Nitrogen Regime Influence on Nutrient and Sediment Surface Runoff

During Vegetative Establishment of Bermudagrass

by

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(ABSTRACT)

Bermudagrass (*Cynodon dactylon* (L.) Pers.) is a popular turfgrass used throughout the Southeast. Bermudagrass is established primarily as sprigs on large acreage sites. Currently, the industry standard practice (ISP) of fertilization during bermudagrass sprig establishment is 48.8 kg N ha^{-1} wk^{-1}. This fertilizer rate can be excessive on morphologically immature sprigs in the initial weeks of establishment, thus making the possibility of offsite surface runoff N events more likely. Two experiments were conducted in 2000 and 2001 where sprigs were established at 2, 4, 6, 8, and 10 weeks prior to applying simulated rainfall (WPRS) following N fertilization rates of the ISP or a lower initial N (LIN) rate of 12.2 kg N ha^{-1} wk^{-1} the first four weeks and then 48.8 kg N ha^{-1} wk^{-1} until full establishment. At the tenth week all treatments were subjected to rainfall simulation at 63.5 mm hr^{-1}. Once surface runoff was induced, rainfall continued for thirty minutes during which time runoff samples were taken every five minutes and analyzed for sediment losses, N concentrations in the nitrate and ammonium forms, and phosphorus losses as dissolved reactive P (DRP). Experimental results indicate an ability to curb N losses through surface runoff during the initial weeks of sprig establishment following the LIN with only modest delays in sprig establishment. Sprigs established for the same time period, under the ISP or LIN, were very similar in growth, release of surface runoff, and sediment losses during runoff events.

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Introduction:

Nutrient movement into surface waters and groundwaters; and soil sediment movement into surface waters are issues of vital importance to water quality. Humans' depend on clean water resources. This increased dependence has led researchers to evaluate potential sources for groundwater and surface water pollution and begin examining methods to reduce contamination from all sources.

In the article "The Fate of Nitrogenous Fertilizers Applied to Turfgrass", A. Martin Petrovic discussed, at the time, the understanding of nitrogen within turfgrass culture and its potential for environmental risks. Petrovic states "This review (N in turfgrass systems) can be useful in providing information on the development of best management practices to minimize the impact of turfgrass fertilization on groundwater quality and to indicate gaps in the knowledge base" (Petrovic, 1990).

One area that has not been investigated thoroughly is pollution by nutrient and sediment losses during surface runoff events. Few studies have taken place to understand the potential for surface nutrient and sediment movement in turfgrass systems. A review of existing studies shows even less scientific research addressing surface runoff during establishment of warm season turfgrasses.

During turfgrass establishment the soil is disturbed and inputs including irrigation and fertilizer increased. The increased use of fertilizer and water to encourage growth and development of morphologically immature plants equates to a period of site vulnerability to surface nutrient and sediment loss. Poor plant density and biomass after initial establishment reduces the sites ability to filter surface water runoff, which in turn could contribute to eutrophication of surrounding water bodies.

Current industry practice of nitrogen use during vegetative establishment of bermudagrass may involve applying rates of N as high as 48.8 N kg ha^{-1} wk^{-1} until full coverage (Carrow et al., 2001). Because sprigs are morphologically immature at the time of planting, reducing early N inputs would theoretically reduce risk associated with N leaching or runoff during rainfall events while providing adequate N to attain similar coverage as sprigs fertilized at higher N rates.

Warm-Season Versus Cool-Season Turfgrasses Adaptation:

There are three primary subfamilies of the *Gramineae* Family: Festucoideae, Panicoideae, and Eragrostoideae (Turgeon, 1999). Of these three families, Panicoideae and Eragrostoideae are classified as warm-season turfgrasses because of their C4 physiology and anatomy allowing them to grow best under warmer climatic conditions compared to cool-season turfgrasses of the Festucoideae subfamily who represent C3 physiology and anatomy (Turgeon, 1999).

The relationship of plant material to its climate has long been observed throughout many agronomic disciplines. Light, temperature, precipitation, and wind are the four main components determining climate. Temperature and precipitation are the most influential factors (Beard, 1973). This relationship between plant and climate has fostered plant adaptation through natural selection, mutation, hybridization, and changes in chromosome complement (Hanson et al., 1969).

This type of turfgrass adaptation has led to regional classification throughout the world as it relates to turfgrass growth. Today, many use a schematic illustration dividing climates into six major groups: tropical, subtropical, temperate, sub-artic, polar, and dry (Turgeon, 1999).

With respect to the aforementioned schematic, the United States generally differentiates turfgrass growth patterns through five zones: cool humid zone, cool arid-semiarid zone, warm humid zone, warm arid-semiarid zone, and the transitional zone (Beard, 1973). The transition zone is an area that extends across the central United States, including portions of the aforementioned zones (Christians, 1998). Due to extreme temperatures during the summer and winter, managing cool or warm season turfgrasses can be quite a challenge in the transition zone (Christians, 1998).

These differences in climate conditions led to the differences in adaptation of the turfgrasses to their environments. Nowhere is this more evident than in the comparison of photosynthesis in cool and warm season turfgrasses. Cool season turfgrasses are referred to as C3 grasses, because they use a three carbon chain during the photosynthetic carbon reduction cycle (PCR or Calvin cycle) compared to the four carbon chain used by C4 or warm season turfgrasses (Taiz et al., 1991). In addition to differences in carbon chain lengths, C3 plant's leaf morphology contain one "photosynthetic, chloroplast-containing cell, the mesophyll, compared to a C4 plant that contains mesophylls and bundle sheaths (Taiz et al., 1991).

Bermudagrass (*Cynodon Dactylon* (L.) Pers.)

Bermudagrass is classified under the subfamily Eragrostoids, tribe Chlorideae, and genus Cynodon (Beard, 1973). Other turfgrasses closely related to the genus Cynodon are the generas Bouteloua and Buchloe containing blue gramagrass (*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.) and buffalograss (Buchloe datyloides (Nutt.) Engelm.) respectively (Turgeon, 1999).

Bermudagrass is a well known turfgrass throughout the world, as indicated from its various names: couchgrass (Australia and South Africa), devil's grass (India), and gramillia (Argentina) (Duble, 1996). Primarily bermudagrass is located in tropical, subtropical, and warm temperate climates (Turgeon, 1999). These areas within the United States include as far north as New Jersey, extending west across the United States to the valleys of California, and as far south as the United States extends (Duble, 1996). The major limiting factor preventing bermudagrass movement farther northward is lack of cold tolerance (Puhulla et al., 1999).

It is believed that bermudagrass along with kikuyugrass (*Pennisetum clandestinum* **Hochst ex Chiov**) developed in the warm climatic conditions of Eastern Africa (Beard, 1998). Due to intense grazing and drought, bermudagrass has evolved a deep, fibrous-root system and aggressive lateral growth habit making recovery possible from grazing as well as survival during harsh environmental conditions (Beard, 1998). Introduction into the United States from Africa is believed to have been around the mid-1700s (Hanson et al., 1969).

The ability of bermudagrass to grow widely throughout the world has led to its acceptance by many turfgrass managers. Today bermudagrass is one of the most widely used warm-season turfgrasses in the warm-humid zone (Christians, 1998). Bermudagrass is used on lawns, roadsides, parks, athletic fields, golf courses, and many other maintained sites (Christians, 1998).

Characteristics such as color, texture, density, vigor, and environmental adaptation of bermudagrass are highly variable and heavily dependent on species and variety (Turgeon, 1999). General identifying characteristics include folded vernation, a fringe of hairs around the ligule, smooth leaf blades that taper to a point, stoloniferious and rhizotomous growth habit, and formation of a raceme inflorescence (Christians, 1998). The root system is deep and fibrous and can originate from nodes on the stolons (Christians, 1998). Root production takes place throughout the growing season, with the greatest production taking place in the spring with increased shoot production (Duble, 1996).

Bermudagrass growth habit is that of a “highly variable, sod-forming perennial” that develops best in climates with high temperatures, mild winters, and moderate rainfall (Duble, 1996). Optimum daytime air temperatures are between 35 and 38°C or an average daily temperature of 24°C (Duble, 1996). Minimum soil temperature needed for root, stolon, and rhizome growth is 18°C with 24°C being optimum (Duble, 1996). The onset of cold temperatures (< 10° C) cause bermudagrass growth to cease, heading into a dormant like state. During this time period the turf appears tan to straw colored until the sustained reoccurrence of warmer temperatures.

In addition to warm temperature requirements, bermudagrass has a significant sunlight requirement. In low light intensities, less than 60% full sunlight, bermudagrass is incapable of aggressively developing, if at all (Duble, 1996). Bermudagrass has adapted to a wide variety of soil conditions; including sandy or heavy soils (clay or silty soils), low pHs, moderate salinity, and water submersion for short periods of time (Turgeon, 1999; Carrow and Duncan, 1998).

The Cynodon genus contains several species of bermudagrass, the most noted being common bermudagrass. Common bermudagrass, unlike the hybrid-bermudagrasses (*C. dactylon* x *C. transvaalensis*), can be easily established by seed, but offers little appeal to high maintenance areas due to its coarse leaf blade texture (Taliaferro, 1995). Other characteristics include a more open canopy, less wear tolerance and thatching tendency, along with susceptibility to insect damage (Beard, 1973).

Due to the less than suitable characteristics of Common bermudagrass, efforts were placed on the development of hybrid and improved bermudagrass cultivars. The Coastal Plain Experiment Station in Tifton, Georgia, has helped lead the way developing several hybrid and improved bermudagrasses used today (Schroeder and Sprague, 1996). The crossing of *Cynodon dactylon* and *Cynodon transvaalensis* resulted in the parentage of modern hybrids (Turgeon, 1999). Today's hybrids include: Tifway, Tifdwarf, Tifeagle, Tifgreen, Tifsport, Midiron, Midlawn, Floradwarf, and Champion (Christians, 1998).

The hybrid and improved bermudagrasses are vast visual improvements over common Bermudagrass. These dense, sod forming perennials have improved wear tolerance and recuperative abilities attributed to the aggressive growth of rhizomes and stolons (Duble, 1996). Unlike common bermudagrass, the hybrids have shorter, narrower leaf blades, making them more visually accepting. Bermudagrass hybrids are only propagated vegetatively due to their inability to produce viable seed. In addition to color and texture differences, hybrid-bermudagrasses offer some advances in tolerances to cold temperatures and diseases.

Bermudagrass Establishment:

Bermudagrass is propagated from seed and vegetatively by sodding, sprigging or plugging (Duble, 1996). Common type bermudagrass has represented the seeded variety. Improved seeded bermudagrasses varieties have not shared the same success in seeding due to winter survivability and inability to produce viable seed. However new improved seeded bermudagrass varieties and planting methods have shown some promise (Munshaw et al., 2001).

Bermudagrass has been traditionally propagated through vegetative means including sodding, plugging, and sprigging. Sodding is "the transplanting of established turf from one area to another" (Christians, 1998). This provides an instant cover with rooting taking place in two to four weeks with the presence of necessary turfgrass plant parts (Turgeon, 1999). In addition to providing full cover, the turfgrass is generally weed-free and has a wider seasonal planting window than other vegetative methods (Rose et al., 1986). Two disadvantages to sod installation include possible soil layering from the transplanted soil of sod strips and high costs that may be prohibitive for large acreage (Turgeon, 1999).

Alternative vegetative establishment methods for large sites include plugging and sprigging. The intent is to plant less plant material to the site while encouraging lateral growth, filling in the space between the plugs or sprigs to create a dense sod canopy (Busey and Meyers, 1979). Plugging is the insertion of sod blocks or plugs into the site

(Ruemmele et al., 1993). The plugs are spaced according to their size, normally 15 to 30 cm between plugs (Duble, 1996). This particular method is quite labor intensive, but uses much less planting material and requires much less management (Duble, 1996). Turfgrasses that primarily employ this method have a strong stoloniferous growth habit (Turgeon, 1999). Plugs are less likely to suffer drought stress compared to that of sprigs (Ruemmele et al., 1993).

Sprigs are stems or rhizome and stolon portions of the turfgrass plant including dormant and active nodes or crowns (growth points) (Duble, 1996). Sprigs are harvested through the shredding of sod (Duble, 1996). Shortly after shredding the sprigs are susceptible to dessication and should be planted quickly with frequent irrigation (Beaty, 1966). Sprig post planting survival varies with species, irrigation availability, soil contact, and temperatures.

Sprigs are measured in bushels, 1m^2 sections of sod before shredding, which may contain 2200 to 4400 sprigs (Brede, 2000). Rates of 538 bu ha^{-1} to 1614 bu ha^{-1} can be used on areas such as golf course fairways and athletic fields. For faster establishment, planting rates in excess of 1614 bu ha^{-1} may be used (Duble, 1996). In order to accelerate bermudagrass cover, the industry standard practice commonly applies 48.8 N kg ha^{-1} wk^{-1} till full bermudagrass ground cover is obtained (Carrow et al., 2001). Time for complete grow in will vary with soil temperature, irrigation rate, N application, and weed control.

Nitrogen:

Nitrogen (N) is an essential element for the establishment, growth, and development of all turfgrasses (Turner and Hummel, 1992). It is the nutrient, that is in greatest demand by the plant itself, while often being the most deficient macronutrient within the soil system (Tisdale et al., 1993).

N can account for three to five percent of dry turfgrass plant biomass (Olson and Kurtz, 1982). Hence the need for proper N fertilization for proper development of chlorophyll molecules, amino acids, proteins, nucleic acids, enzymes, and vitamins required in turfgrass growth and development (Olson and Kurtz, 1982).

N application helps develop healthy shoots and roots, giving the plant the ability to effectively compete within its given environment. Excessive N can cause poor rooting, depleted carbohydrate reserves, lessen tolerance to heat, cold, disease, wear, and drought, while ultimately only producing excessive shoot growth (Turner and Hummel, 1992).

Nitrogen utilization by turfgrass plants, is generally in the nitrate and ammonium forms (Walker and Branham, 1992). Preference depends heavily on the availability and pH surrounding the root and root hairs (Carson, 1974). However, ammonium is the more physiological efficient form due to the necessary use of two NADH molecules per nitrate molecule during reduction of nitrate in protein synthesis (Tisdale et al., 1993). Nitrate and ammonium, though the preferred N forms for plant growth, are not the only chemical forms of N in soils.

Nitrogen forms are divided into two major categories, organic and inorganic. The organic fraction occurs as proteins, amino acids, amino sugars, and other complex N compounds (Tisdale et al., 1993). It can represent anywhere from 95% to 99% of the total N within the soil. This particular form is primarily produced through degredation by soil bound bacteria and fungi (Stern, 1997). Though present and stable, organic N is largely unavailable for plant use (Brady and Weil, 1996).

Inorganic forms of N include: ammonium (NH_3^+), nitrite (NO_2^-), nitrate (NO_3^-), nitrous oxide (N_2O), nitric oxide (NO) and elemental N (N_2) (Tisdale et al 1993). Of these N forms ammonium, nitrite, and nitrate are the principal forms discussed in soil fertility. These three forms can account for two to five percent of the total N within a soil system (Tisdale et al., 1993).

"An atom of N may appear in many different chemical forms, each with its own properties, behaviors, and consequences" (Brady and Weil, 1996). These changes are best described through an interlocking of processes known as the N cycle. Each process is dependent on one another in addition to certain environmental and microbial factors. The biological N transformations include immobilization, nitrification, mineralization, and fixation (Walker and Branham, 1992).

Immobilization is the transformation of inorganic N to organic N with mineralization being the reverse process (Tisdale et al., 1993). Microbes in the soil compete with plants for inorganic forms of N. Once converted, N is adsorbed to a carbon source such as organic matter within the soil. In order for this transformation to take place a carbon to N ratio of 8:1 is needed to support a growing microbial population (Tisdale et al., 1993).

