1988; Gross et al., 1990; Linde et al., 1994). However, the grass establishment phase has been identified as a period of increased risk to ground and surface water quality (Easton and Petrovic, 2004; Linde and Watschke, 1997).

In order to accelerate grass growth to protect levee surfaces, fertilization is a common practice. Multiple studies have found nutrient losses in runoff from mature grass systems to be small and insignificant (Morton et al., 1988; Gross et al., 1990; Linde et al., 1994). According to Easton and Petrovic (2004), fertilizing grass systems ultimately reduces nutrient losses compared to unfertilized grass even though fertilized grassed areas are prone to nutrient losses especially when fertilizer are applied to areas with low plant densities (Easton and Petrovic, 2004; Snyder and Cisar, 2000; Bowman et al., 1998; Rosenthal and Hipp 1993).

Nitrogen and P contamination of surface waters via runoff have been shown to significantly contribute to eutrophication and subsequent deterioration of surface water quality (Sharpley et al., 1994; Uttormark et al., 1974). Concentrations as low as 1 mg N L^{-1} and 25 µg P L^{-1} have been reported to increase algal growth and impair water quality (Walker and Branham, 1992; Koehler et al., 1982; Mallin and Wheeler, 2000). Because water quality impairment is recognized as an important issue, continued develop of best management practices post-levee construction is needed.

Current USACE grass establishment specifications require 67 kg N and P ha^{-1} of water-soluble fertilizer applied at the time of seeding. Based on past research, greater nutrient losses have been associated with application of water-soluble fertilizer sources (Quiroga-Garza, 2001; Gaudreau et al. 2002), whereas, the use of slow-release fertilizers have been reported to reduce nutrient losses from grass systems (Hummel and Waddington, 1981; Gaudreau et al. 2002). Quiroga-Garza (2001) found that highly insoluble N sources such as Hydroform N decreased N losses compared to urea and sulfur-coated urea (SCU). Similarly, urea formaldehyde (UF) has been reported to have less nitrate (NO_3-N) and ammonium (NH_4-N) losses than NH_4-NO_3 fertilizer (Brown et al., 1982). Application of less soluble-N forms should reduce N losses while providing sufficient N to accelerate grass establishment on levee embankments to reduce surface runoff impacts.

The objectives of this study were to 1) determine the effect of grass coverage on surface runoff 2) evaluate bermudagrass establishment between water-soluble and insoluble fertilizers and 3) quantify the effect of fertilizer sources on nutrient and sediment losses from surface runoff during grass establishment.

Materials and Methods

Site Characterization

Field plots were installed on the western slope of the Bonnet Carré Spillway levee near LaPlace, LA on 2009 May 20 (latitude = 30°, 2.4 minutes North; longitude = 90°, 25.8 minutes West). The 20% sloped embankment was constructed from a sandy loam consisting of 55.4% sand, 29.9% silt, and 14.7% clay. Water bodies adjacent to the levee included the Bonnet Carré Spillway that empties into Lake Pontchartrain located on the flood side (East) and a bayou on the protected side (West). Long-term precipitation data (30 yr) recorded for the months of June through August averages 532 mm of total precipitation (LA Office of State Climatology, 2009). Environmental conditions during the runoff monitoring period are described in Figure A.2.

Runoff Collection Plot Construction

Runoff was collected using stainless steel trays (15.25 cm x 208.5 cm x 75 cm) with an internal area of 1.5 m^2. At the base of each tray, runoff collection troughs (8.5 cm x 75 cm x 5 cm) were located on the down slope side. A stainless steel bar bent at a 90° angle was placed inside the down-slope of the tray to ensure runoff movement into the collection trough. The right side of each collection gutter contained a runoff water exit port 6.3 cm in length with a diameter of 2.5 cm. Trays were installed using a level to ensure proper water flow through gutter exit ports. To prevent rainfall from collecting directly in the troughs, sheet metal was secured over each trough. Runoff trays were installed at a depth of 8 cm below the soil surface and plastic tubing (2.5 cm diameter) connected the trays' exit ports to 3 meters of polyvinyl chloride (PVC) tubing running down slope into covered collection reservoirs. Collection reservoirs (117 L) were installed below ground level to allow gravity induced water flow during natural and simulated runoff events.

Vegetation Establishment and Fertilizer Treatments

Common bermudagrass (*Cynodon dactylon* L.) seed was sown at 195.3 kg PLS ha^{-1} (4 lbs 1000 ft^{-2}) on 2009 June 16 within each tray. Treatments consisted of 100 kg N ha^{-1} of water soluble ammonium-nitrate (NH_4-NO_3), 100 kg N ha^{-1} urea-formaldehyde (UF) a slow- release fertilizer and unfertilized control. Fertilizer treatments were applied at seeding with the exception of ammonium-nitrate that was applied as a split application at seeding and 35 DAS on 19 July 2009.

Rainfall Simulation

Experimental rainfall simulation followed the methods outlined by the United States Department of Agriculture's (USDA) National Phosphorous Research Project's (NPRP) protocol for rain simulation (USDA, 2008). Simulated rainfall was applied to plots using a Tlaloc 3000 Rainfall Simulator (Joern's Inc. in West Lafayette, IN), a field mobile unit based on the designs of Miller (1987) and Humphry et al. (2002). The Tlaloc 3000 was fitted with a Spraying Systems Co. Fulljet ½HH SS 30WSQ nozzle with a spray angle of 104° (±5%) and delivered 9.9 L per minute at 7 psi (USDA, 2008). The nozzle and associated plumbing assemblies are mounted to a cubed shaped aluminum frame (3m x 3m x3m) that elevated the nozzle 3 m above the soil surface. Two leg extensions were installed on the down-slope corners of the simulator to level the apparatus for more uniform raindrop distribution.

Water applied during rainfall simulation was obtained from a municipal water supply and transported to the research site in a 300 gal polycarbonate tank. Water was supplied to the rainfall simulator via a utility pump (Water Ace® Portable Utility Pump rated at 151 L min^{-1}). Water temperature was monitored during calibration and simulations (27°±1° C).

To approximate local conditions, a rainfall intensity for a one-year, one-hour precipitation extreme of 76 mm h^{-1}, was applied during all rainfall simulations. The simulator was calibrated to deliver 1920 mL min^{-1} at 9 psi. Rainfall simulations were conducted at 2 week intervals commencing 14 DAS with subsequent simulations at 28, 42, and 56 DAS.

Simulated runoff events consisted of 30 minutes of continuous runoff from plots. Initiation of surface runoff was marked at the start of a continuous trickle of water into collection reservoirs with runoff water collected *in toto* for 30 minutes.

Data Collection

Environmental and Plot Data

On 2009 June 16, soil samples were collected outside and adjacent to each runoff collection tray. Soil samples were analyzed by the Louisiana State University (LSU) AgCenter Soil Testing and Plant Analysis Lab (LSU STPAL) for N, P, K and pH. After completing the final simulation 56 DAS, soil samples were collected within each tray and analyzed (Table 3.1).

Table 3.1. Soil analysis from samples taken at seeding and after final simulation, 56 DAS.

	JUNE 16, 2009 (0 DAS)				AUGUST 11, 2009 (56 DAS)			
Treatment	**N**	**P**	**K**	**pH**	**N**	**P**	**K**	**pH**
	%	**mg kg^{-1}**	**mg kg^{-1}**	**1:1 Water**	**%**	**mg kg^{-1}**	**mg kg^{-1}**	**1:1 Water**
CONTROL	**0.21**	**38.8**	**232.2**	**10.0**	**0.20**	**37.5**	**178.5**	**10.0**
NH_3-NH_4	**0.22**	**41.5**	**215.5**	**10.1**	**0.21**	**41.5**	**171.9**	**9.8**
UF	**0.23**	**42.1**	**231.7**	**9.8**	**0.22**	**41.3**	**153.7**	**10.1**

Source water for each simulation was collected and analyzed for conductivity, pH, ammonium (NH_4-N) and nitrate (NO_3-N), total dissolved phosphorous (TDP), total phosphorous (TP), and concentrations of cations that could potentially react with phosphate and/or nitrate ions. Water source analysis data were used to correct nutrient loss data from plots.

For each simulated runoff event the following data were collected: volumetric water content ($m^3 m^{-3}$) (EC-5 soil moisture sensors, Decagon Devices Inc., Pullman, WA); visual percent vegetative ground coverage; time for runoff to occur; total runoff volume; temperature; and previous rainfall. Percent coverage was assessed using a scale of 0 to 100% with 0% = bare ground and 100% = no soil visible. Total runoff volume was determined after 30 min runoff with composite samples collected.

In addition to the simulated runoff events, four natural runoff events occurred during the 56 day monitoring period. For each naturally occurring runoff, percent vegetative ground cover, total runoff volume, and total rainfall were collected and recorded.

Runoff Water Data Analysis

Runoff water samples obtained from simulated and naturally occurring runoff events were analyzed for TDP, TP, and NH_4-N and NO_3-N concentrations and sediment. Water samples were stored at 4°C with analysis occurring with 72 hr after collection. Samples were prepared for TDP analysis by filtering runoff samples through a 0.45 µm filter. Potassium persulfate digestions as described by Pierzynski (2000) in *Methods of P Analysis for Water and Soil* were used to prepare samples for TP analysis. Both TDP and TP were analyzed by the Louisiana State University STPAL using Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES). Nitrogen (NH_4-N and NO_3-N) analysis was performed by the LSU's Ag Chemistry Department using a modified version of Environmental Protection Agency's (EPA) Method 351.2 (prepared by Bran Luebbe). Nutrient runoff data is presented as concentration (mg L^{-1}) and as a mass loss. Sediment analysis was performed through oven drying 40 mL runoff water samples with weight recorded.

Data Treatment and Statistics

The three fertilizer treatments were arranged in a completely randomized design (CRD) with three replications for a total of 9 plots. Data were analyzed according to the Analysis of Variance (ANOVA; α=0.05) using the mixed procedure in the statistical software SAS (SAS Institute, 2000). Post-hoc testing was performed using a Fisher's protected least significant difference (Fisher's LSD; α=0.05). Data for DTP, TP, and Total N are reported not only as concentration but mass loss to account for discrepancies in total runoff volume over time. Rainfall simulated data (sediment, time until runoff, runoff volume and infiltration rate), simple linear regressions (SLR; α=0.05) were used to evaluate correlations between percent vegetative groundcover and runoff data for each fertilizer treatment. Raw data for sediment, time until runoff and infiltration rate were transformed using the natural log to normalize and homogenize residuals before regression analyses were performed.

Results and Discussion

Surface Runoff

Relationships between runoff parameters (runoff initiation, volume, and infiltration) and vegetative ground cover were consistent with those observed during the 2008 runoff monitoring period (Chapter 2). Infiltration prior to runoff and time until runoff occurred were strongly correlated (R^2=0.81) with percent ground cover (Figure 3.1). Under tested conditions, surface runoff was delayed twice as long at 85% vegetative groundcover (>717 sec) compared to 15% groundcover with corresponding infiltration increasing from 0.77 cm to 1.52 cm (Figure 3.2). Conversely, runoff volume, as a percentage of applied water during rainfall simulation, was negatively correlated to percent vegetative groundcover. For 85% groundcover, runoff volume was reduced 4x that of 15% groundcover.

Delayed runoff initiation, reduced runoff volumes, and higher infiltration rates from increased plant growth have been documented in previous runoff studies (Easton and Petrovic, 2004; Linde and Watschke, 1997). Gaudreau et al. (2002) reported reduced runoff volumes to be consistent with large grass clipping dry weights, an indirect measurement of verdure and biomass. Linde at Watschke (1997) showed stoloniferous grass, such bentgrass or in this case bermudagrass, created a dense vegetative mat that slows lateral water flow, trapped suspended sediment and increased infiltration to reduce surface runoff and pollution. Increased shoot density in more developed swards increases water infiltration and decreases runoff volumes and velocities (Easton and Petrovic, 2004; Linde et al., 1995, 1998). Beard and Green (1994) attributed soil stabilization and reductions in runoff severity to a combination of high biomass matrix, high shoot density, and high rooting mass found in mature grass. Because mature bermudagrass is highly resistant to runoff, one could posit any cultural practice that accelerates grass establishment should enhance runoff resistance to reduce erosion and pollution losses.