Mineralization, being the opposite of immobilization, requires the use of two processes, aminization and ammonification, to convert organic N sources into inorganic forms (Tisdale et al., 1993). The processes of mineralization are enhanced with warmer temperatures and adequate moisture and oxygen (Tisdale et al., 1993). The conversion from organic to inorganic forms determines the availability of N forms for plant uptake.

Nitrification converts ammonium to nitrate through a two-step process involving the specific bacteria: nitrosomonas and nitrobacteria (Brady and Weil, 1996). Ammonium is first oxidized into nitrite by the nitrosomonas bacteria followed by nitrobacter, that further oxidize the nitrite to nitrate (Brady and Weil, 1996). This process can be reversed through denitrification with ammonia ultimately being lost from the system through volatilization (Tisdale et al., 1993). Environmental conditions for nitrification to take place include: ample ammonium, necessary nitrosomonas and nitrobacter populations, pH between 4.5 and 10, adequate soil moisture, and temperatures between 25°C and 35°C (Tisdale et al., 1993).

The last transformation capable of taking place within the soil system includes fixation of N. Ammonium ions unlike nitrate ions, are positively charged. This allows the ammonium ions to be held in exchangeable form on soil colloids, humus, and other negatively charged surfaces (Brady and Weil, 1996). Due to its ion size and positive charge, ammonium can become entrapped within certain soil structures. Clay structures with 2:1 characteristics such as vermiculite and smectites can fix the ammonium ion within its layers rendering it unavailable to plant use (Brady and Weil, 1996).

These processes help determine the forms N may take once in the soil system. These forms have certain advantages as well as disadvantages. For example, forms of ammonium and nitrate transformed through mineralization and nitrification help supply necessary N to many plants. However, nitrate when not taken up by the plant can pose a significant risk to the environment.

Nitrate is the more mobile form of N within the soil since it is extremely soluble and relatively unaffected by negatively charged surfaces due to its negative molecular charge (Tisdale et al., 1993). Therefore this form of N poses the risk of movement, possibly to groundwater through leaching or surface waters via runoff (Petrovic, 1990).

Phosphorus:

In discussing proper nutrition of plants, often times N is placed at the forefront. However, phosphorus (P) is considered an essential macronutrient for plant growth and development. Phosphorus is critical in the development process during establishment of both seeded and vegetative turfgrass varieties (Turner and Hummel, 1992). In recent years more attention has been placed on the amounts of P needed for plant development versus its potential environmental risks posed to all water bodies (Daniel et al., 1998).

Content of P varies from 0.04% to 0.3% in surface soils throughout the United States (Tan, 2000). Soils of the Northwestern United States generally have higher P contents compared to Southeastern soils (Tan, 2000).

Phosphorus makes up 0.5% of turfgrass dry matter compared to higher nutrient contents of N and potassium (Turgeon, 1999). Its role within the plant involves many vital growth processes including ATP (adenosine triphosphate) used in both respiration and photosynthesis processes (Brady and Weil, 1996). In addition to those specific processes, P can be found in deoxyribonucleic acid (DNA); ribonucleic acid (RNA), as well as in cellular membranes (Brady and Weil, 1996). In order to meet critical plant needs, concentrations between 0.2 and 0.3 mg/L of P must exist within the soil system (Daniel et al., 1998).

The chemical forms of phosphorus in a soil system vary. Therefore, when discussing P within the soil system one must evaluate availability and transformation relationships. Simplified, the P cycle includes three major categories: soil solution P, labile P, and nonlabile P (Tisdale et al., 1993).

Soil solution P provides phosphorus to plant roots for proper growth and development. As plants reduce this source of P from the soil, soil solution P is replenished by labile P sources. Labile P is organic and inorganic forms of P not directly available to the plant; instead, they maintain high disassociation rates rendering them capable of replenishing or buffering the amount of soil solution P. This form of P can be held in the soil through adsorption to soil colloidal surfaces and precipitates as single bonds with aluminum and iron in acidic soils (Tisdale et al., 1993). In addition to buffering soil solution P, labile P can also be converted into nonlabile P sources.

Nonlabile P represents a fraction of P within the soil that is considered highly unavailable for plant nutrition as well as soil solution. Soil solution P becomes nonlabile through a process known as immobilization or precipitation as a double bond with metals such as aluminum or iron (Tisdale et al., 1993). Several time consuming processes can convert nonlabile P forms to labile P (Tisdale et al., 1993).

Soil solution P contains the inorganic form of orthophosphate ions, $H_2PO_4^-$ and HPO_4^{-2}, that represent the forms primarily utilized by plant roots (Walker and Branham, 1992). The form preferred by plants depends on surrounding pH. Soils with pH 7.2 have equal amounts of $H_2PO_4^-$ and HPO_4^{-2} ions. As pH is lowered, $H_2PO_4^-$ is the predominant form taken up by the plant. The reverse is true for higher pHs (Walker and Branham, 1992).

The transport of P offsite is characterized primarily through sediment or organic movement (Daniel et al., 1998). This is largely due to the quick reduction in the amount of soluble P in soil from precipitation and adsorption reactions (Balogh and Walker, 1992). Since the majority of P is bound by soil and organic matter or precipitates with metals such as iron and aluminum soon after application, soil erosion was thought necessary for P to contribute to eutrophication. Recently this trend has somewhat reversed with researchers, who recognize soluble P as a substantial form of P loss during surface runoff (Daniel et al., 1998).

Surface Runoff Charateristics:

Surface runoff is the movement of water along a slope when rainfall or irrigation exceeds the soil's infiltration capabilities (Hino et al., 1987). In a turfgrass system the possibility of increased soil moisture can be the result of irrigation and/or combination of rainfall events (Morton et al., 1988).

Several factors influence a soil's ability to infiltrate excess water such as root channels, soil cracks, and macrofauna pathways (Merwin et al., 1996). However, soil structure plays the most important role. Clayey textured soils are much more vulnerable to surface runoff compared to soils high in sand content (Rosenthal et al., 1993). This can be explained through soil particle size. Generally, minute clay particles diminish macro-pores while increasing micro-pores. Clay particles may aggregate to form large peds potentially increasing macro-pore drainage. Sand, on the other hand, contains more macro-pores, increasing gravitational drainage pathways. An increase in gravitational drainage pathways (macro-pores) aids infiltration while reducing soil saturation.

Furthermore, increased micro-pores in clayey soils can be detrimental not only through lack of gravitational drainage ways, but in their ability to retain soil moisture through capillary forces. Increased soil moisture in turn can increase runoff quantities while reducing time till runoff (Harrison et al., 1993).

Surface runoff occurrence is primarily influenced by soil characteristics such as texture. Another factor altering surface runoff includes plant growth. Plant matter can decrease surface runoff through increasing infiltration as well as reducing energy associated with water droplet impacts that can cause soil compaction and sealing (Welterlen et al., 1989).

Nutrient and Sediment Losses Via Surface Runoff in Turfgrasses:

The issue of nutrient and sediment runoff in turfgrass has evolved since the mid-nineteen-seventies. Studies first took place examining sediment and nutrient loss in row-crop agriculture as indicated in articles written by McDowell and McGregor, 1980 and Angle et al., 1985. However, due to the differences in growth habit and uses of turfgrasses, further studies were needed to understand the complexities between nutrient management and losses through runoff.

A lack of turfgrass runoff research is evident in an article written by A. Martin Petrovic in the Journal of Environmental Quality entitled "The Fate of Nitrogenous Fertilizers Applied to Turfgrass." Petrovic discusses the various fates of N in the soil-plant-atmosphere continuum. The topic of N runoff is only briefly covered in a three paragraph section preceded by the note "A limited number of studies have been conducted to determine the quantity of fertilizer containing N that will run off a turfgrass site" (Petrovic, 1990).

One of the earliest publications concerning possible nutrient losses via surface runoff in a turfgrass system was written by K. A. Kelling and A. E. Peterson (1975). They simulated rain for 90 minutes at 12 cm hr^{-1} on nine established home lawns treated with low, normal, high, and no amount of N and phosphorus. Differences between the treatments occurred at the high level of fertilization. In addition to making a distinction between fertilizer regimes, Kelling and Peterson helped define the concentration of N and P as a component of time. The N and P levels were found to be highest in the initial runoff with reduced concentrations in runoff.

Years later, T. G. Morton, A. J. Gould and W. M. Sullivan, studied the relationship between over-watering and loss of nitrate (NO3-N) on established Kentucky bluegrass (*Poa pratensis* L.) stands in Rhode Island (Morton et al., 1988). Various N application rates were used ranging from 0.97 to 244 kg ha^{-1} yr^{-1} in conjunction with two irrigation rates, one to water as needed to prevent drought stress and the other an application of 3.75 cm per week. Runoff on the sandy loam soil occurred only twice and accounted for less than 7% of inorganic N loss of any selected treatments (Morton et al., 1988).

Three studies were conducted in Maryland concerning nutrient and sediment losses from plots sodded with tall fescue (*Festuca arundinacea* Schreb.) and Kentucky bluegrass plots and treated with granular and liquid fertilizers (Gross et al., 1990, 1991). One study analyzed sediment content, N in the nitrate and ammonium forms and P as ortho-phosphate, total soluble P, and total P as runoff. Results from the second year indicated that granular application had a significantly (0.05 level) higher runoff loss in the ammonium form versus liquid application, but that there was no difference between nitrate levels of the liquid, granular, or control for both years (Gross et al., 1990). Various P measurements did not differ with treatment the first year. However, in the second year liquid fertilizer application increased loss of ortho-P to 123.10 g ha^{-1} compared to the granular fertilizer and control of 46.53 and 29.99 g ha^{-1} respectively (Gross et al., 1990). The increased ortho-P loss from the liquid fertilizer was thought to be related to the increased runoff amounts compared to the granular fertilized and control plots.

A second study monitored nitrate levels in soil under tall fescue/Kentucky bluegrass sod through two years (Gross et al., 1990). The total N applied was 220 kg N ha^{-1} yr^{-1} according to the following schedule: 25 March (49 kg N ha^{-1}), 20 May (24 kg N ha^{-1}), 1 September (49 kg N ha^{-1}), 15 October (49 kg N ha^{-1}), 1 December (49 kg N ha^{-1}) (Gross et al., 1990). Soil samples were taken in the spring and autumn to analyze for soil nitrate N concentrations. Differences in concentrations were not found between the granular and liquid fertilizer treatments, but both soil N concentrations were higher compared to the untreated control. This experiment demonstrated the fluctuation of soil nitrate content and the ability to increase soil nitrate levels through fertilizer applications. Nitrate levels were highest for all three treatments during the Fall of 1987 after two years of N application. It was suggested that lack of differences in nitrate levels among the treatments could be due to the split application of N “when plants were actively growing and could efficiently utilize the N fertilizer” (Gross et al., 1990). This particular research indicated the presence of N within the soil system and the role of N application. The increased N concentration within the soil indicates higher risks of nutrient movement off the site during rainfall events.

Gross et al. (1991) also examined runoff and sediment losses from turf-type tall fescue under rainfall simulation. The treatments included seeding rates of 0, 98, 344, 390, 488 kg ha^{-1} and rain intensities including a low, medium, and high rates: 76, 94, and 120 mm hr^{-1} respectively. The results demonstrated that generally as the seeding rate increased so did the time till runoff regardless of the rain intensity. At the 0 kg ha^{-1} seeding rate there was greater sediment loss and runoff volume at the low and medium rain intensities compared to all other seeding rates. The only exception occurred at the high intensity rainfall (120 mm hr^{-1}) where the only difference in sediment loss between the 0 kg ha^{-1} and other seeding rates was observed for the highest seeding rate of 488 kg ha^{-1}, which significantly reduced sediment loss. The authors concluded that turfgrass cover could increase infiltration, while absorbing most of the energy of falling raindrops, and disrupting water flow, thus trapping sediment (Gross et al., 1991).

Linde et al. (1997) conducted a study of nutrient and sediment runoff of creeping bentgrass (*Agrostis palustris* Huds.) and perennial ryegrass (*Lolium perenne* L.). These turfgrasses were studied as six year old mixed established stands, using 9-11% sloped plots 6.5 m wide and 19 m long. Plots were fertilized using a 19-1.3-15.8 (N-P-K) granular fertilizer applied at the rate of 4.9 g N m^{-2}, 0.3 g P m^{-2}, and 4.1 g K m^{-2}, eight hours before rainfall simulation. Rain was simulated at 139 mm hr^{-1} for 25 minutes on creeping bentgrass and 15 minutes on perennial ryegrass by installed irrigation heads. Rainfall simulation occurred every two weeks between June and October in 1994 and May and September for 1995 with fertilizer being applied twice. After two years of data collection nitrate levels were reported to be consistently lower than the 10 mg L^{-1} drinking water standard set by the USEPA (United States Environmental Protection Agency). However P (orthophosphates) was detected in runoff, accounting for as much as 17% of lost P. P losses through surface runoff were highest for plots which received fertilizer applications prior to rainfall simulation compared to rainfall events which did not receive fertilizer applications. In addition, samples collected soon after surface runoff initiation were generally higher in P concentrations than subsequent samples collected over the rainfall event.

Sediment losses were also collected. Because the water runoff samples contained little to no sediment, it was concluded that on average very little sediment transport took place, even with the addition of management practices such as vertical mowing to thin the canopy (Linde et al., 1997).

Comparing bentgrass to perennial ryegrass showed several differences in runoff occurrence. Due to the stoloniferous growth habit of bentgrass, the pathway for runoff appeared more tortuous allowing additional time for the water to infiltrate. The perennial ryegrass canopy tiller-type growth habit was thought limited in its ability to hinder water runoff movement, resulting in a faster occurrence of surface runoff (Linde et al., 1995).

The length of the grass buffer, mowing height, and the use of solid-tine aerification on pesticide and nutrient runoff in bermudagrass was studied in Oklahoma (Cole et al., 1997). The experiment was conducted on established 6% sloped common bermudagrass turf tracts as buffers of 0, 2.4, and 4.9 m, mowed at a height of 1.3 cm and 3.8 cm three times per week. Plots were fertilized at a rate of 98 kg N ha^{-1} in August 1994 and 49 kg N ha^{-1} in May 1995 using urea (46%). In addition to different buffer lengths some plots were deep, solid-tine aerated to determine its influence on surface runoff and losses. Rainfall was administered using a portable rainfall simulator, that dispensed 14,500 and 21,600 L. Results of the study showed nitrate levels to be well below the USEPA 10 mg L^{-1} with buffer lengths of 2.4 m and 4.9 m irrespective of aerification practice or mowing height during 1994. In 1995 the 4.9 m buffer was the only treatment able to show a significant reduction in surface runoff N loss compared to the 0 and 2.4 m buffers. Bermudagrass canopy architecture was thought to reduce sediment losses through increased infiltration created by the aggressive growth, disrupting surface water pathways (Cole et al., 1997).

Research associated with surface runoff in turfgrass has largely focused on N and sediment movement. This may simply be due to the belief that N and sediment from turfgrass systems contribute more heavily to eutrophication of surrounding water bodies; or that P runoff is closely correlated with sediment losses and that the reduction in sediment erosion results in less P loss during surface runoff. Established turfgrass systems differ from traditional agriculture in lack of soil tillage associated with annual cropping systems. Researchers cited turfgrass sod as excellent buffer plants to prevent or mediate N and sediment losses (Beard, 1994). However, P presence in runoff may or may not always be correlated with sediment. Probably at no other time does turf resemble traditional row crop agriculture in potential runoff than during establishment. Therefore, the limited research concerning P runoff specifically in turfgrass systems, prompts investigation into literature pertaining to P runoff in traditional agriculture.