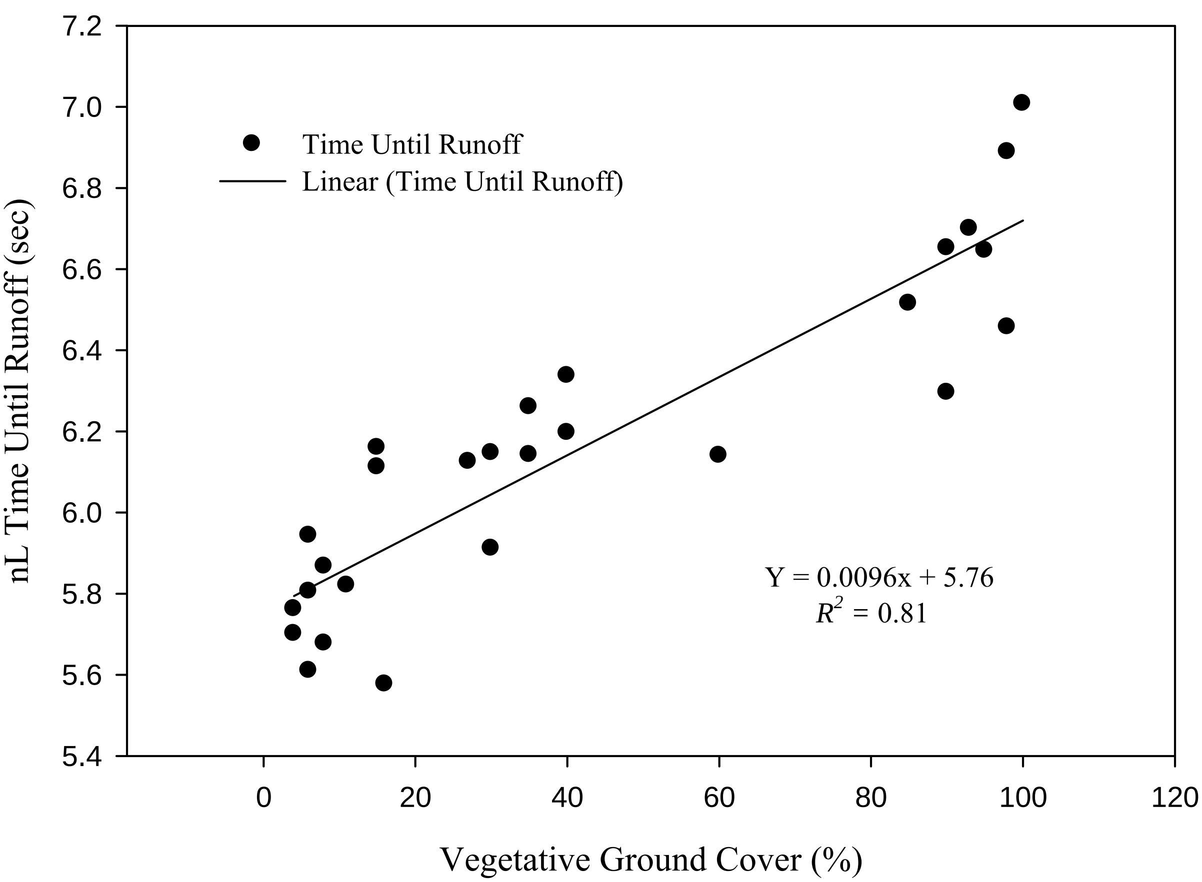

Figure 3.1. Time until runoff as a function of percent vegetative ground cover. Significant at α = 0.05. Separate regression lines for individual treatments are not shown as slopes were not different (α = 0.05) (Table 3.2).

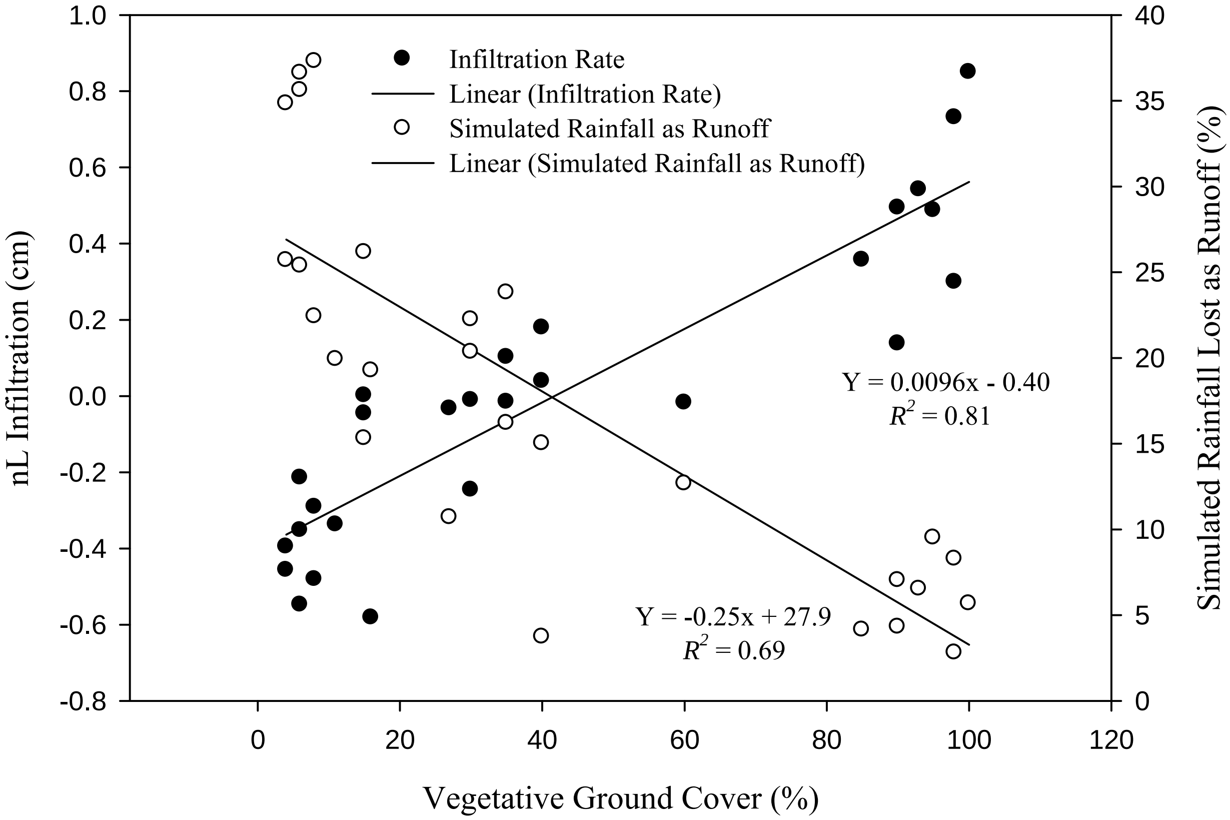

Figure 3.2. Soil infiltration and percent of simulated rainfall lost as runoff water as a function of percent vegetative ground cover. Significant at α = 0.05. Separate regression lines for individual treatments are not shown as slopes were not different (α = 0.05) (Tables 3.3 and 3.4).

<u>Sediment Losses</u>

Sediment losses from simulated rainfall were negatively correlated to percent vegetative ground cover (R^2=0.61) (Figure 3.3). Gross et al. (1991) reported similar findings of reduced sediment losses from mature grass stands compared to bare soil. Sediment losses at 14 DAS from 10% ground cover, 82.3 kg ha^{-1}, were reduced to 35.4 kg ha^{-1} at 30% ground cover (28 DAS) and 12 kg ha^{-1} at 90% ground cover (56 DAS) (Table 3.2). Vietor et al. (2004) similarly reported losses of 90 kg ha^{-1} from bermudagrass during initial runoff events (8.5% slope). In addition, Gross et al. (1991) reported comparable sediment losses from establishing grass during similar 30 minute rainfall simulation events (76 mm hr^{-1}) on 8% slopes.

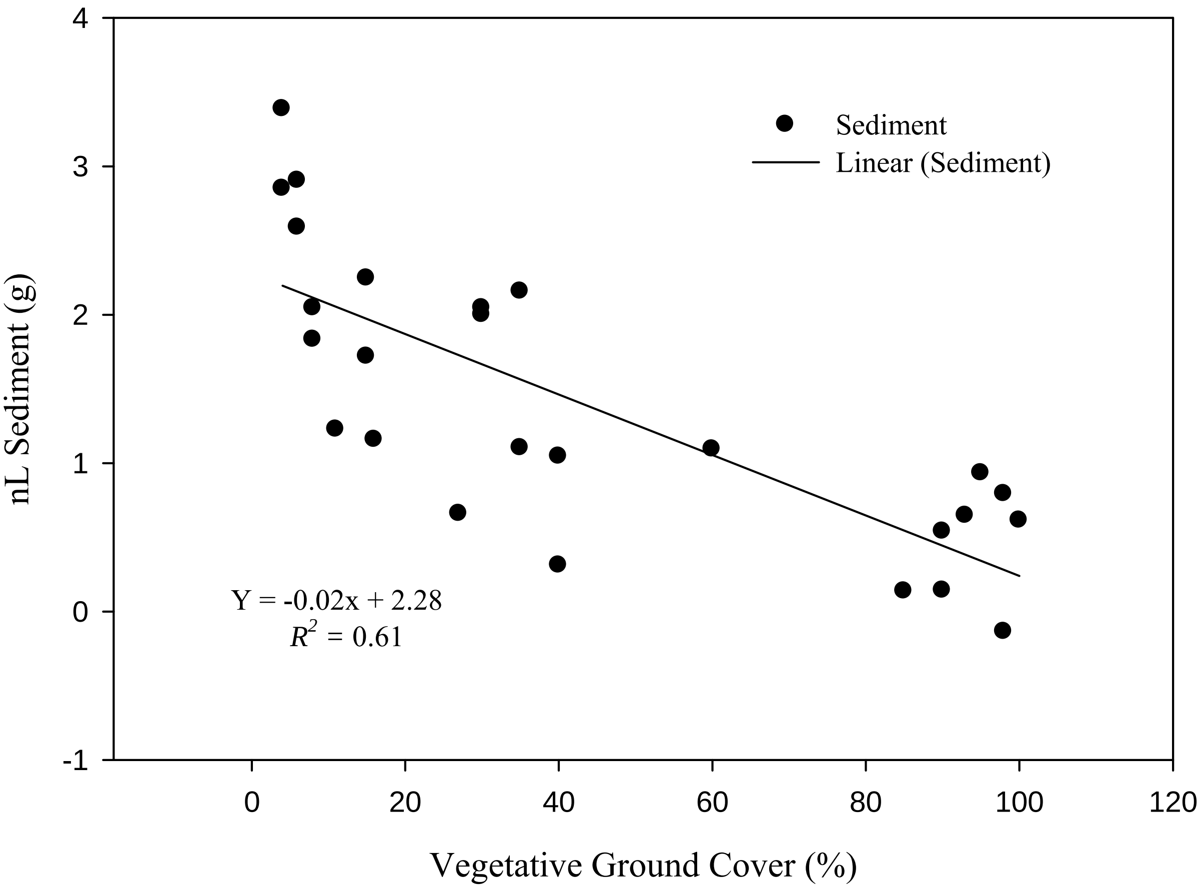

Figure 3.3. Sediment loss as a function of percent vegetative ground cover. Significant at α = 0.05. Separate regression lines for individual treatments are not shown as slopes were not different (α = 0.05) (Table 3.6).

Table 3.2. Volume and sediment losses during bermudagrass establishment (June 16 - August 11, 2009).

DAS	Rainfall	Sediment			Volume		
		Control	AN	UF	Control	AN	UF
	mm	——— kg ha^{-1} ———			——— L ———		
14 §	43 - 47	63b	159c	51a	15a	24b	19a
21	28	26a	41a	27a	3a	5a	4a
28 §	45 - 50	20a	54a	32a	7a	16b	14b
30	28	103b	156c	53a	8a	14b	10ab
41	43	41a	52a	37a	11a	14a	13a
42 §	41 - 44	29a	45a	27a	16a	20ab	21b
46	13	34a	29a	23a	9a	11a	11a
56 §	47 - 62	13a	13a	10a	6a	6a	5a
Totals		329a	549a	261a	76a	111a	96a

§ Simulated rainfall event.
‡ Numbers followed by the same letter within a row are not significantly different according to Fisher's LSD at α = 0.05.

Reductions in sediment losses due to increases in grass growth have previously been attributed to high shoot density which increases water infiltration, decreasing runoff volumes and velocities (Easton and Petrovic, 2004; Linde et al., 1995, 1998). Grass vegetation disperses energy associated with rainfall impact and sediment dislodgement (Krenitsky et al., 1998). Reduced runoff severity has also been attributed to a combination of high biomass matrix, high shoot density, and high rooting mass (Beard and Green, 1994).

In general, sediment losses per runoff event did not differ between fertilizer treatments. Total sediment losses were 261, 549, 329 kg ha^{-1} from UF, NH_4-NO_3, and unfertilized grass. Growth response to N application was not adequate to reduce total sediment losses. These data are in contrast to Easton and Petrovic (2004), who concluded fertilization ultimately reduced sediment losses by increasing grass density. Differences between the two studies may be attributed to differing climates, soil conditions, and grass species.

Bermudagrass Response to N Application

Nitrogen fertilization enhanced bermudagrass establishment relative to unfertilized controls (Figure 3.4). Several studies have reported positive grass growth responses from N and P applications (Parkins et al., 1993; Easton and Petrovic, 2004; Quiroga-Garza et al., 2001). Gaudreau et al. (2002) showed N fertilization increases grass density, and Parkins et al. (1993) reported increased biomass and shoot, foliage, and root growth.

For the first 21 DAS all treatments had similar bermudagrass coverages. Beginning 35 DAS, unfertilized control ground cover, 45%, consistently lagged both fertilized bermudagrass treatments, 53%, until the end of the monitoring period. By 56 DAS, unfertilized controls attained 79% ground cover compared to 95% ground cover for fertilized bermudagrass. Over the monitoring period, bermudagrass growth responses from UF or NH_4-NO_3 applications were similar except at 28 and 31 DAS UF-fertilized grass attained 37% and 38% ground cover, respectively, while NH_4-NO_3-fertilized grass attained 25% and 27% groundcover.