Phosphorus, a limiting nutrient in algae growth, represents the most studied nutrient in agriculture in relation to surface water eutrophication (Pote et al., 1999b). In the past P was described as a nutrient that was less soluble and mobile compared to nitrate. This lack of mobility may have resulted in overlooking potential movement from turf systems. Recently, P hazards have been discussed in terms of dissolved reactive P from manure applications in production agriculture (Pote et al., 1999b, Daniel et al., 1998, Sharpley, 1995).

Phosphorus concentrations of 250 $\mu g\ L^{-1}$ in surface waters are capable of causing eutrophication. Concentrations of P causing eutrophication in streams entering lakes/reservoirs and lakes/reservoirs themselves have been reported at 0.05 mg L^{-1} and 0.025 mg L^{-1} respectively (Daniel et al., 1998). Available P, in the aforementioned concentrations, promotes algae growth. As the algae population explodes the rate of algal death and decaying increases, resulting in processes depleting dissolved oxygen concentrations. The reduced concentration of dissolved oxygen within the water alters the biological ecosystem and its ability to sustain aquatic life.

In research concerning potential P runoff, sediment erosion prevention has been addressed, but the issue of dissolved reactive P (DRP) has only begun to be evaluated. Recent investigations have begun to address the issue of P applications and their transfer through surface runoff as dissolved P (Sharpley et al., 2000).

Sharpley (1995) discusses the loss of bioavailable P and its direct relationship with extractable P. Using soils from fescue fields in Oklahoma receiving regular poultry litter applications, Sharpley demonstrated the relationship of available P and runoff P. Soil samples were taken and incorporated with poultry litter to the 5 cm depth. Soil samples were then taken to the 1 cm depth and analyzed for bioavailable P. Irrigation was applied, inducing surface runoff. Runoff samples were collected and separated according to filtered and non-filtered. Filtered samples were analyzed for dissolved P, while unfiltered samples measured particulate, bioavailable, and total P (Sharpley, 1995).

Sharpley's research reported low P-sorbing soils had a higher tendency to contribute P to surface runoff than high P-sorbing soils. However surface runoff losses from soils saturated with P can be similarly characterized regardless of the P-sorbing potential. This information relating P-sorbing potential and release of P through surface runoff recognized the importance of soil characteristics and P levels as factors in determining P losses during rainfall events. Therefore, caution is warranted when using soil P levels alone as a P loss indicator through surface runoff, rather this is a starting point to the development of P nutrient management plans (NMP) (Sharpley, 1995).

Pote et al. (1999a) compared soil phosphorus (STP) levels and runoff concentrations. Soil tests, examining exchangeable P were taken and analyzed for three Ultisols (Nella, Linker, and Noark) used in agriculture production. These soils received regular applications of swine or cattle manure and/or commercial fertilizer. Using simulated rainfall, surface runoff was created with subsamples taken every five minutes and analyzed for dissolved reactive P (DRP). The results showed a convincing linear relationship between STP and DRP. P levels in the upper 2 cm of soil contribute heavily to the DRP in surface runoff, but that differences in STP determination of DRP can occur across soil types (Pote, 1999a).

Both Sharpley and Pote demonstrated the threat of phosphorus overloading in soils relating to soil type, and its potential movement off site as DRP (Sharpley, 1995, Pote, 1999a). The threat of eutrophication cannot solely be characterized by soil P levels as they relate to soil P-sorption capabilities. Instead, the issue of specific site evaluation in respect to runoff potential has been emphasized among researchers. Through recognition of important factors such as climate, topography, and other agronomic factors, one is better able to assess surface runoff risks. Better risk calculations through site assessment can translate to P application recommendations and timing regardless the P source (Sharpley, 1995).

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Introduction

Eutrophication first observed during the later half of the nineteenth century continues to plague water bodies throughout the United States. Once productive estuaries, like the Chesapeake Bay, have been polluted through continuous nutrient overloading (Welterlen et. al 1989).

Nutrient movement into surface water bodies aids in the proliferation of algae, resulting in depletion of existing dissolved oxygen levels, and ultimately rendering areas inhabitable to aquatic plant and animal life (Starrett et al 1995). Such results have prompted researchers to study the complicated relationships of watersheds and man as well as evaluate potential sources of contamination in hopes of developing effective strategies to prevent or reduce the risk of eutrophication.

In order to begin this enormous undertaking scientists and government regulatory agencies have classified nutrient loading into two major categories, point and non-point, dependent upon the origin. Point sources, including waste water treatment centers and industry, are often easy to identify and quantify. Because non-point sources, such as agricultural land, are heavily dependent on a variety of environmental conditions and anthropogenic activity, it has not been as easy to identify areas of direct contamination or their participation within the eutrophication process (Daniel et al. 1998).

One area of non-point contamination to fall under increased scrutiny is the occurrence of surface runoff on land used for agricultural purposes (Daniel et al. 1998). Sloped lands, continual soil disturbance, poor plant coverage, use of fertilizer, and intense rains all impact surface runoff. Large rural acreage and the threat of surface runoff has spurred agronomic disciplines to take a more active research role into evaluating methods to prevent eutrophication of streams, rivers, ponds, and lakes.

Turfgrass science, grouped as an agronomic science, as a whole does not share similar objectives in regard to production agriculture. Rather it is concerned mainly with the visual aesthetics and functional use of turfgrass for a variety of applications under different levels of maintenance. Because turfgrass systems, once established, lacks appreciable soil disturbance or fallow periods of exposed soil, many researchers have recognized the environmental benefits associated with turfgrass cover (Beard 1994).

Bermudagrass, a popular turfgrass used widely throughout the Southeast, has been noted for its ability to reduce surface runoff, therefore decreasing nutrients lost to surrounding water bodies (Cole et al. 1997). Aggressive stoloniferous and rhizomatous bermudagrass growth helps weave a dense canopy allowing the turf to be capable of: dispersing energy associated with falling raindrops, thus reducing soil compaction; hindering lateral movement of water; reducing sediment loss; and increasing the soils infiltration capabilities (Welterlen et al. 1989, Linde et al. 1995,1997; Cole et al.1997; Gross et al. 1990, 1991). However, these qualities have only been recognized for mature turf and do not take into account the risks associated with periods of exposed soil during bermudagrass sprig establishment.

Currently, improved varieties of bermudagrass are established primarily through two vegetative methods, sprigging and sodding (Duble 1996). Use of seeded bermudagrasses especially in the transitional zone has been limited because of historically poor winter survival (Puhulla et. al. 1999). Vegetative cultivars have been more reliable in winter survivability.

Sprigging is less costly, yet an effective method to establish bermudagrass when compared to sod. The practice is to plant sprigs, depending heavily on aggressive rhizomatous and stoloniferous lateral growth to form a densely covered turf (Ruemmele et al. 1993).

In order to attain a dense bermudagrass turf from sprigs, a common fertilization rate of 48.8 kg N ha^{-1} wk^{-1} is applied (Carrow et al. 2001). This rate allows full establishment by at least the eighth week after planting given optimal environmental conditions. However, the rate may be excessive during the first two to four weeks of bermudagrass sprig establishment because sprigs are morphologically immature. Sprigs have not developed much of a root system and are unable to take advantage of available N, relying more heavily on stored carbohydrate reserves for initial growth processes.

Nutrient fate research focusing on bermudagrass vegetative establishment from sprigs is lacking and has called current establishment practices into question. Unlike mature bermudagrass, the establishment process involves tillage, a period of soil disturbance, low initial plant densities, with relatively high N fertilization and frequent irrigation. In addition, bermudagrass can often be found in areas ranging in soil type and slope (Duble 1996). The combination of establishment driven cultural practices in conjunction with site characteristics results in potential periods of significant surface runoff and environmental risks.

This research investigates the threat of nutrient and sediment movement through surface runoff during bermudagrass sprig establishment. The hypothesis considers that sprigs are too morphologically immature in the first few weeks after planting to effectively use the N that is typically applied during turf establishment.

Materials and Methods

Two separate experiments, one in 2000 and one in 2001, were located on two different sites at the Turfgrass Research Center in Blacksburg, Virginia. The site in 2001 was changed in order to reduce the effect of residual soil nitrogen from the 2000 site which may have magnified nitrogen losses through surface runoff. The 2000 and 2001 sites had slopes ranging from 8 to 10 % and 10 to 12 %, respectively. The soil was classified as a fine, mesic, Typic Hapludult (Groseclose – Urban Land Complex). Composite soil samples were taken from each site the month prior to the first sprig establishment date. Soil test results from the two sites used in 2000 and 2001 were determined by the Virginia Tech soil testing laboratory following Mechlich I procedures (Nelson et al., 1953). The 2000 and 2001 sites soil test results were as follows:

Table 1.1 Soil test results of the 2000 and 2001 study sites in Blacksburg, Virginia

Nutrient/pH	2000		2001	
	--mg L^{-1}--	--Range†--	--mg L^{-1}--	--Range†--
pH	6.1		5.8	
Phosphorus	22	H-	25	H-
Potassium	76	M+	98	H-
Calcium	521	M	762	H-
Magnesium	90	H	120	H

† Range refers to the level within the soil L = low, M = moderate, H = high

Prior to establishment, sites were sprayed with glyphosate (Roundup®) at 9.4 L ha^{-1} to eradicate any existing vegetation. One week later, the soils were tilled in two directions by a tractor operated tiller, raked to remove any rocks and debris, and rolled to maintain evenness of the slope.

Experiments began July 7, 2000 and June 6, 2001. The 2000 date was delayed from June to July due to construction of the rainfall simulator and metal frames used for runoff collection. Because of cooler weather during rainfall simulation in September 2000, the date for beginning in 2001 was moved from July to June to enable rainfall simulation to take place in August, a time when weather is generally more suitable for bermudagrass growth.

Experimental units consisted of sequential establishment of Tifway bermudagrass sprigs at two week intervals over a ten week establishment period. In 2000 this included sprigs planted at 4, 6, 8, and 10 weeks prior to rainfall simulation (WPRS) (Fig. 1.2). In 2001, sprigs were planted 2, 4, 6, 8, and 10 WPRS (Fig. 1.2). Each sprig treatment was established using one of two N application regimes. One used the industry standard practice (ISP) rate of 48.8 kg N ha^{-1} wk^{-1}. The other followed the lower initial N (LIN) treatment which received 12.2 kg N ha^{-1} wk^{-1} for the first four weeks after planting followed by the ISP-N rate the remaining weeks. Sod was transplanted 4 and 10 WPRS in 2000 and 2 and 4 WPRS in 2001. Sodded plots were fertilized with 48.8 kg N ha^{-1} at an interval of two weeks beginning two weeks after sod transplanting. The only difference between experiments in 2000 and 2001 aside from time of sod establishment was the absence of the two week establishment date in 2000. This was due to logistical complications concerning rainfall simulation during 2000.

Table 1.2 Vegetative establishment and nitrogne treatments for 2000 and 2001 experiments.

Vegetative Establishment		Experiment Year		N Applied During Growth Period†		N Applied 30 minutes Prior to Rainfall Simulation	Total N Applied
Method	Period	2000	2001	Weeks 1 – 4	Weeks 5 – 10		
	----WPRS----			----------kg ha^{-1} wk^{-1}----------		------------ kg ha^{-1}------------	-- kg ha^{-1}--
Sprigs	10	+	+	48.8	48.8	48.8	488.0
Sprigs	10	+	+	12.2	48.8	48.8	341.6
Sprigs	8	+	+	48.8	48.8	48.8	390.4
Sprigs	8	+	+	12.2	.48.8	48.8	244.0
Sprigs	6	+	+	48.8	48.8	48.8	292.8
Sprigs	6	+	+	12.2	48.8	48.8	146.4
Sprigs	4	+	+	48.8	0	48.8	195.2
Sprigs	4	+	+	12.2	0	12.2	48.8
Sprigs	2	-	+	48.8	0	48.8	97.6
Sprigs	2	-	+	12.2	0	12.2	24.4
Sod	10	+	-	48.8	48.8	48.8	244.0
Sod	4	+	+	48.8	0	48.8	97.6
Sod	2	-	+	48.8	0	48.8	48.8
Bare	0	+	+	0	0	0	0

† Sod was fertilized on two week intervals beginning two weeks after planting

Sprigs and sod were planted in 1 by 2.8 m plots constructed to be larger than the metal frames used during rainfall simulation. The metal frames used in rainfall simulation were constructed to simultaneously rain on two adjacent plots. Therefore, treatments were randomly paired to satisfy statistical requirements. In order to separate adjacent plots during the establishment period, a buried plastic divider extended perpendicularly down between paired plots. Between replications, bermudagrass buffer strips (1 m wide) were used to prevent nutrient and sediment movement during natural rainfall occurrences over the ten week establishment period.

Sprigs were obtained by harvesting and shredding mature Tifway bermudagrass sod grown at the Turfgrass Research Center. Sod strips measuring 30.5 cm wide and 50.8 cm long were cut and shredded for each sprig treatment. Plots were roto-tilled to a 10 to 12 cm depth and leveled by raking prior to each establishment date. The surface 3 to 4 cm of soil was removed and used for topdressing after the sprigs were broadcast at the rate of 988.4 bu ha^{-1}. After lightly topdressing, plots were hand-rolled to increase sprig-soil contact. Sprigs were irrigated immediately to prevent desiccation and irrigation was applied as needed to encourage development.

Soil preparation for sodded treatments was similar, with the exception of the elimination of soil removal for topdressing. Sod was harvested from the same location as sprigs. It took three sod strip sections, laid following the downward slope, to cover the 1m by 2.8 m plots. Irrigation was applied immediately and as needed to encourage sod rooting.

The control, bare ground, was sprayed every other week with paraquat (Gramoxone®) to prevent any weed infestation. The week prior to rainfall simulation the control plot vegetation was completely removed. Bare ground plots were never tilled and had no nitrogen applied at or prior to rainfall simulation.

The N treatments consisted of granular ammonium nitrate (NH_4NO_3 34-0-0) dissolved in water and applied using a CO_2 pressurized sprayer delivering 373.46 L ha^{-1}, with fertilizer concentrations of 194.32 g L^{-1} for the ISP and 97.16 g L^{-1} for the LIN. ISP N applications were administered as split applications, twice a week, to minimize fertilizer burn. The only exception to the split application of the 48.8 kg N ha^{-1} wk^{-1} rate was the week of rainfall simulation when N treatments were applied at the full rate. N applications were followed by light irrigation for all fertilizer applications during the experiment except prior to rainfall simulation.

The only misapplication of fertilizer occurred in 2001 on the sod treatment installed 4 weeks prior to rainfall simulation. Sod was transplanted from a portion of the sod/sprig harvesting site that had been fertilized with 48.8 kg N ha^{-1} of ammonium sulfate (24-0-0) in preparation for another experiment. The transplantation of fertilized sod increased N content and resulted in greater N loss through surface runoff.

Regular plot maintenance consisted of a 2.54 cm mowing height, irrigation as necessary, and the use of paraquat (Gramoxone®) between paired plots, replications, and on bare ground treatments to prevent weed infestation. Oxadiazon (Ronstar® 2G), applied by a drop spreader at the rate of 1.68 kg a.i. ha^{-1} was used to prevent grassy and broadleaf weed invasion in both sprigged and sodded plots. Hand weeding was used as needed throughout the ten weeks.

At the end of the ten week experiment simulated rainfall, at a rate of 63.5 mm hr^{-1}, was dispersed as evenly as possible over each treatment. Rainfall simulation took place

September 12 – 20, 2000 and August 13 – 20, 2001. Individaul paired plot rainfall simulation continued for a period of thirty minutes after the initiation of surface runoff. The procedure for simulated rainfall was based on the procedures outlined by SERA-IEG 17 (Southern Extension – Research Activity Information Exchange Group 17) for the National P Project. The rainfall rate of 63.5 mm hr^{-1} was also adopted from SERA-IEG 17 as well as represented a historical precipitation rate that can occur every ten years in Western Virginia.