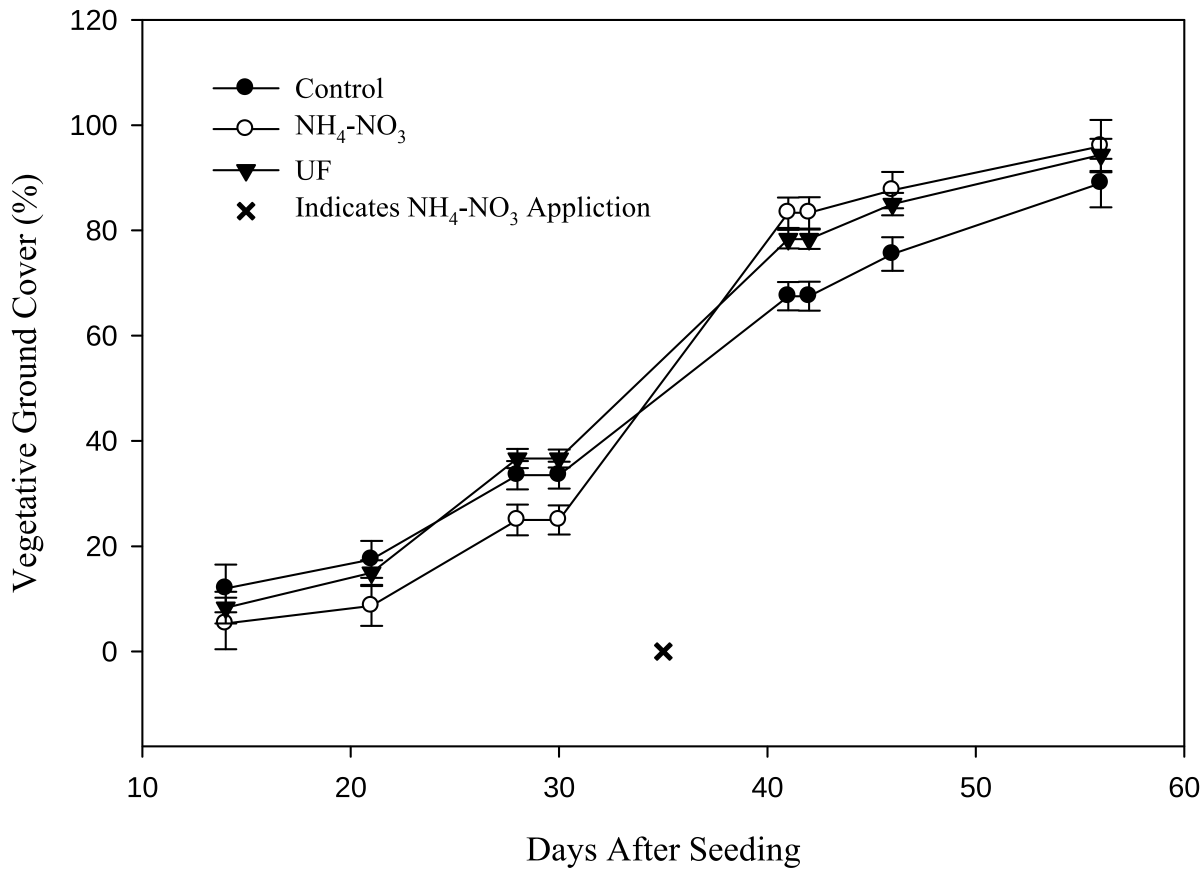

Figure 3.4. Bermudagrass vegetative ground cover as a function of time. Each point represents a mean of three replicates.

Multiple studies have reported limited grass growth response from UF fertilization relative to other more soluble N fertilizers (Goatley et al.,1998; Volk and Horn, 1975). Mineralization of N from UF occurs by microbial decomposition, a temperature mediated process (Watschke and Waddington, 1974). Growth response similarities observed between UF and NH_4-NO_3 may be attributed to warmer summer temperatures and frequent rainfall that allowed faster N release to support grass establishment (Appendix A.3).

The lack of greater response by bermudagrass to N fertilization compared to unfertilized bermudagrass may be due to plant maturity and N losses. Shallow root systems of newly germinated bermudagrass coupled with the compacted soil structure of a levee may have limited N uptake thereby reducing plant growth. Grass rooting has been shown to greatly affect N uptake (Bowman et al., 1998). Even at 35 DAS, bermudagrass was unable to reduce N runoff losses of 0.597 kg ha^{-1} 41 DAS compared to 0.693 14 DAS through plant uptake. Nitrogen losses via runoff and volitalization from high soil pH may have reduced available N, thus limiting plant uptake and growth (Table 3.1) (Reddy and DeLaune, 2008; Horgan et al., 2002).

The ability of groundcover to delay runoff initiation, decrease runoff volume and reduce erosion has been previously documented (Easton and Petrovic, 2004; Quiroga-Garza et al., 2001; Gaudreau et al. 2002). Intuitively any practice, such as fertilization, which accelerates plant growth should shorten the duration of exposure and significantly reduce overall surface runoff and pollution. However, at no runoff event, natural or simulated during the monitoring period, were runoff volumes or sediment loading significantly lowered for fertilized bermudagrass compared to unfertilized bermudagrass. Unfertilized controls resulted in 76 L of total runoff and 329 kg total sediment ha^{-1} compared to corresponding losses of 111 L and 96 L and 549 kg ha^{-1} and 261 kg ha^{-1} for NH_4-NO_3 and UF, respectively.

Nutrient Losses

Phosphorus Losses

Phosphorus was not applied in this study, and was examined to evaluate N fertilization's potential to reduce P losses by accelerating bermudagrass establishment. Labile and non-labile sediment bound P has been identified as a cause of accelerated eutrophication (Reddy and DeLaune, 2008; Sondergaard et al., 2003). Because phosphorus transport into aquatic ecosystems occurs primarily as sediment bound P (Daniel et al., 1994; Sharpley et al., 1994), reductions in sediment losses from accelerated vegetative growth could significantly reduce total P losses.

Previous studies evaluating losses after P fertilization consistently report the largest P losses occur during initial runoff events, and P losses decrease over time (Vietor et al., 2004; Gaudreau et al., 2002; Easton and Petrovic, 2004). In contrast, P losses increased from 14 DAS to 41 DAS (Table 3.3 and Appendix A.4). Throughout the monitoring period, TP losses never exceeded 2.5 mg L^{-1} or 0.250 kg ha^{-1} for any N treatment or rainfall event. The majority of P lost for <60% groundcover was associated with higher sediment loss. After 41 DAS and >60% groundcover, TP losses were comprised mostly of dissolved P. For example, TDP losses for unfertilized bermudagrass 21 DAS was 25% of TP compared to 83% of TP 46 DAS. This pattern of greater dissolved P losses from denser ground cover is consistent with previous studies concerning mature grass swards (Gross et al., 1990). Variations observed between simulated runoff events were relatively small, however, all P concentration losses (natural and simulated) were above 25 μg L^{-1}; a concentration capable of causing eutrophication (Mallin and Wheeler, 2000).

Table 3.3. Nutrient masses (N, TDP, and TP) lost in runoff during bermudagrass establishment (June 16 - August 11, 2009).

DAS	Rainfall	Total NO3-N + NH_4-N			Total TDP			Total TP		
		Control	AN †ƀ	UF †	Control	AN †ƀ	UF †	Control	AN †ƀ	UF †
	mm	kg ha^{-1}								
14 §	43 - 47	0.087a	0.693c	0.440b	0.005a	0.003a	0.005a	0.007a	0.007a	0.010a
21	28	0.012a	0.057a	0.028a	0.007a	0.015a	0.004a	0.028a	0.051a	0.011a
28 §	45 - 50	0.016a	0.076a	0.067a	0.018a	0.045a	0.026a	0.022a	0.052a	0.028a
30	28	0.015a	0.068a	0.074a	0.039a	0.068b	0.042ab	0.126a	0.207b	0.111a
41	43	0.030a	0.597b	0.051a	0.072a	0.076a	0.066a	0.142a	0.172a	0.135a
42 §	41 - 44	0.003a	0.129a	0.017a	0.102a	0.111a	0.114a	0.156a	0.204a	0.199a
46	13	0.069a	0.082a	0.041a	0.025a	0.014a	0.013a	0.030a	0.017a	0.015a
56 §	47 - 62	0.010a	0.025a	0.013a	0.024a	0.020a	0.010a	0.010a	0.010a	0.010a
TOTALS		0.242a	1.728b	0.732a	0.292a	0.352a	0.280a	0.521a	0.722a	0.503a

§ Simulated rainfall event.

‡ Numbers followed by the same letter within a row are not significantly different according to Fisher's LSD at $\alpha = 0.05$.

† All treatments except the unfertilized control consisted of total N applications of 100 kg ha^{-1}.

ƀ Split fertilizer application at seeding and 35 DAS.

Except at 30 DAS, N fertilizer applications did not have a significant effect on TDP or TP mass losses in surface runoff. At 30 DAS, mass losses of TDP and TP from NH_4-NO_3-fertilized grass were greater compared to UF or the unfertilized control. This is consistent with differences in volume and sediment losses 30 DAS. Greater significant variability was observed in TDP and TP concentration losses. Because mass losses take into account runoff volumes and represent total nutrient losses, mass loss data may be a more appropriate method for treatment comparisons. In general, no differences were observed in total TDP or TP mass losses between treatments. The effect of applied N on bermudagrass growth was not sufficient to reduce DTP or TP losses during the establishment period.

Nitrogen Losses

Regardless of fertilizer source, N concentrations and mass losses were greatest during runoff events following application (Table 3.3 and Appendix A.4). Easton and Petrovic (2004), Gaudreau et al. (2002), and Linde and Watschke (1997) reported similar findings of greater N losses from the initial runoff events. During the first runoff event, UF and NH_4-NO_3 fertilized grass resulted in N losses of 0.693 kg ha^{-1} and 0.440 kg ha^{-1}, respectively, compared to 0.087 kg ha^{-1} for the unfertilized control. These N losses represented 60% and 40% of the total N lost from UF and NH_4-NO_3-fertilized grass.

At 14 DAS with 8% ground cover, bermudagrass was too immature to acquire or retain large quantities of applied N or significantly reduce surface runoff. Quiroga-Garza et al. (2001) and Hesketh et al. (1995) reported N use efficiency to be higher in fully established grass. To potentially reduce N losses of water-soluble N and allow greater plant uptake, the second NH_4-NO_3 application was applied 35 DAS with ≥50% ground cover. However, N loss, 0.597 kg ha^{-1}, during the following runoff event, 41 DAS, from NH_4-NO_3-fertilized grass were significantly higher than the 0.03 kg ha^{-1} and 0.05 kg ha^{-1} lost from UF-fertilized and unfertilized grass, respectively. Nitrogen lost from NH_4-NO_3-fertilized bermudagrass 41 DAS was 34.5% of total N lost during the monitoring period.

Nitrogen losses decreased after initial rainfalls post-N application over the runoff monitoring period. These observations are consistent with reductions in volume and sediment losses noted previously. Linde et al. (1998) reported reductions in runoff losses to be the result of reduced soil moisture and subsequent higher soil infiltration capacities caused by greater evapotranspiration rates of established grass. In addition, Bowman et al. (1998) concluded that reductions in NO_3-N concentration losses were most likely due to greater NO_3-N uptake from increased root growth as well as increased soil infiltration capacity caused by root channeling. Multiple studies have reported increased shoot densities to be consistent with reductions in runoff and NH_4-N losses (Easton and Petrovic, 2004; Gross et al., 1990, 1991; Krenitsky et al., 1998).

Total N losses were significantly higher from NH_4-NO_3-fertilized grass compared to UF or unfertilized grass. Cumulative N mass losses from NH_4-NO_3-fertilized grass were 1.7 kg ha^{-1} compared to 0.7 kg ha^{-1} and 0.2 kg ha^{-1} for UF and unfertilized controls, respectively. Compared to total mass losses from NH_4-NO_3-fertilized grass, UF fertilizer reduced total N mass losses by 57%.

Independent of fertilizer source, N application did not ultimately reduce total nutrient runoff losses. Large runoff losses at 14 DAS (UF and NH_4-NO_3-fertilized grass) and 41 DAS (NH_4-NO_3-fertilized grass) due to inadequate plant density and uptake capacities, prevented fertilizer applications from ultimately reducing N losses. In contrast, Easton and Petrovic (2004) reported reduced runoff and nutrient losses from fertilized grass. Further research is needed concerning additional N sources and application timings to more accurately determine percent bermudagrass groundcover effects on N losses via surface runoff.

Conclusions

Nitrogen fertilization enhanced bermudagrass establishment. However, neither NH_4-NO_3 nor UF applications enhanced bermudagrass establishment sufficiently to reduced runoff volume, total sediment, TP, or TDP losses to offset increased total N losses over the unfertilized control. Moreover, split NH_4-NO_3 fertilization applications resulted in elevated total N losses from surface runoff demonstrating that 60% bermudagrass groundcover was incapable of retaining applied N.