Treatments, a combination of establishment period and N regime, were subjected to rainfall simulation using a 10 m cubed portable rainfall simulator based on the design of Miller (Miller, 1987). Thirty minutes prior to rainfall simulation the final N application was applied and soil moisture readings taken using time domain reflectometry (TDR) in 2000 and soil moisture probe (thetaprobe, Delta-t Devices Ltd, Burwell, Cambridge, UK) in 2001. Soil moisture levels were taken to assure similar moisture levels of the plots as well as provide information concerning any discrepancies in the data (appendices 12 and 13). Metal frames with an outside measurement of 1.5 m wide and 2 m in length were placed over the two paired treatments and driven 6 to 8 cm into the ground. Paired treatments were separated by a sheet of metal, the center divider that was part of the metal frame, a replacement to the original plot divider. This prevented contamination between treatments during the rainfall simulation event.

A flume was attached to the lower side of the metal plot frames to collect surface runoff. Each flume had hoses attached to lead runoff from the paired treatments into separate carboyles located further down the sloped site. Every five minutes after runoff started, 1 liter samples for the thirty minute rainfall simulated duration were taken from the carboyles with the excess runoff emptied into weighed barrels. Weights of the barrels between samples were recorded.

The 1 liter, five minute interval samples, were taken to the lab each day after rainfall simulation, where they were weighed and 50 ml filtered using 45 μm filter paper and vacuum pump system. The filtrate from each sample was covered and frozen until completion of the rainfall simulation on all treatments and replications. The remaining unfiltered portion of the 1 liter samples were placed in a refrigerator and used for sediment analysis. At completion of the rainfall simulation, the filtered samples were taken into the laboratory and analyzed for N in the nitrate and ammonium forms and phosphorus in organic and inorganic forms.

Section 1

Post Plant Applied Nitrogen Regime Effect on Bermudagrass Vegetative (sprigging) Establishment

The first section of the study is concerned with the establishment of bermudagrass sprigs as influenced by the industry standard practice (ISP) and lower initial N regimes.

Objectives

The objectives of this study were to:

1. Evaluate a lower initial N (LIN) rate during sprig establishment and its effects on bermudagrass development and cover compared to the industry standard practice.

2. Determine how the N regimes LIN and ISP might impact stages of bermudagrass sprig development.

Data Recorded

At rain simulation each treatment was evaluated for percent cover, visual quality, and biomass production for the 1.5 m^2 rain simulated plot portions. Percent cover was a visual assessment of bermudagrass growth with a range 0 to 100% (no cover to full cover). Visual quality is based on the National Turfgrass Evaluation Program (NTEP) rating scale of 1 through 9 where 1 represents bare ground; 5 acceptable turf; and 9 high quality turf (Skogely and Sawyer, 1982). Biomass measurements were accomplished through the taking of three randomly pulled cores (5.08 cm radius) per treatment plot. Roots were then cut from the cores and soil removed. Biomass samples were oven dried at 100°C for 24 hours. The dry weight of the three biomass samples per treatment plot were averaged and calculated to represent the biomass of the 1.5 m^2 treatment plots. Therefore contents of biomass are given as grams per 1.5 m^2.

The statistical design was a randomized complete block design with three replications in 2000 and four replications in 2001. This was accomplished through the randomized pairing of treatments which were based on vegetative method of establishment (sprig or sod), length of establishment period and N regime. The observations in section 1 were able to be analyzed using the statistical package, SAS (Statistical Analysis System) (SAS, 1985), to create ANOVA tables. Means were separated following Duncan's multiple range procedure at the 0.05 alpha level.

2000 Results and Discussion

Bermudagrass Cover at Various Stages of Establishment

The control (Bare), with no vegetation present was given a rating of zero percent. This was significantly ($p = 0.05$) lower than all other treatments, sprig or sod. The control rating represented the base for bermudagrass cover comparison of sprigged bermudagrass treatments.

Beginning with the shortest establishment period, 4WPRS, there was no growth cover difference between the ISP and LIN regimes with 15.0% and 20.0% cover respectively (Table 1.3 and Fig 1.1). Though statistically higher in coverage than the bare ground, the 4WPRS sprigged treatments demonstrated the morphological immaturity of sprigs following both N regimes, resulting in slow growth and lateral spread for the initial four weeks.

Longer establishment periods such as 6WPRS displayed higher coverage as seen by the ISP with 75.0% and 61.6% for the LIN regime than the cover of 4WPRS. In addition, the 6WPRS represented the only statistical cover difference between sprigs following the ISP and LIN N regimes during the same establishment period. The higher bermudagrass cover of the ISP suggested the LIN regime limited N and hindered growth and cover in comparison to the ISP.

Sprigs established 8WPRS and 10WPRS for both the ISP and LIN regimes had no significant differences in bermudagrass growth. The range of cover was between 88.3% and 98.3% for treatments 8WPRS following the LIN regime and 10WPRS under the ISP respectively. Having no statistical difference between the 8WPRS and 10WPRS for both N regimes demonstrated the possibility of slowed bermudagrass growth due to maturation dynamics such as self competition.

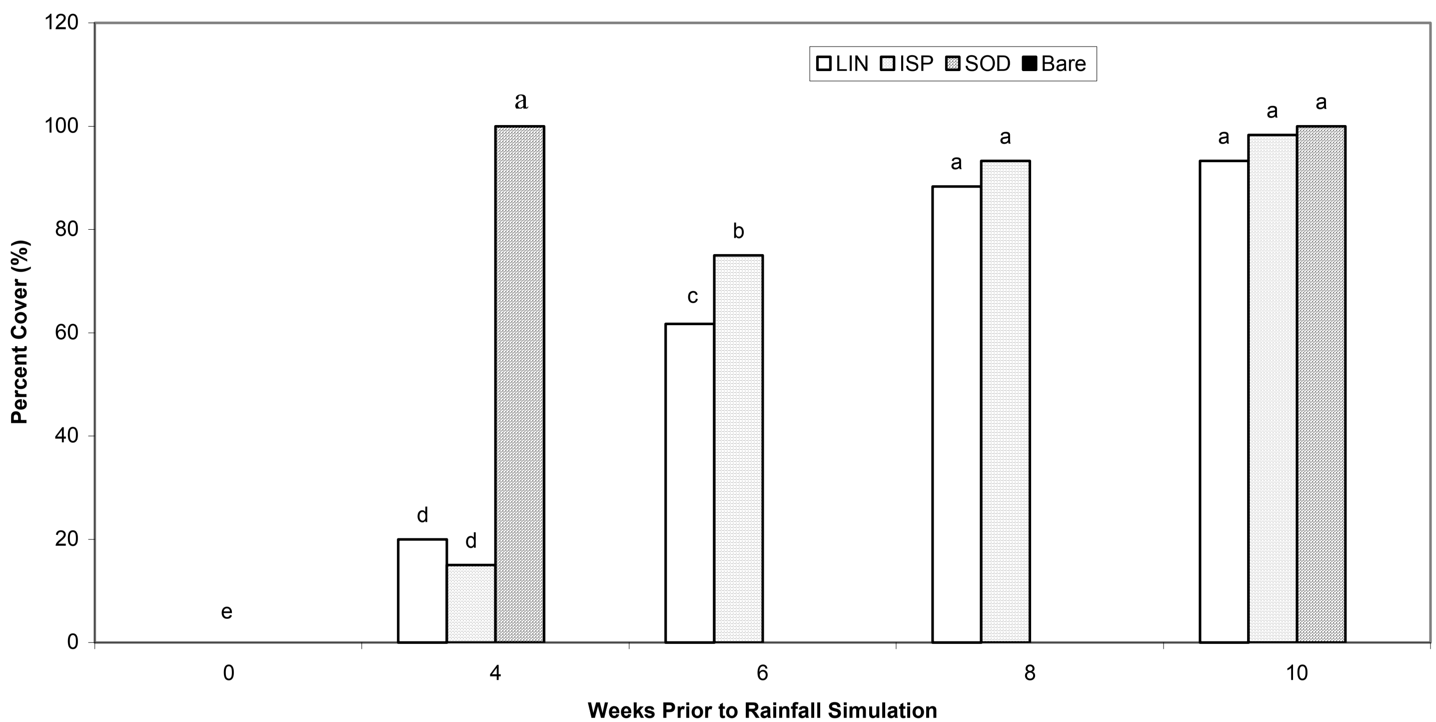
Sprigs receiving the 48.8 kg N ha^{-1} wk^{-1} (ISP) N regime were only higher in bermudagrass percent cover for 6WPRS compared to the LIN N regime of 12.2 kg N ha^{-1} wk^{-1} the first four weeks and 48.8 kg N ha^{-1} wk^{-1} the remaining weeks. The difference may be due to N availability to the plant as related to application timing and plant development. Treatments established longer than 6WPRS, had no statistical differences between establishment periods and N regimes. This suggests sprigs do not gain any long term benefit with early, heavy N fertilization rates at establishment.

Table 1.3 Nitrogen regime influence on 2000 percent ground cover of bermudagrass established 4, 6, 8, and 10 weeks prior to rainfall simulation (WPRS)

Vegetative Establishment		N Applied During Growth Period†		N Applied 30 minutes Prior to Rainfall Simulation	Total N Applied	Ground Cover*
Method	Period	Weeks 1 – 4	Weeks 5 – 10			
	----WPRS----	----------kg ha^{-1} wk^{-1}----------		------------- kg ha^{-1}------------	-- kg ha^{-1}--	---------%--------
Sod	4	48.8	0	48.8	97.6	100.0 a
Sprigs	10	48.8	48.8	48.8	488.0	98.3 a
Sprigs	10	12.2	48.8	48.8	341.6	93.3 a
Sprigs	8	48.8	48.8	48.8	390.4	93.3 a
Sprigs	8	12.2	48.8	48.8	244.0	88.3 a
Sprigs	6	48.8	48.8	48.8	292.8	75.0 b
Sprigs	6	12.2	48.8	48.8	146.4	61.7 c
Sprigs	4	12.2	0	12.2	48.8	20.0 d
Sprigs	4	48.8	0	48.8	195.2	15.0 d
Bare	0	0	0	0	0	0 e

* Means with the same letter are not significantly different according to Duncan's Multiple range test at the 0.05 level of probability.
† Sod was fertilized on two week intervals beginning two weeks after planting

Figure 1.1 Nitrogen regime† influence on 2000 percent ground cover for bermudagrass established 4, 6, 8, 10 weeks prior to rainfall simulation (WPRS).



* Means with the same letter are not significantly different according to Duncan's multiple range test at the 0.05 level of probability.

† ISP – 48,8 kg N ha^{-1} wk^{-1} LIN – 12.2 kg N ha^{-1} (weeks 1 – 4) and 48,8 kg N ha^{-1} (weeks 5 – 10)

SOD - 48,8 kg N ha^{-1} on two week intervals beginning two weeks after planting.

The sod treatments at 10WPRS and 4WPRS, rated at 100%, represented a full stand or upper limit of the cover ratings. Only treatments 8WPRS and 10WPRS under both N regimes were statistically similar to the sodded treatments. However, turf density rated as percent cover of the sodded treatments were above the highest sprig treatment, 10WPRS of the ISP with a rating of 98.3%. Sod represented an instant cover with mature plants able to maintain full density with applied N.

Visual Quality at Various Stages of Bermudagrass Establishment

Visual quality ratings, based on the NTEP method, assess the uniformity, density, color, and texture of a turfgrass stand. The data is summarized in Table 1.3 and in Figure 1.2, quality ratings improved with longer establishment periods as a result of increased bermudagrass cover (Table 1.4 and Figure 1.2). The control (Bare) was given the lowest rating, a one rating, because of the lack of vegetation.

Sprigs established 4WPRS and 6WPRS following the ISP and LIN regimes showed no differences at the 0.05 level. In fact, the ratings were the same for both N regimes at 4WPRS with a rating of 2.7 and 6WPRS at 4.3. The sprigs 4WPRS represented morphologically immature plants and lacked the density to truly represent an acceptable turf (rating ≥ 5). The 6WPRS sprigs, with unacceptable status, showed better quality compared to the 4WPRS establishment period. This improvement marked the influence of increased growth and as a result better aesthetic appeal that can occur with two additional weeks growth on visual quality ratings.

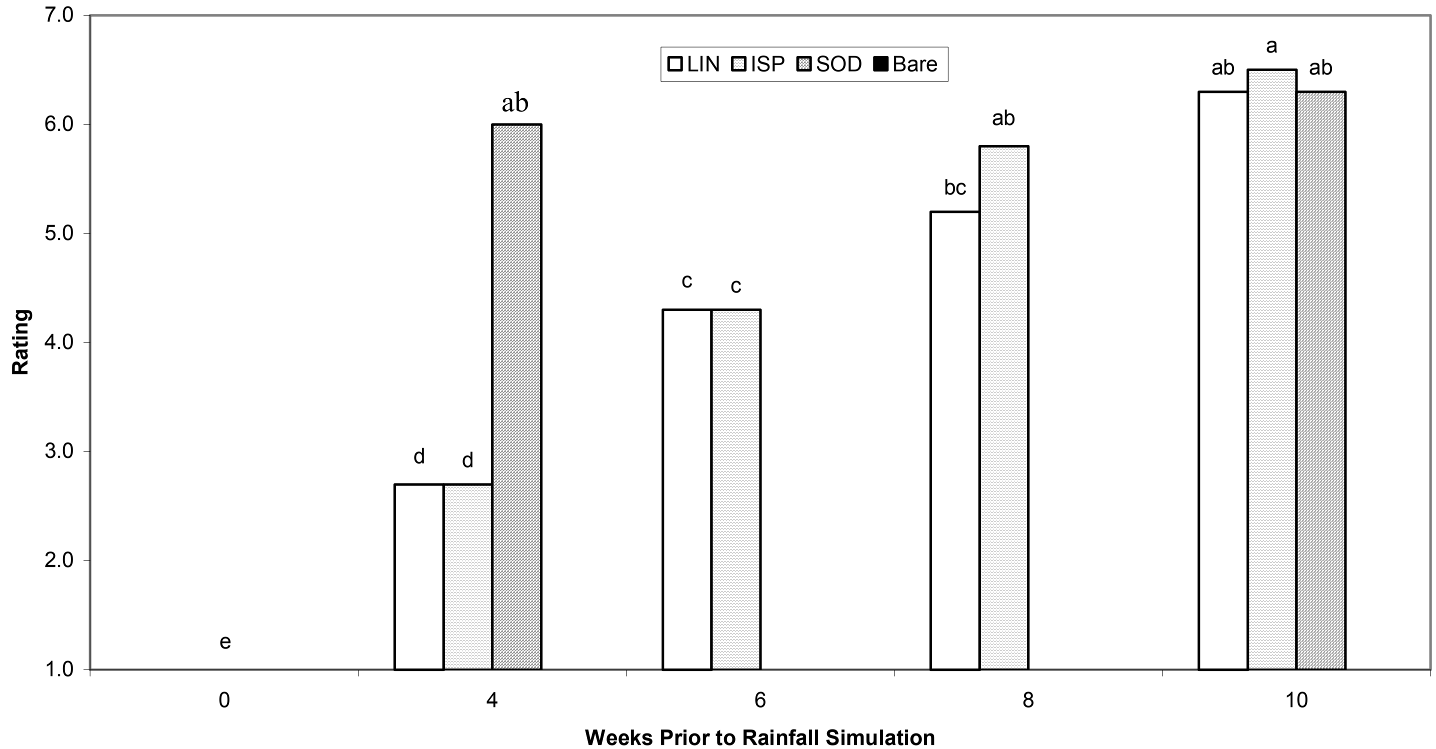
As the length of the establishment period increased and bermudagrass cover improved, ratings edged upward as demonstrated with the establishment treatments

Table 1.4 Nitrogen regime influence on 2000 visual quality of bermudagrass established 4, 6, 8, and 10 weeks prior to rainfall simulation (WPRS)

Vegetative Establishment		N Applied During Growth Period†		N Applied 30 minutes Prior to Rainfall Simulation	Total N Applied	Quality‡*
Method	Period	Weeks 1 – 4	Weeks 5 – 10			
	----WPRS----	----------kg ha^{-1} wk^{-1}----------		------------- kg ha^{-1}------------	-- kg ha^{-1}--	---rating---
Sprigs	10	48.8	48.8	48.8	488.0	6.5 a
Sprigs	10	12.2	48.8	48.8	341.6	6.3 ab
Sod	10	48.8	48.8	48.8	244.0	6.3 ab
Sod	4	48.8	0	48.8	97.6	6.0 ab
Sprigs	8	48.8	48.8	48.8	390.4	5.8 ab
Sprigs	8	12.2	48.8	48.8	244.0	5.2 bc
Sprigs	6	48.8	48.8	48.8	292.8	4.3 c
Sprigs	6	12.2	48.8	48.8	146.4	4.3 c
Sprigs	4	12.2	0	12.2	48.8	2.7 d
Sprigs	4	48.8	0	48.8	195.2	2.7 d
Bare	0	0	0	0	0	0 e

* Means with the same letter are not significantly different according to Duncan's Multiple range test at the 0.05 level of probability.
† Sod was fertilized on two week intervals beginning two weeks after planting
‡ Quality rating scale is 1 through 9 (1 = bare ground; 5 = acceptable turf; 9 = highest quality turf)

Figure 1.2 Nitrogen regime† influence on 2000 visual quality for bermudagrass established 4, 6, 8, and 10 weeks prior to rainfall simulation (WPRS).