In general, most research studies report N fertilization accelerates grass establishment. Because levees soils are constructed from imported soils, high variability in soil fertility is common. In some situations, failure to provide adequate N could severely limit grass establishment leading to greater sediment and P losses into adjacent water bodies. If N fertilization is required, UF is a more suitable N source for areas prone to surface runoff. During the establishment period, N losses from UF fertilized grass were <57% of the losses from NH_4-NO_3 fertilized grass.

Other, factors such as mulches and seeding rates should be examined as alternatives to current seeding rates that rely on N fertilization to accelerate canopy closure for erosion resistance. Further research is needed to determine at what point newly established grass is able to reduce N losses to better target N fertilization applications.

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CHAPTER 4: SUMMARY

The United States Army Corps of Engineers (USACE) defines a levee as "an embankment whose primary purpose is to furnish flood protection from seasonal high water and which is therefore subject to water loading for periods of only a few days or weeks a year. Designed to provide floodwater protection, a levee is typically constructed of heavy soils compacted into an embankment of approximately 30% slope. Although compacted soils are excellent materials for structural integrity that limit water infiltration, heavy soils compacted into slopes with extreme gradients are prone to sediment and nutrient transport via surface runoff during precipitation events.

Nitrogen fertilization enhanced bermudagrass establishment in both years of the study. However, neither urea, SCU, NH_4-NO_3 nor UF applications enhanced bermudagrass establishment sufficiently to reduced runoff volume, total sediment, TP, or TDP losses to offset increased total N losses over the unfertilized controls. Moreover, a split NH_4-NO_3 fertilization applications resulted in elevated total N losses from surface runoff demonstrating that 60% bermudagrass groundcover was incapable of retaining water-soluble applied N.

In general, most research studies report N fertilization accelerates grass establishment. Because levees soils are constructed from imported soils, high variability in soil fertility is common. In some situations, failure to provide adequate N could severely limit grass establishment leading greater sediment and P losses to adjacent water bodies. If N fertilization is required, UF is the most suitable N source tested for areas prone to surface runoff.

Other, factors such as mulches and seeding rates should be examined as alternatives to current seeding rates that rely on N fertilization to accelerate canopy closure for erosion resistance. Further research is needed to determine at what point newly established grass is able to reduce N losses to better target N fertilization applications.

APPENDIX

ENVIRONMENTAL DATA

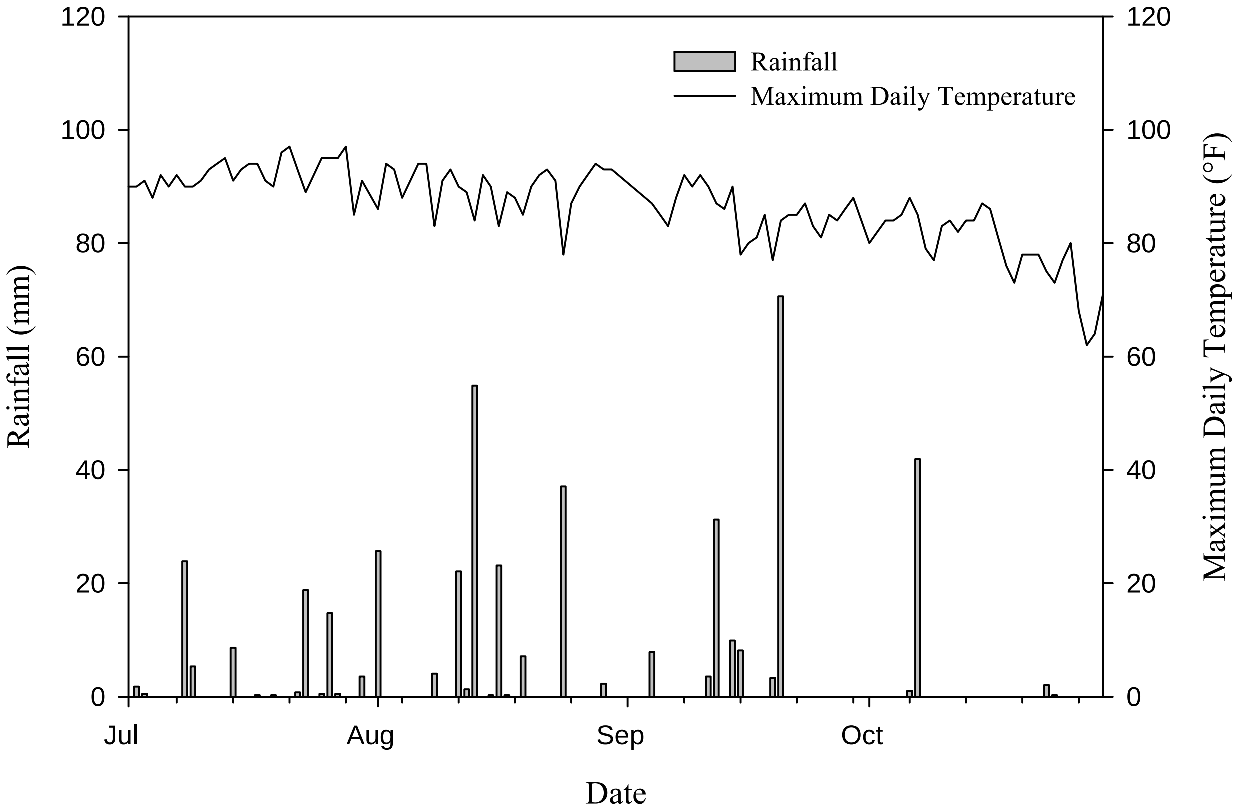

Figure A.1. Temperature and rainfall conditions of southeastern LA during summer 2008. Rainfall and maximum daily temperatures during summer 2008 runoff monitoring period. Data recorded 12.2 miles from research levee at the New Orleans International Airport.

Table A.1. Nutrient concentrations (N, TDP, and TP) lost in runoff during bermudagrass establishment (August 6 - October 22, 2008).

DAS	Rainfall	NO_3-N + NH_4-N			TDP			TP		
		Control	Urea †	SCU †	Control	Urea †	SCU †	Control	Urea †	SCU †
	mm	mg L^{-1}								
8	110	1.53a	4.78b	5.47b	0.20a	2.79b	2.79b	10.24a	14.67b	13.24b
12	50	2.26a	4.48b	5.66c	0.27a	1.37b	1.52b	3.51a	6.00a	5.38a
14 §	49 - 51	0.98a	1.38a	1.49a	0.04a	0.07a	0.12a	6.58a	8.12a	8.08a
19	54	0.15a	0.48a	0.21a	0.12a	0.59b	0.57b	1.33a	2.16a	2.50a
28	24	0.35a	0.18a	0.40a	0.37a	0.60ab	0.60b	1.61a	2.93a	3.54a
37	60	0.69a	0.56a	0.88a	0.42a	0.60a	0.63a	5.85a	5.71a	4.28a
42 §	50 - 54	0.16a	0.08a	0.35a	0.08a	0.10a	0.10a	5.29a	4.40a	5.23a
45	17	0.31a	0.28a	0.26a	0.85a	1.14a	1.07b	3.24a	3.46a	3.24a
70 §	59 - 78	1.60a	1.71a	2.14a	0.10a	0.14a	0.11a	1.54a	1.01a	1.07a

§ Simulated rainfall event.