* Means with the same letter are not significantly different according to Duncan's multiple range test at the 0.05 level of probability.

† ISP – 48,8 kg N ha^{-1} wk^{-1} LIN – 12.2 kg N ha^{-1} (weeks 1 – 4) and 48,8 kg N ha^{-1} (weeks 5 – 10)

SOD - 48,8 kg N ha^{-1} on two week intervals beginning two weeks after planting.

The 8WPRS and 10WPRS with 5.2 and 6.0 ratings for the LIN regime and 5.8 and 6.3 ratings for the ISP, respectively. Additionally, sprigs established 8WPRS and 10WPRS demonstrated no statistical differences between N regimes during the same establishment period. However, the ISP regime quality ratings trended higher than the LIN regime 8WPRS and 10WPRS. At 8WPRS, both N regimes attained acceptable turf status with ratings above 5 representing dense, uniform, aesthetically pleasing turf stands. Sprigs established 10WPRS were statistically similar to the 8WPRS for both N regimes with 10WPRS of the ISP representing the most uniform and aesthetically pleasing turf stand with the highest rating, 6.5.

Sod treatments at 10WPRS and 4WPRS represented acceptable turf stands as seen with ratings of 6.3 and 6.0, respectively, regardless of the establishment period. Both sodded treatments were statistically similar to sprigs established 8WPRS and 10WPRS for both the ISP and LIN regimes, signifying sprigs can be as visually accepting compared to sod after eight weeks of establishment.

Biomass Production at Various Stages of Bermudagrass Establishment

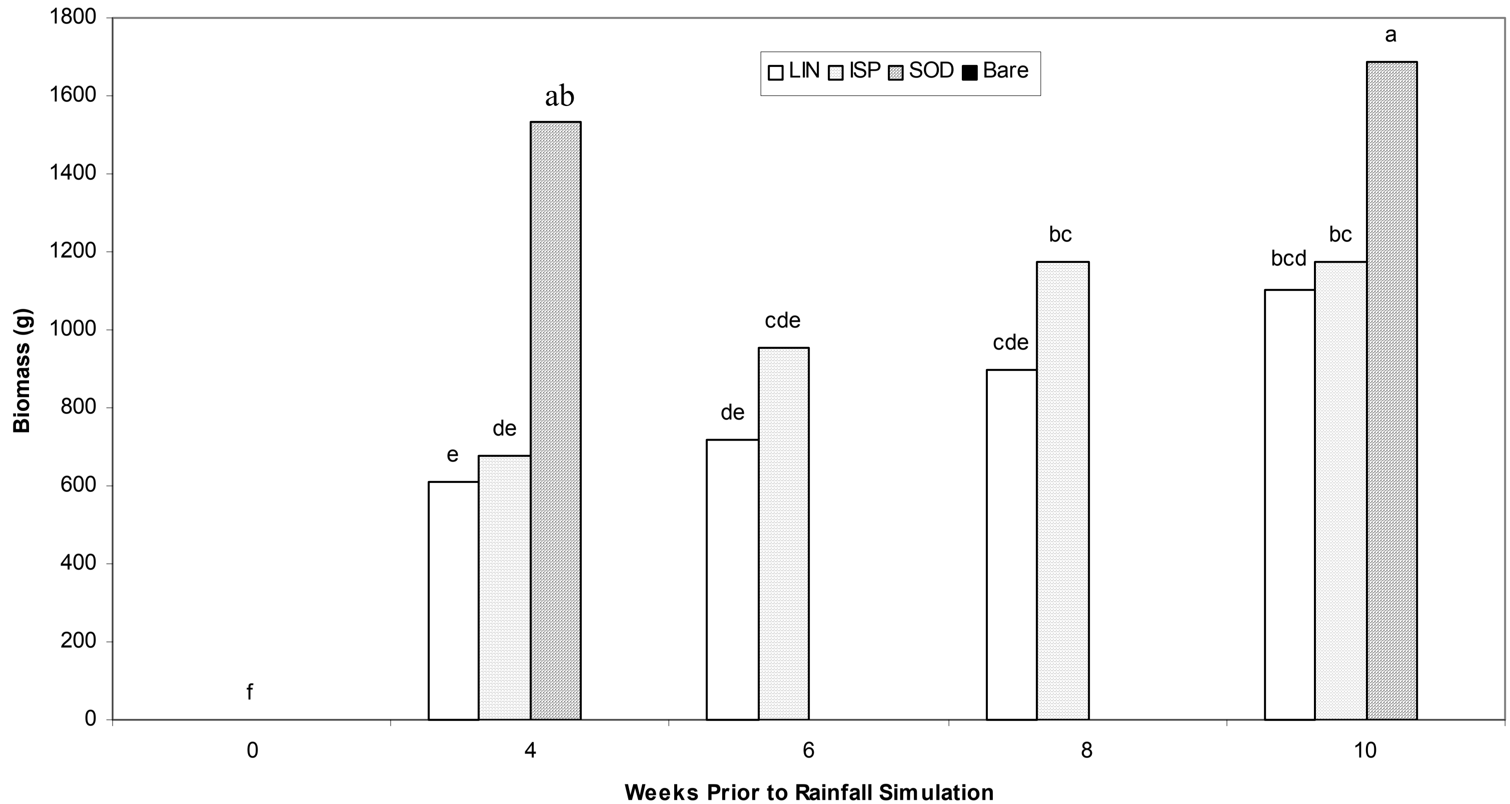
The bare treatment plots had no samples taken because of the lack of vegetation. No differences existed between the ISP and LIN regimes for each establishment period of 4, 6, 8, and 10 WPRS (Table 1.5 and Fig. 1.3). The lack of differences between the ISP and LIN regimes suggests both N fertilization regimes satisfied bermudagrass sprig N requirements for proper growth and development for each establishment period. Sprigs following the ISP regime did have slightly heavier biomass from 4WPRS to and including 10WPRS compared to sprigs growing under the LIN regime. The difference

Table 1.5 Nitrogen regime influence on 2000 biomass of bermudagrass established 4, 6, 8, and 10 weeks prior to rainfall simulation (WPRS)

Vegetative Establishment		N Applied During Growth Period†		N Applied 30 minutes Prior to Rainfall Simulation	Total N Applied	Biomass*
Method	Period	Weeks 1 – 4	Weeks 5 – 10			
	----WPRS----	----------kg ha^{-1} wk^{-1}----------		------------- kg ha^{-1}------------	-- kg ha^{-1}--	--g / $1.5m^2$--
Sod	10	48.8	48.8	48.8	244.0	1687.0 a
Sod	4	48.8	0	48.8	97.6	1535.8 ab
Sprigs	8	48.8	48.8	48.8	390.4	1174.0 bc
Sprigs	10	48.8	48.8	48.8	488.0	1172.7 bc
Sprigs	10	12.2	48.8	48.8	341.6	1102.8 bcd
Sprigs	6	48.8	48.8	48.8	292.8	952.3 cde
Sprigs	8	12.2	48.8	48.8	244.0	896.0 cde
Sprigs	6	12.2	48.8	48.8	146.4	715.6 de
Sprigs	4	48.8	0	48.8	195.2	679.1 de
Sprigs	4	12.2	0	12.2	48.8	607.8 e
Bare	0	0	0	0	0	0 f

* Means with the same letter are not significantly different according to Duncan’s Multiple range test at the 0.05 level of probability.
† Sod was fertilized on two week intervals beginning two weeks after planting

Figure 1.3 Nitrogen regime† influence on 2000 biomass of bermudagrass established 4, 6, 8, and 10 weeks prior to rainfall simulation (WPRS).



* Means with the same letter are not significantly different according to Duncan's multiple range test at the 0.05 level of probability.

† ISP – 48,8 kg N ha^{-1} wk^{-1} LIN – 12.2 kg N ha^{-1} (weeks 1 – 4) and 48,8 kg N ha^{-1} (weeks 5 – 10)

SOD - 48,8 kg N ha^{-1} on two week intervals beginning two weeks after planting.

was only a small gain suggesting the LIN regime was able to provide adequate levels of N to attain similar turfgrass biomass while reducing N inputs by 70% the first four weeks and 30% for a ten week establishment period.

Longer establishment periods resulted in heavier biomass as seen from 4WPRS with biomass of 607.8g and 679.1g until 10WPRS at 1172.7g and 1102.8g for the ISP and LIN respectively. The only exception to the pattern of increased biomass with extended establishment periods was noted between the sprigs established 8WPRS and 10WPRS under the ISP which had relatively equal biomass. Increase in plant biomass can be attributed to the additional time allowed for sprig development. As the sprigs aged, root systems capable of using available N also developed; allowing increased N uptake. Increased N uptake supported plant growth processes resulting in higher plant population and size. Once a level of higher growth cover is established as seen between sprigs established 8WPRS and 10 WPRS under the ISP, the increase in biomass may be slowed. Slowed growth may indicate entrance of the turf stand into the maturity dynamics of self-competition (Busey and Myers, 1979).

The sodded bermudagrass treatments, 4WPRS and 10WPRS had the heaviest biomass at 1535.8g and 1687.0g respectively. Sod biomass was increased with the inclusion of a well-developed thatch layer transplanted during establishment.

2001 Results and Discussion

Bermudagrass Cover at Various Stages of Establishment

The bare plot representing the control was rated as zero because of the lack of vegetation. The 2WPRS sprig treatments rated at 9.3% and 10.0% for the ISP and LIN regimes respectively (Table 1.6 and Fig. 1.4). This lack of differentiation between the treatments at 2WPRS establishment period demonstrated the morphologically immaturity and lack of density of bermudagrass sprigs for at least the first two weeks after establishment.

The 4WPRS establishment period did not display any differences between sprigs under the ISP and LIN regimes at 36.3% and 28.8% cover respectively, but were higher in growth compared to the 2WPRS establishment period given two additional weeks growth. The lack of difference in growth between sprigs following both N regimes suggest the sprig N requirements are being satisfied under the LIN as compared to the higher initial N rate of the ISP.

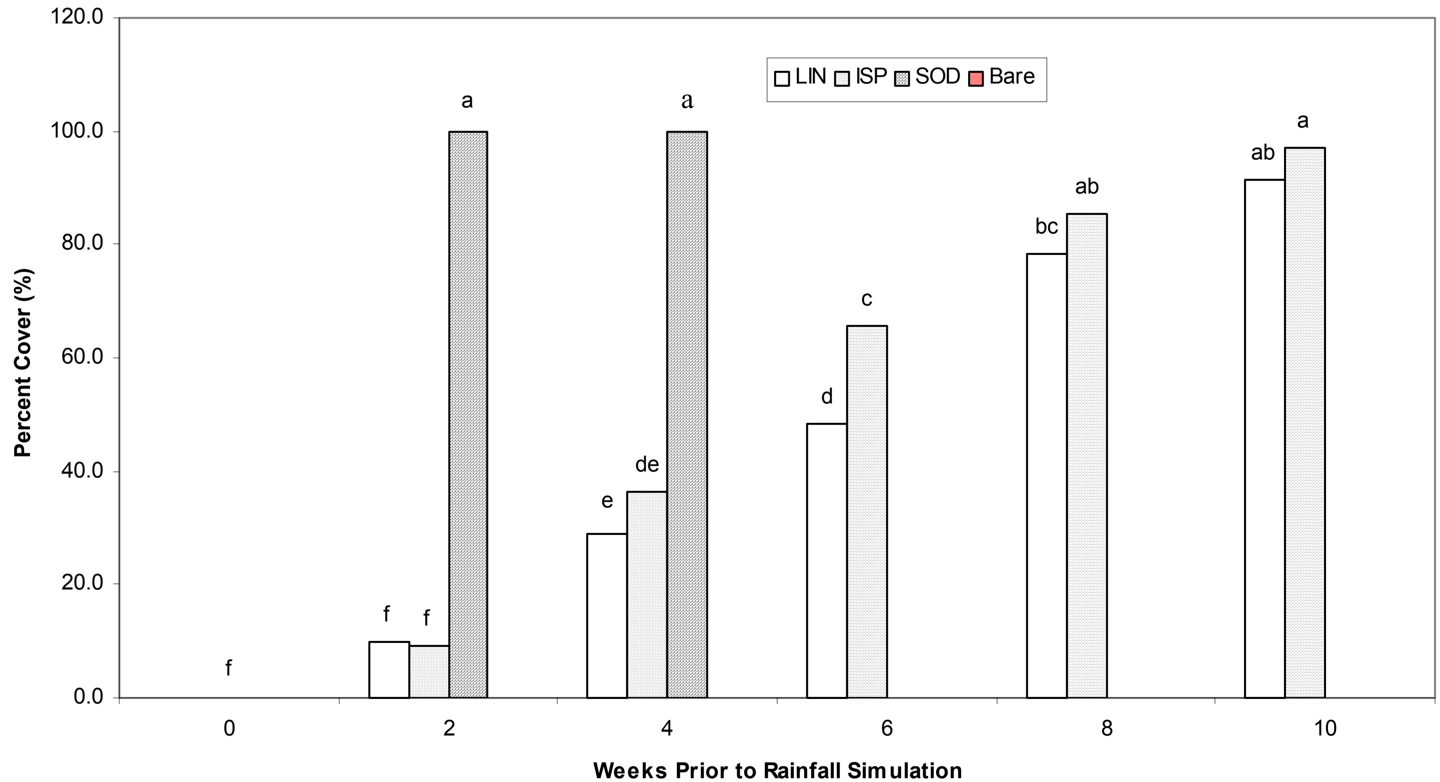
Sprigs established 6WPRS represented the only establishment period in which a statistical difference was noted between sprigs of the ISP and LIN regimes. The sprigs following the ISP experienced greater growth at 65.8% compared to 48.3% under LIN regime. The hindered growth of the sprigs at 6WPRS under the LIN may be due to reduced N applied the initial four weeks. Higher repeated N applications by the ISP could increase the soil N concentration and thus be available for plant growth (Tisdal et al. 1993).