‡ Numbers followed by the same letter within a row are not significantly different according to Fisher's LSD at $\alpha = 0.05$.

† All treatments except the unfertilized control consisted of single N applications of 50 kg ha^{-1}.

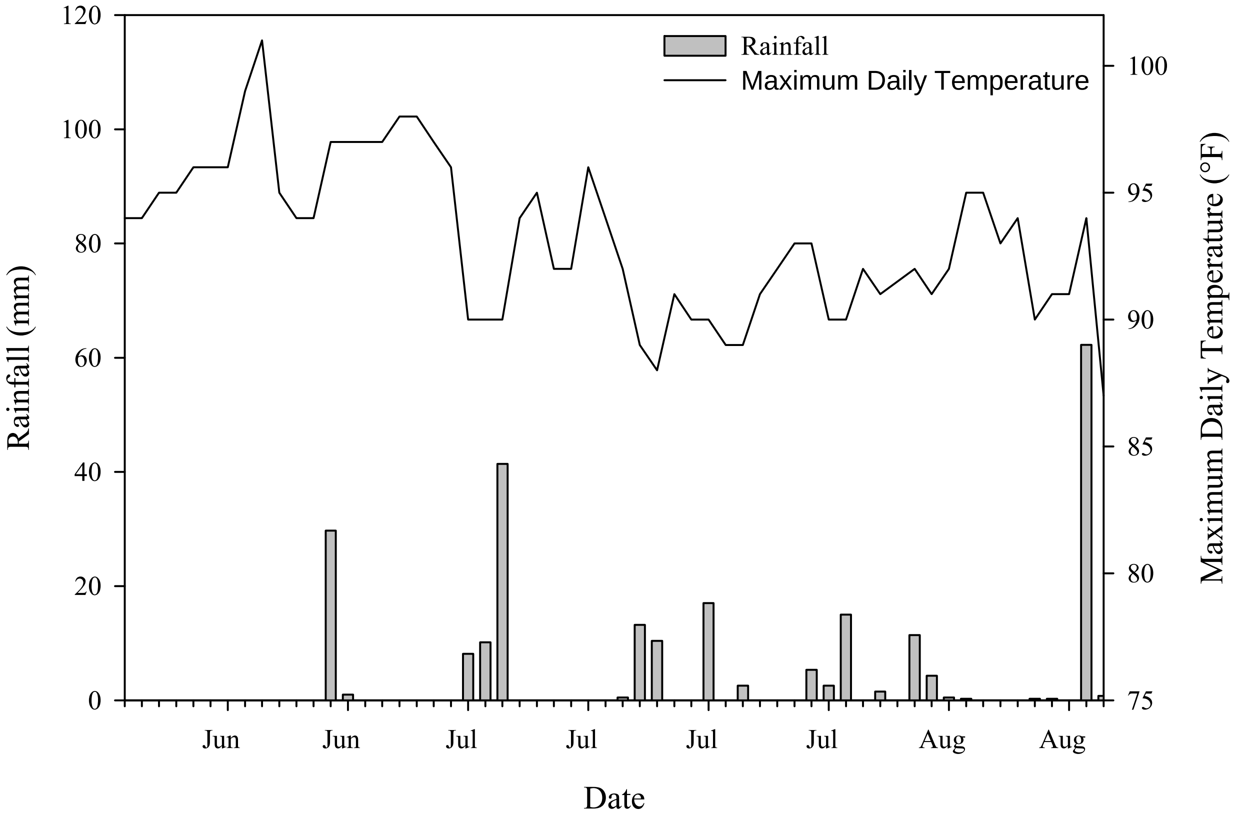

Figure A.2. Temperature and rainfall conditions of southeastern LA during summer 2009. Rainfall and maximum daily temperatures during summer 2009 runoff monitoring period. Data recorded 12.2 miles from research levee at the New Orleans International Airport.

Table A.2. Nutrient concentrations (N, TDP, and TP) lost in runoff during bermudagrass establishment (June 16 - August 11, 2009).

DAS	Rainfall	NO3-N + NH_4-N			TDP			TP		
		Control	AN †ѣ	UF †	Control	AN †ѣ	UF †	Control	AN †ѣ	UF †
	mm	——— mg L^{-1} ———								
14 §	43 - 47	0.82a	4.36b	3.69b	0.05a	0.02a	0.04a	0.07a	0.05a	0.08a
21	28	0.45a	1.52a	1.19a	0.33ab	0.46b	0.15a	1.01b	1.45c	0.37a
28 §	45 - 50	0.38a	0.68a	0.74a	0.40a	0.41a	0.29a	0.50a	0.47a	0.30a
30	28	0.27a	0.73a	1.13a	0.74a	0.74a	0.63a	2.24b	2.23b	1.64a
41	43	0.45a	6.36b	0.59a	1.01b	0.82ab	0.75a	1.92a	1.85a	1.54a
42 §	41 - 44	0.04a	0.96a	0.11a	0.94a	0.82a	0.80a	1.44a	1.49a	1.40a
46	13	1.40a	1.29a	0.64a	0.48b	0.21a	0.19a	0.54a	0.25a	0.22a
56 §	47 - 62	0.29a	0.63a	0.56a	0.60a	0.40a	0.37a	0.33a	0.30a	0.4a

§ Simulated rainfall event.

‡ Numbers followed by the same letter within a row are not significantly different according to Fisher's LSD at $\alpha = 0.05$.

† All treatments except the unfertilized control consisted of total N applications of 100 kg ha^{-1}.

ѣ Split fertilizer application at seeding and 35 DAS.

VITA

Robert Wilson Burwell, Jr. was born in 1983 as the youngest child of Sandy Fogle and Robert Wilson Burwell. Robert Burwell graduated from Bolton High School in 2002 and enrolled at Louisiana State University that fall. Graduating with a Bachelor of Science in plant and soil sciences in May 2007, Robert moved to the Big Island of Hawaii. In Hawaii, Robert worked as the agricultural associate for M.L. Macadamia, Inc. until his return as a graduate student to Louisiana State University in January 2008. Currently working under the direction of Dr. Jeffrey Beasley, Robert is a candidate for a Master of Science in horticulture with a research emphasis in environmental soil science.