Table 1.6 Nitrogen regime influence on 2001 percent ground cover of bermudagrass established 2, 4, 6, 8, and 10 weeks prior to rainfall simulation (WPRS)

Vegetative Establishment		N Applied During Growth Period†		N Applied 30 minutes Prior to Rainfall Simulation	Total N Applied	Ground Cover*
Method	Period	Weeks 1 – 4	Weeks 5 – 10			
	----WPRS----	----------kg ha^{-1} wk^{-1}----------		------------- kg ha^{-1}------------	-- kg ha^{-1}--	--------%--------
Sod	2	48.8	0	48.8	48.8	100.0 a
Sod	4	48.8	0	48.8	97.6	100.0 a
Sprigs	10	48.8	48.8	48.8	488.0	97.0 a
Sprigs	10	12.2	48.8	48.8	341.6	91.3 ab
Sprigs	8	48.8	48.8	48.8	390.4	85.3 a
Sprigs	8	12.2	48.8	48.8	244.0	78.5 bc
Sprigs	6	48.8	48.8	48.8	292.8	65.8 c
Sprigs	6	12.2	48.8	48.8	146.4	48.3 d
Sprigs	4	48.8	0	48.8	195.2	36.3 de
Sprigs	4	12.2	0	12.2	48.8	28.8 e
Sprigs	2	12.2	0	12.2	24.4	10.0 f
Sprigs	2	48.8	0	48.8	97.6	9.3 f
Bare	0	0	0	0	0	0.0 f

* Means with the same letter are not significantly different according to Duncan's Multiple range test at the 0.05 level of probability.
† Sod was fertilized on two week intervals beginning two weeks after planting

Figure 1.4 Nitrogen regime† influence on 2001 percent ground cover for bermudagrass established 2, 4, 6, 8, and 10 weeks prior to rainfall simulation (WPRS).



* Means with the same letter are not significantly different according to Duncan's multiple range test at the 0.05 level of probability.

† ISP – 48,8 kg N ha^{-1} wk^{-1} LIN – 12.2 kg N ha^{-1} (weeks 1 – 4) and 48,8 kg N ha^{-1} (weeks 5 – 10)

SOD - 48,8 kg N ha^{-1} on two week intervals beginning two weeks after planting

The 8WPRS and 10WPRS establishment periods had no differences in bermudagrass sprig growth at each establishment period. Therefore if any growth differences between sprigs following the N regimes occurred at six weeks after establishment, no significant growth differences were apparent at 8 and 10 WPRS. Additionally, bermudagrass sprigs established 8WPRS at 85.3% under the ISP regime were similar in growth to that of 10WPRS with a cover of 97.0% and 91.3% for sprigs under the ISP and LIN, respectively. The bermudagrass cover similarity of the 8 and 10 WPRS sprig establishments had less increase in cover from one establishment period to the next compared to the sprigs established 6 and 8 WPRS. The difference in growth may be due to self competition as a result of turf stand maturity or possibly poor weather conditions during the first two weeks of sprigs planted 10WPRS resulting in less aggressive growth. Given the 8WPRS coverage of both N regime treated sprigs, reduction in N application rates after eight weeks is warranted.

Bermudagrass growth and cover ratings increased with longer establishment periods, regardless of the N regime. Though not significant except at 6WPRS, sprigs following the ISP fertilization rate did have higher bermudagrass cover for 4WPRS to and including 10WPRS compared to sprigs under the LIN regime. The increase in bermudagrass cover following the ISP was only minimal compared to sprigs under the LIN. This suggests sprigs under the LIN can attain similar coverage to that of ISP treated sprigs, while reducing N inputs by as much as 75% during the first four weeks and 30% for the ten week establishment period.

Sod treatments established 2WPRS and 4WPRS had bermudagrass cover of 100%. Sodded treatments had higher percent cover ratings than any sprig establishment regardless of the N regime and represented an establishment method able to attain and maintain full coverage from applied N. Statistically, the sodded treatments were no different than the sprig treatments established 8WPRS and 10WPRS under the ISP and 10WPRS for the LIN N regimes. These results suggest that sprigs needed eight weeks following the ISP to establish versus ten weeks for LIN.

Visual Quality at Various Stages of Bermudagrass Establishment

The visual quality of bermudagrass sprigs improved with longer establishment periods, as a result of increased bermudagrass growth. Increased growth equated to improved turfgrass uniformity and aesthetic appeal as demonstrated by sprigs fertilized following the ISP and LIN regimes at 2WPRS with ratings of 1.9 and 1.8 compared to 7.4 and 6.8 ratings at 10WPRS, respectively (Table 1.7 and Fig. 1.5). In comparison to the sprigged treatments, the control (bare) was given the lowest rating, one, because no vegetation was presence.

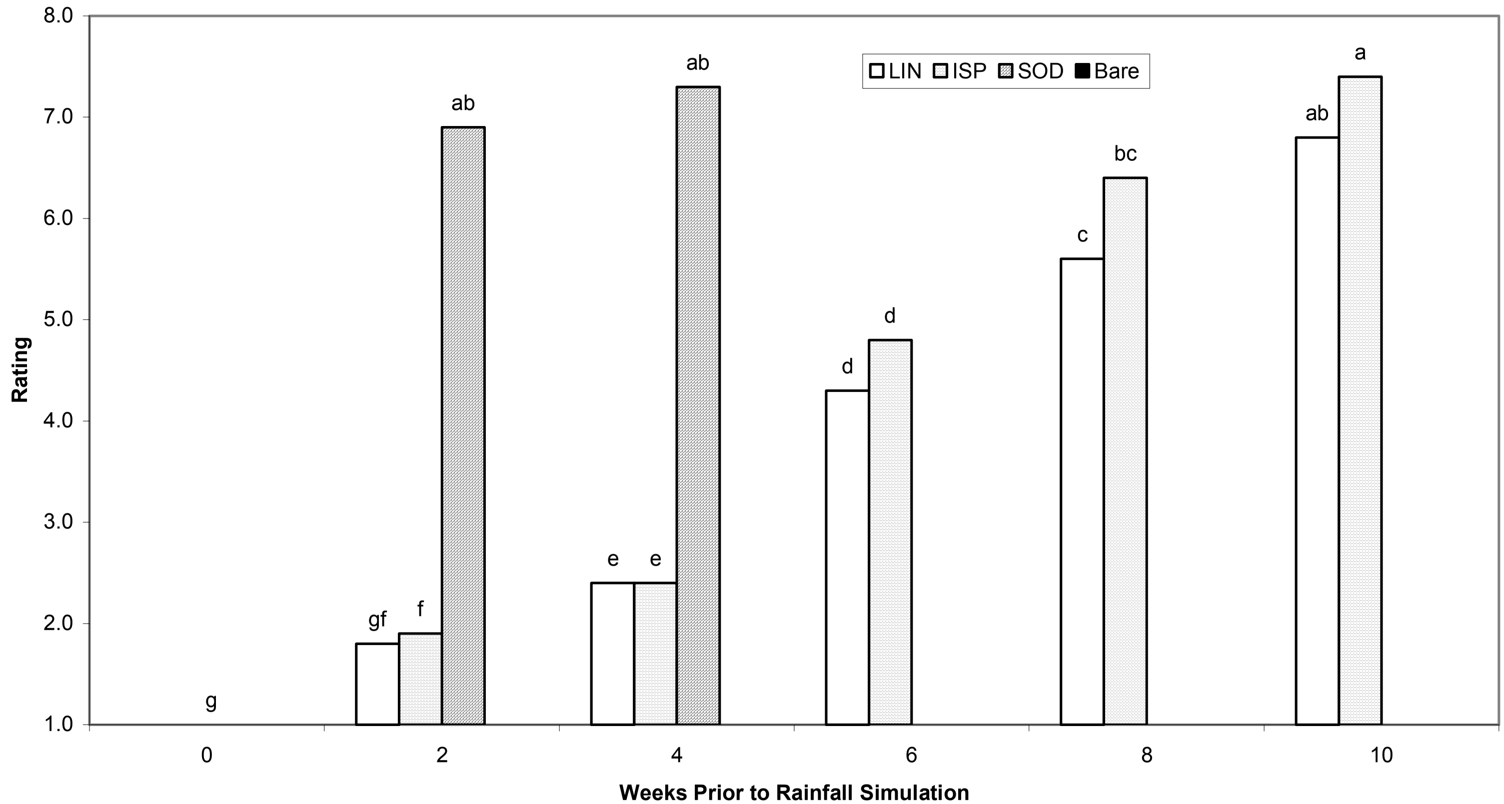
Sprigs had no statistical differences in quality ratings between the ISP and LIN regimes during the same establishment period. However there was a trend for sprigs following the ISP regime to have higher quality ratings from the 2WPRS to and including the 10WPRS compared to sprigs under the LIN regime. The only exception was at the establishment date 4WPRS where both N regimes attained a rating of 2.4. The increased ratings of sprigs fertilized at the ISP are the result of a slight increase in cover compared to sprigs fertilized at the LIN. Establishment periods 2WPRS, 4WPRS, and 6WPRS had sprigs that lacked the density to provide acceptable uniform turf stands. Sprigs were first

Table 1.7 Nitrogen regime influence on 2001 visual quality of bermudagrass established 2, 4, 6, 8, and 10 weeks prior to rainfall simulation (WPRS)

Vegetative Establishment Method	Vegetative Establishment Period	N Applied During Growth Period† Weeks 1 – 4	N Applied During Growth Period† Weeks 5 – 10	N Applied 30 minutes Prior to Rainfall Simulation	Total N Applied	Quality‡*
	----WPRS----	----------kg ha^{-1} wk^{-1}----------		------------- kg ha^{-1}------------	-- kg ha^{-1}--	---rating---
Sprig	10	48.8	48.8	48.8	488.0	7.4 a
Sod	4	48.8	0	48.8	97.6	7.3 ab
Sod	2	48.8	0	48.8	48.8	6.9 ab
Sprigs	10	12.2	48.8	48.8	341.6	6.8 ab
Sprigs	8	48.8	48.8	48.8	390.4	6.4 bc
Sprigs	8	12.2	48.8	48.8	244.0	5.6 c
Sprigs	6	48.8	48.8	48.8	292.8	4.8 d
Sprigs	6	12.2	48.8	48.8	146.4	4.3 d
Sprigs	4	12.2	0	12.2	48.8	2.4 e
Sprigs	4	48.8	0	48.8	195.2	2.4 e
Sprigs	2	48.8	0	48.8	97.6	1.9 f
Sprigs	2	12.2	0	12.2	24.4	1.8 f
Bare	0	0	0	0	0	0.0 f

* Means with the same letter are not significantly different according to Duncan's Multiple range test at the 0.05 level of probability.
† Sod was fertilized on two week intervals beginning two weeks after planting.
‡ quality rating scale is 1 through 9 (1 = bare ground; 5 = acceptable turf; 9 = highest quality turf)

Figure 1.5 Nitrogen regime† influence on 2001 visual quality for bermudagrass established 2, 4, 6, 8, and 10 weeks prior to rainfall simulation (WPRS).



* Means with the same letter are not significantly different according to Duncan's multiple range test at the 0.05 level of probability.

† ISP – 48,8 kg N ha^{-1} wk^{-1} LIN – 12.2 kg N ha^{-1} (weeks 1 – 4) and 48,8 kg N ha^{-1} (weeks 5 – 10)

SOD - 48,8 kg N ha^{-1} on two week intervals beginning two weeks after planting.

given acceptable quality ratings after eight weeks of growth with ratings of 5.6 and 6.4 at 8WPRS under the ISP and LIN regimes. Bermudagrass sprig growth at 8WPRS and 10WPRS were a dense and uniform stand.

The 2WPRS and 4WPRS sodded treatments had ratings of 6.9 and 7.3, respectively. Sod represented an immediate dense uniform turf stand that was aesthetically pleasing. Sprigged treatments 8WPRS and 10WPRS following the ISP and 10WPRS under the LIN regime were statistically similar to both sodded treatments. This indicated that sprigs could attain similar visual ratings comparable to sod within eight weeks from planting following the ISP and ten weeks under the LIN.

Biomass Production at Various Stages of Bermudagrass Establishment

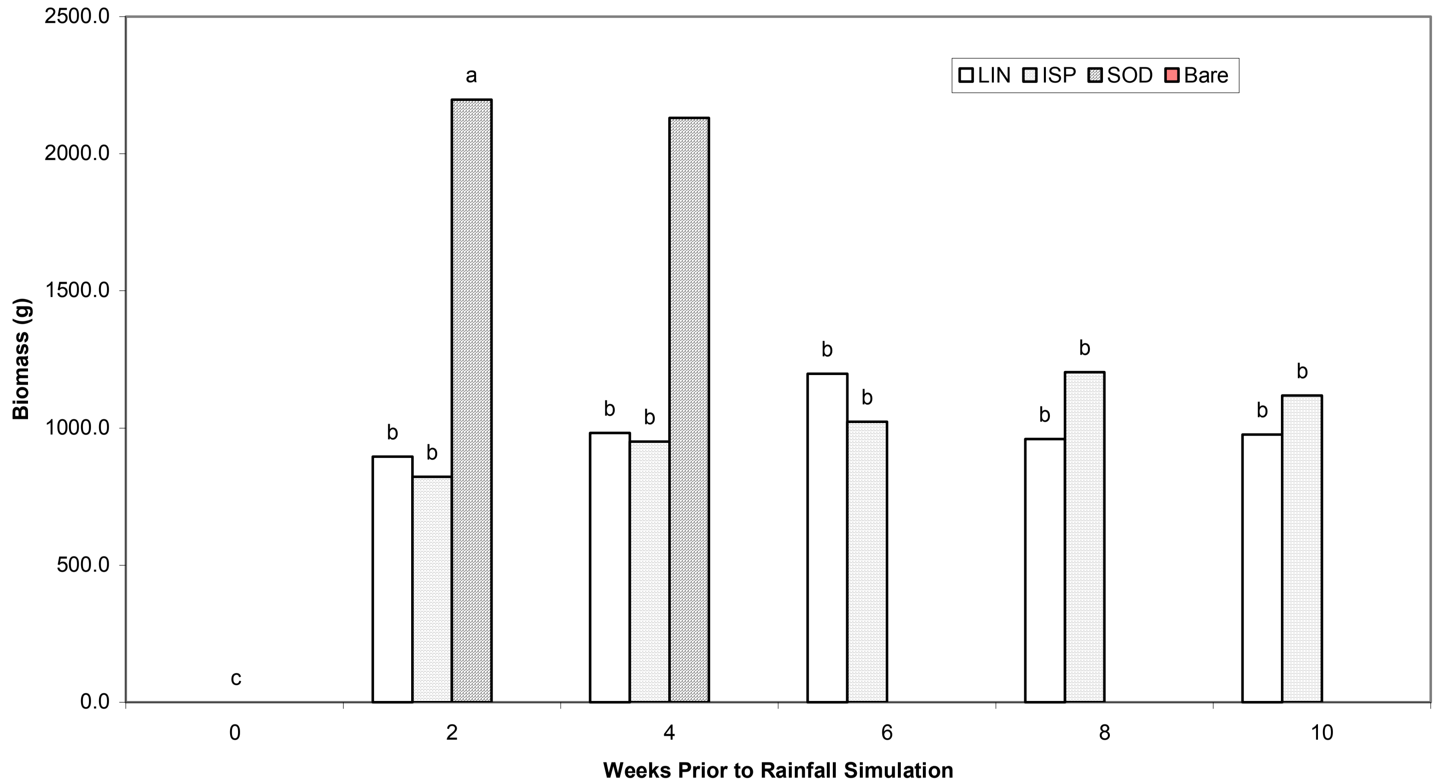
Accumulated biomass production lacked distinguishable differences between the ISP and LIN regimes within and among all establishment periods. Generally the biomass weights increased with extended establishment periods (Table 1.8 and Fig. 1.6). Unlike the 2000 biomass results, many of the sprigged biomass weights for 2001 appeared to be too heavy for establishment periods 2, 4, and 6 WPRS. Over statement of biomass weights can be attributed to the difficulties associated with sampling techniques on poorly covered treatments as a result of variability associated with sprig shredding, planting and less aggressive growth. Therefore, only minor trends and results can be assessed using sprigs established for 8 and 10 WPRS with greater ground cover. The control was not sampled because of lack of vegetation, giving a recorded weight of zero.

Table 1.8 Nitrogen regime influence on 2001 biomass of bermudagrass established 2, 4, 6, 8, and 10 weeks prior to rainfall simulation (WPRS)

Vegetative Establishment		N Applied During Growth Period†		N Applied 30 minutes Prior to Rainfall Simulation	Total N Applied	Biomass*
Method	Period	Weeks 1 – 4	Weeks 5 – 10			
	----WPRS----	----------kg ha^{-1} wk^{-1}----------		------------- kg ha^{-1}------------	-- kg ha^{-1}--	--g / $1.5m^2$--
Sod	2	48.8	0	48.8	48.8	2197.6 a
Sod	4	48.8	0	48.8	97.6	2130.9 a
Sprigs	8	48.8	48.8	48.8	390.4	1204.2 b
Sprigs	6	12.2	48.8	48.8	146.4	1198.5 b
Sprigs	10	48.8	48.8	48.8	488.0	1119.0 b
Sprigs	6	48.8	48.8	48.8	292.8	1023.2 b
Sprigs	4	12.2	0	12.2	48.8	982.2 b
Sprigs	10	12.2	48.8	48.8	341.6	975.7 b
Sprigs	8	12.2	48.8	48.8	244.0	959.7 b
Sprigs	4	48.8	0	48.8	195.2	950.9 b
Sprigs	2	12.2	0	12.2	24.4	895.7 b
Sprigs	2	48.8	0	48.8	97.6	821.5 b
Bare	0	0	0	0	0	0.0 c

* Means with the same letter are not significantly different according to Duncan's Multiple range test at the 0.05 level of probability.
† Sod was fertilized on two week intervals beginning two weeks after planting.

Figure 1.6 Nitrogen regimes† influence on 2001 biomass of bermudagrass established 2, 4, 6, 8, and 10 weeks prior to rainfall simulation (WPRS).



* Means with the same letter are not significantly different according to Duncan's multiple range test at the 0.05 level of probability.

† ISP – 48,8 kg N ha^{-1} wk^{-1} LIN – 12.2 kg N ha^{-1} (weeks 1 – 4) and 48,8 kg N ha^{-1} (weeks 5 – 10)

SOD - 48,8 kg N ha^{-1} on two week intervals beginning two weeks after planting.

Focusing in on older establishment dates, sprigs established 8 and 10 WPRS for both N regimes demonstrated a leveling of biomass production. Similar weights are exhibited with sprigs established 8 and 10 WPRS under the ISP with weights of 1204.2 g and 1119.0 g respectively. For the LIN regime the change was similar to the ISP with only a 16.0 g difference between sprigs 8 and 10 WPRS. The constant biomass levels between the older establishment dates demonstrates the maturity of the bermudagrass sprig establishment or possible poor weather conditions for the first two weeks of planting for sprigs 10WPRS, resulting in slowed growth.

Increased production of biomass, by sprigs established 8 and 10 WPRS, will continue over time through slow development of a thatch layer. Sodded treatments at 2WPRS and 4WPRS were significantly greater in biomass from all sprigged treatments with weights of 2197.6 g and 2130.9 g respectively. Sod offers an instant weed-free cover with turfgrass organs capable of quickly developing to continue necessary growth processes at applied N rates.

Conclusion

The first objective was to determine whether a lower initial N (LIN) rate during the first four weeks would provide similar cover and development compared to the current industry stand practice (ISP) of 48.8 kg N ha^{-1} wk^{-1}. To provide a simple yet practical solution, one must setup the qualifications of each measurement in determining when a sprigged bermudagrass plot has reached maturity. In holding criteria steady, only then can proper comparison between treatments be made.

In determining turf maturity from a sprig establishment, percent ground cover values are often used (Busey and Myers 1979). For the purpose of this particular test, percent cover values of sodded treatments (all 100%) were used in statistical relation to sprig treatments to represent maturity and full cover. Full coverage by bermudagrass sprigs and thus mature turfgrass stands were attained eight weeks after planting during 2000 for the ISP (93.3%) and LIN (88.3%) regimes and 2001 for the ISP (85.3%). Only the LIN regime (91.3%) during 2001 needed ten weeks to attain maturity.

Not only was maturity not recognized until eight or ten weeks of establishment for both years using percent cover data, but visually the sprig treatments were first given acceptable turfgrass ratings after eight weeks of development. Based on the qualitative numerical rating system, turfgrass stands are considered acceptable with a rating of five or higher. All sprig treatments with establishment periods of or above eight weeks rated consistently above five regardless of the N regime.

Additionally, biomass weights for the ISP in 2000 and the ISP and LIN regime in 2001 showed lowered increases for sprigs established 8WPRS to 10WPRS. Less dramatic increases in biomass may be a result of poor weather conditions in for the first two weeks for sprigs established 10WPRS in 2001 or the static biomass could signal the entrance of the bermudagrass stands towards maturity. Busey and Myers (1979) reported turf growth slows as a result of self-inhibition or competition. The growth rate decreases with increased cover due to “thatch buildup, canopy shading, and root competition” (Busey and Myers 1979). In 2000, biomass measurements showed continual production with sizeable gains as the establishment period for sprigs increased. Both N regimes increased in biomass weight from 4WPRS to 8WPRS, while sprigs under the LIN regimes continued until 10WPRS. The 2001 data was less reliable in regard to earlier establishment periods, but did offer some concurrence in discussing sprigs at 8 and 10 WPRS. Much like 2000, the 2001 data showed static biomass weights of sprigs at 8WPRS to 10WPRS. This supported the entrance of bermudagrass sprigs into the early stages of a mature turf stand.

The combination of data, from the three measurements, exhibited the ability of bermudagrass sprigs to develop and cover within an eight to ten week establishment period using the lower initial N (LIN) rate, 24.4 kg N ha^{-1} wk^{-1} for the first four weeks and 48.8 kg N ha^{-1} wk^{-1} the remaining weeks, compared to the industry standard practice (ISP) of 48.8 kg N ha^{-1} wk^{-1}. The ability to attain mature coverage was not necessarily similar between the two regimes as displayed by the LIN regime through delayed maturation levels of percent cover and biomass production for 2001. However maturity did take place with the additional two week establishment period (10WPRS) LIN treated sprigs. Therefore a one to two week delay for LIN treated sprigs is an acceptable delay in establishment, depending on time of year and the use of 75% less N the first four weeks after planting.

The second objective questioned the manner in which bermudagrass sprig growth progressed until maturity. Clearly, maturity was attained eight or ten weeks after establishment by all sprigged treatments for 2000 and 2001. The patterns in which each year and N regime came to maturity probably differed. The study provided limited insight into sprig development based on the timing of sprig establishments.

Because sprigs were planted in accordance to an end of study rainfall simulation, shorter establishment periods could have had varying environmental conditions compared to longer establishment periods. For example, in 2000 the weather was cooler and more cloudy later in the experiment compared to the beginning (appendix 1). This difference can be attributed to the experiment beginning in July and lasting until September in 2000. Important factors for bermudagrass growth such as air and soil temperatures as well as photoperiod would have differed, affecting bermudagrass growth.

With the above stated, there were two important pieces of information gained from the study. First, sprigs established 4WPRS did not exhibit any difference in growth cover, quality, or biomass production under the ISP and LIN regimes for each year of the experiment; and most sprig growth occurred after the first four weeks after establishment. This determination in bermudagrass sprig growth, supported the hypothesis that sprigs could receive adequate levels of N the first four weeks after establishment following the LIN compared to the ISP.

Clearly one can feel confident that bermudagrass sprigs are able to become established (near 100%) within eight to ten weeks following either N regime. In addition, one can see that substantial periods of growth existed primarily after the initial four weeks. Thus bermudagrass sprigs appear unable to utilize higher N concentrations under the ISP until proper root development and plant density is evident. Even with delayed growth maturity following the LIN, by week ten the ISP and LIN sprigs were very similar.

Given the above information, bermudagrass establishment fertility programs could reduce the amount of N applied during the first four weeks by 75% and 30% over the ten week establishment period following the LIN compared to the ISP. The reduction of N could translate into a reduced potential for N lost through leaching or surface runoff, helping to curtail the risk of eutrophication to surrounding water bodies.

Section 2

Post Plant Applied Nitrogen Regimes Effects on Sediment and Surface Runoff Losses During Vegetative Establishment of Bermudagrass

Section two is concerned with the surface runoff characterization of bermudagrass sprigs following the ISP and LIN regimes, sod, and bare ground.

Objectives

The objectives of this study were to evaluate bermudagrass sprig establishment periods as influenced by two N regimes (ISP and LIN) to determine:

1. The impact on surface water runoff.

2. The potential for sediment loss from surface water runoff.

Data Recorded

Observations for this particular experiment included time until surface runoff occurrence, surface water runoff volumes, and sediment runoff losses as a result of rainfall simulation. The surface water runoff data is given as liters per 1.5 m^2, while sediment losses are given on a mass basis, as grams per 1.5 m^2.

The amount of time elapsed until surface runoff began was measured from rainfall simulator initiation until the release of the first visible surface runoff. At the point of surface runoff, 1 liter samples of surface runoff were collected every five minutes over a period of thirty minutes. All other runoff was collected and weighed in barrels.

Sediment losses were determined through oven induced evaporation of 40 mL aliquots for each five minute interval sample at 100°C. Differences in initial and final weights were determined. Sediment was then calculated as a percent of runoff sample weight to allow proper calculation of sediment runoff from individual plots.

The statistical design was a complete randomized design with three replications in 2000 and four replications in 2001. Statistical analysis was performed using the program SAS (Statistical Analysis System) (SAS, 1985). The proc glm procedure was followed to create analysis of variance (ANOVA) tables with Duncan's multiple range test at the 0.05 alpha level being used to separate means for time until runoff initiation measurements. Surface water runoff and sediment loss measurements were analyzed using repeated measure commands with subsampling as a complete randomized design used for mean separation. The LSD (Least significant differences) procedure was followed for mean separation at the 0.05 alpha level.

2000 Results and Discussion:

Time until Runoff Initiation and Bermudagrass Establishment Period

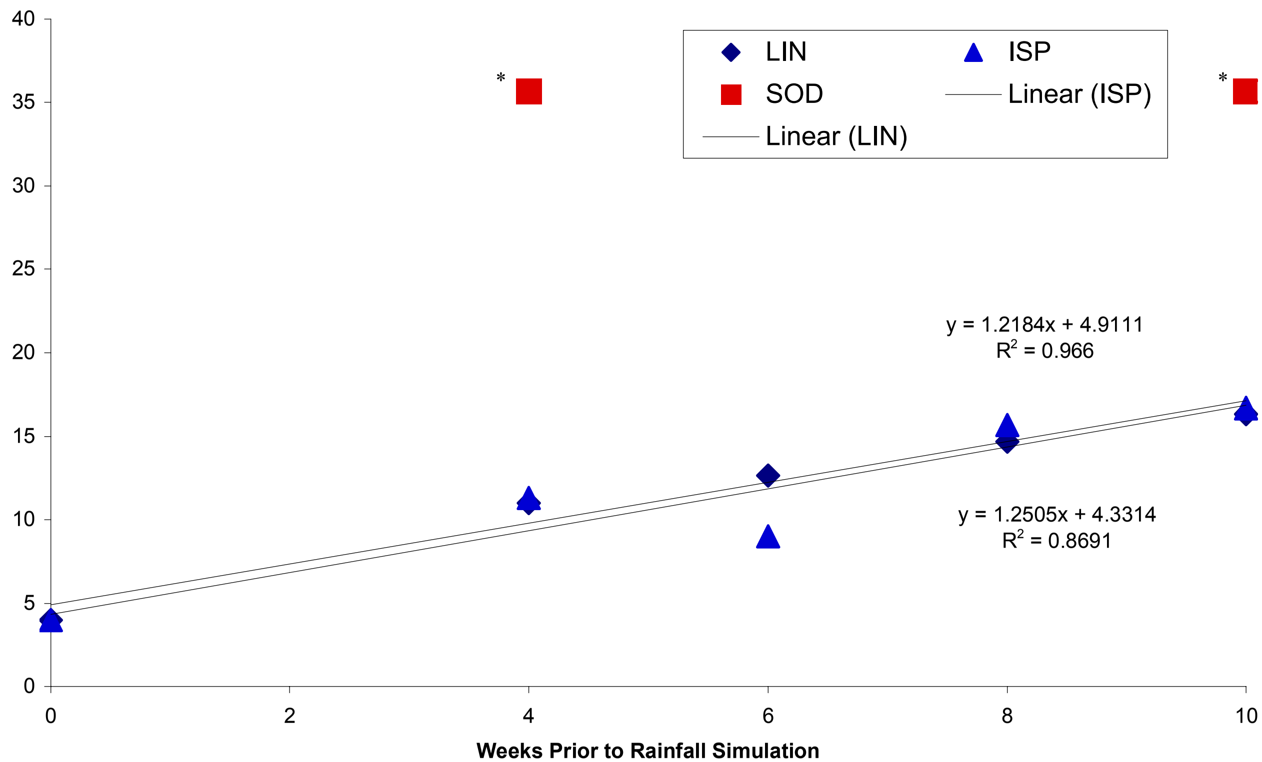
Significant differences in time until runoff measurements were not experienced among or between all sprigged treatments. Sodded treatments established 10WPRS and 4WPRS both with a time of 35.67 minutes, were much slower to release surface runoff water than all sprigged treatments or bare ground (Table 2.1 and Fig. 2.1). Having a two-

Table 2.1 Nitrogen regime influence on 2000 time to initiation of rainfall simulator induced surface water runoff from bermudagrass established 4, 6, 8, and 10 weeks prior to rainfall simulation (WPRS)

Vegetative Establishment		N Applied During Growth Period†		N Applied 30 minutes Prior to Rainfall Simulation	Total N Applied	Time Until Runoff*‡
Method	Period	Weeks 1 – 4	Weeks 5 – 10			
	----WPRS----	----------kg ha^{-1} wk^{-1}----------		------------- kg ha^{-1}------------	-- kg ha^{-1}--	--min--
Sod	10	48.8	48.8	48.8	244.0	35.67 a
Sod	4	48.8	0	48.8	97.6	35.67 a
Sprigs	10	48.8	48.8	48.8	488.0	16.67 b
Sprigs	10	12.2	48.8	48.8	341.6	16.33 b
Sprigs	8	48.8	48.8	48.8	390.4	15.67 b
Sprigs	8	12.2	48.8	48.8	244.0	14.67 b
Sprigs	6	12.2	48.8	48.8	146.4	12.67 b
Sprigs	4	48.8	0	48.8	195.2	11.33 b
Sprigs	4	12.2	0	12.2	48.8	11.00 b
Sprigs	6	48.8	48.8	48.8	292.8	9.00 b
Bare	0	0	0	0	0	4.00 b

* Means with the same letter are not significantly different according to Duncan's Multiple range test at the 0.05 level of probability.
† Sod was fertilized on two week intervals beginning two weeks after planting
‡ Rainfall simulation – 63.5 mm hr^{-1}

Figure 2.1 Nitrogen regime† influence on 2000 time to initiation of rainfall simulator induced surface water runoff from bermudagrass established 4, 6, 8, and 10 weeks prior to rainfall simulation (WPRS).



* Means are significantly different according to Duncan's multiple range test at the 0.05 level of probability.

† ISP – 48,8 kg N ha^{-1} wk^{-1} LIN – 12.2 kg N ha^{-1} (weeks 1 – 4) and 48,8 kg N ha^{-1} (weeks 5 – 10)

SOD - 48,8 kg N ha^{-1} on two week intervals beginning two weeks after planting.

fold difference from the highest sprigged treatments at 10WPRS with 16 minute delays, demonstrated the ability of sodded bermudagrass to prevent the early onset of nutrient or sediment losses from surface runoff. This can be attributed to the well-developed thatch layer, forming a tortuous pathway through aggressive stoloniferous growth as well as infiltration pathways of root channels created from the fibrous root system (Merwin et al., 1993, Linde et al., 1995).

Lacking significant differences, the sprigged treatments did display highly correlated, positive linear relationships with $r^2 = 0.869$ and $r^2 = 0.9661$ for the ISP and LIN regimes respectively. Both trends were extremely similar implying little difference between N regimes, but rather dependence on bermudagrass cover. This was clearly evident with the, bare ground control treatment, which displayed the lowest time until surface runoff initiation of 4 minutes.

Longer establishment periods WPRS had greater sprig development. With increased bermudagrass cover, a pattern of older weeks increasing the time until runoff initiation was detected. Greater bermudagrass cover provided more vegetative influence on retardation of surface water release; preventing soil sealing, creating tortuous pathways, and enhancing the soil's infiltration capacities through root channels.

Runnoff Losses

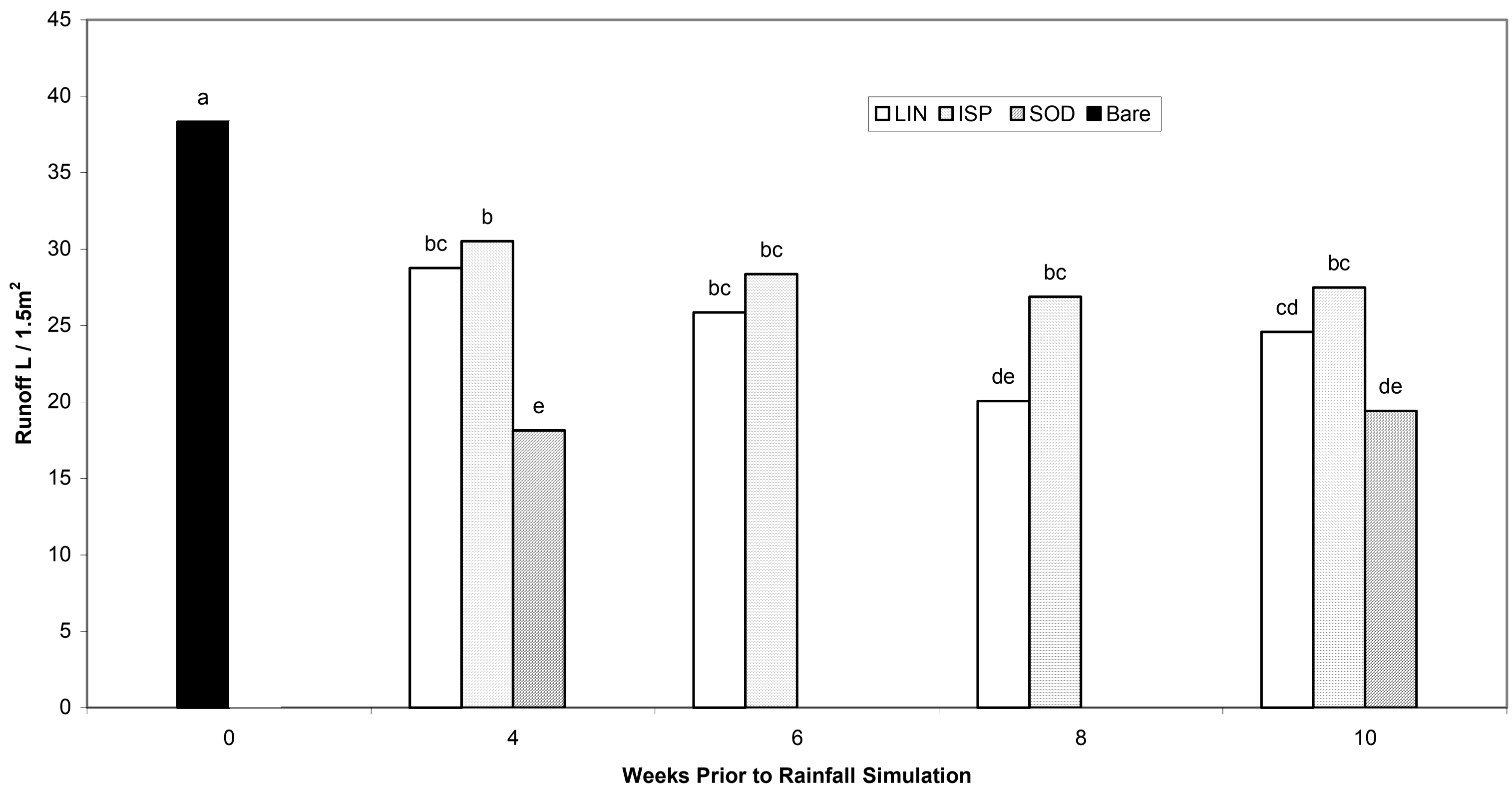
Water losses through surface runoff from bare ground were significantly greater from all sprigged treatments with the highest volume of 38.83 L (Table 2.2 and Fig. 2.2). Unshielded from the rain by vegetation, the bare ground could have suffered from soil compaction from rain or irrigation droplet forces. The compaction facilitated soil sealing,

Table 2.2 Nitrogen regime influence on 2000 total rainfall simulator induced surface water runoff from bermudagrass established 4, 6, 8, and 10 weeks prior to rainfall simulation (WPRS)

Vegetative Establishment		N Applied During Growth Period†		N Applied 30 minutes Prior to Rainfall Simulation	Total N Applied	Total Water Runoff*‡
Method	Period	Weeks 1 – 4	Weeks 5 – 10			
	----WPRS----	----------kg ha^{-1} wk^{-1}----------		------------- kg ha^{-1}------------	-- kg ha^{-1}--	-------L / 1.5 m^2-------
Bare	0	0	0	0	0	38.83 a
Sprigs	4	48.8	0	48.8	195.2	30.52 b
Sprigs	4	12.2	0	12.2	48.8	28.77 bc
Sprigs	6	48.8	48.8	48.8	292.8	28.36 bc
Sprigs	10	48.8	48.8	48.8	488.0	27.49 bc
Sprigs	8	48.8	48.8	48.8	390.4	26.88 bc
Sprigs	6	12.2	48.8	48.8	146.4	25.86 bc
Sprigs	10	12.2	48.8	48.8	341.6	24.57 cd
Sprigs	8	12.2	48.8	48.8	244.0	20.07 de
Sod	10	48.8	48.8	48.8	244.0	19.41 de
Sod	4	48.8	0	48.8	97.6	18.15 e

* Means with the same letter are not significantly different according to the LSD procedure at the 0.05 level of probability. LSD = 5.30
† Sod was fertilized on two week intervals beginning two weeks after planting
‡ Rainfall simulation – 63.5 mm hr^{-1}

Figure 2.2 Nitrogen regime† influence on 2000 total rainfall simulator induced surface water runoff from bermudagrass established 4, 6, 8, and 10 weeks prior to rainfall simulation (WPRS)



* Means with the same letter are not significantly different according to the LSD procedure at the 0.05 level of probability. LSD= 5.30

† ISP – 48,8 kg N ha^{-1} wk^{-1} LIN – 12.2 kg N ha^{-1} (weeks 1 – 4) and 48,8 kg N ha^{-1} (weeks 5 – 10)

SOD - 48,8 kg N ha^{-1} on two week intervals beginning two weeks after planting.

disrupting infiltration capacities and reducing resistance to lateral surface water flow (Welterlen et al., 1989).

Simulated rainfall events showed heavy losses of water runoff for shorter sprig establishment periods with runoff decreasing with increased age of sprigs. Sprigs established 6, 8 and 10 WPRS under the ISP and LIN regimes had lower static runoff losses. Decreased water runoff as sprigs aged indicates the important influence of vegetation. The 6, 8 and 10 WPRS bermudagrass treatments probably reduced surface runoff through increasing infiltration capacities. Additionally, bermudagrasses aggressive growth habit through stoloniferous proliferation created tortuous pathways that could hinder surface lateral water movement. The reduction in water momentum would most likely increase infiltration capabilities with downward pathways created by the development of numerous root channels and present macrofauna activity as proposed by Merwin (Merwin et al., 1996).

The ISP and LIN regimes were similar in water runoff losses for all sprigged WPRS establishment periods with the exception of 8WPRS. Treatment 8WPRS under the LIN regime had the lowest runoff losses of the sprigged treatments with 20.07 L, but sprigs 10WPRS (LIN) exhibited 24.57 L of runoff. These differences only demonstrate the variability that exist among plots. Each individual plot could contain bumps and/or ridges in the soil reducing water movement. This would not be uncommon to find in any sprig establishment. Such differences in plots could be caused at the time of soil preparation or anthropogenic disturbances during the establishment period. Therefore it may be more appropiate to discuss the trends developed from the data versus individual treatment results. The lack of differences between treatments and establishment periods along with the high correlation of trendlines (ISP $r^2 = 0.9313$ and LIN $r^2 = 0.9988$) suggest the runoff amounts between the ISP and LIN regimes are extremely similar. Therefore, bermudagrass sprigs developed canopies equally well under each N regime.

The only major differences in the treatments concerned the sodded plots. Both 10WPRS and 4WPRS sodded treatments had the lowest runoff losses with 19.41 and 18.15 L respectively. The decreased runoff showed the importance and role a well developed thatch layer could play. Therefore based on the data for sodded treatments one could expect sprig treatment runoff losses to decrease with increased thatch layer development. Sod would also have a reduced need for applied N.

Sediment Losses

Sediment losses were greatest in plots with limited bermudagrass cover. Bare ground, significantly different from all other treatments, represented the highest sediment loss with 132.61 g (Table 2.3 and Fig. 2.3). Sediment losses for the bare ground treatments fluctuated between the five minute samples gathered between plots ($p = 0.05$) indicating no specific pattern for loss (appendix 2). This type of erratic results implies the variability that exist between bare plots.

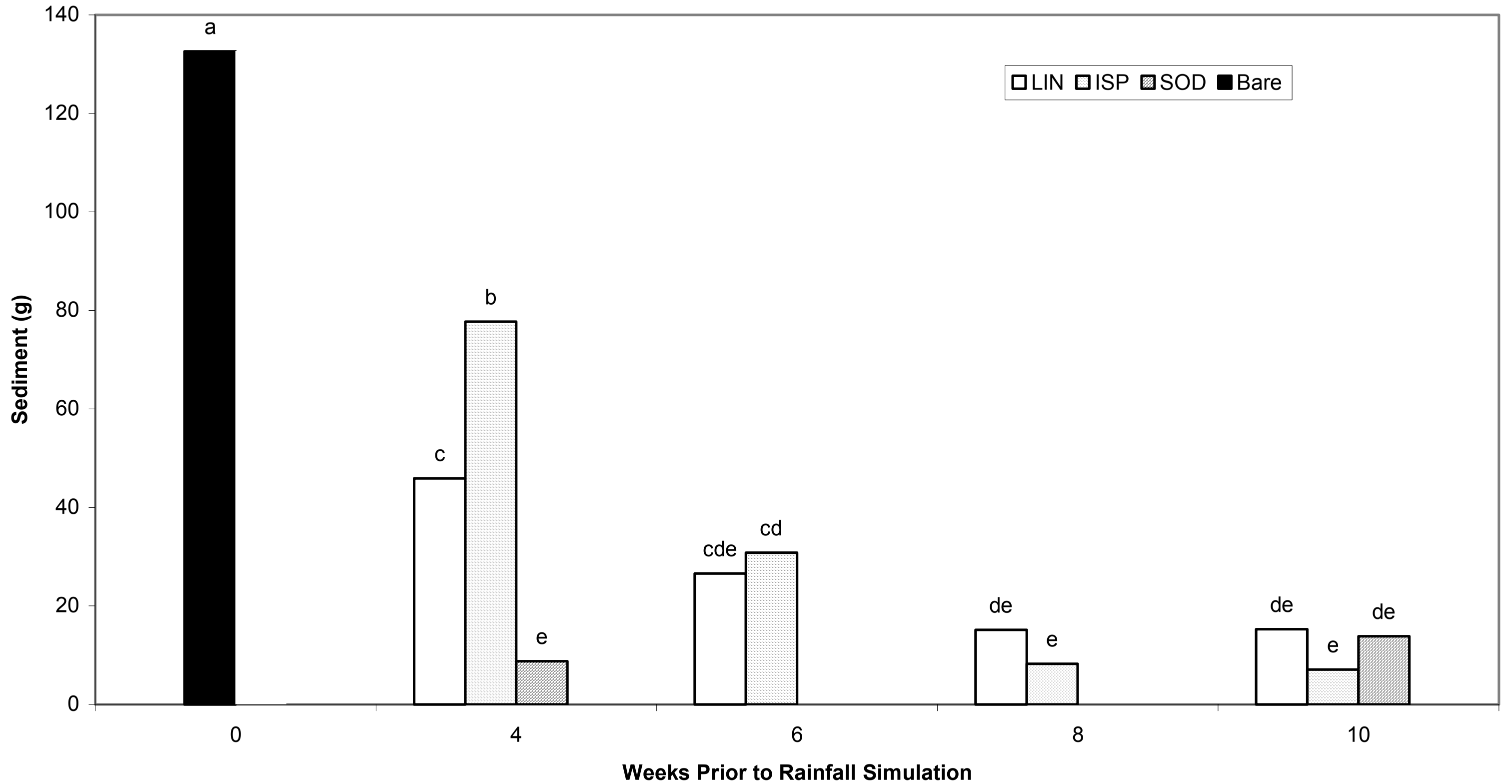
The 4WPRS establishment periods continued this erratic behavior showing a lack of consistency between samples. In addition the 4WPRS sprig bermudagrass treatments demonstrated the only statistical difference between N regimes. The difference in the 4WPRS establishment periods ability to reduce sediment loss eluded to the fact that early in sprig establishment, turf cover is limited and sprig placement, amount of movable

Table 2.3 Nitrogen regime influence on 2000 rainfall simulator induced sediment surface runoff from bermudagrass established 4, 6, 8, and 10 weeks prior to rainfall simulation (WPRS)

Vegetative Establishment Method	Vegetative Establishment Period	N Applied During Growth Period† Weeks 1 – 4	N Applied During Growth Period† Weeks 5 – 10	N Applied 30 minutes Prior to Rainfall Simulation	Total N Applied	Sediment Runoff*‡
	----WPRS----	----------kg ha^{-1} wk^{-1}----------		------------- kg ha^{-1}------------	-- kg ha^{-1}--	------g / 1.5 m^2------
Bare	0	0	0	0	0	132.61 a
Sprigs	4	48.8	0	48.8	195.2	77.69 b
Sprigs	4	12.2	0	12.2	48.8	45.89 c
Sprigs	6	48.8	48.8	48.8	292.8	30.82 cd
Sprigs	6	12.2	48.8	48.8	146.4	26.59 cde
Sprigs	10	12.2	48.8	48.8	341.6	15.29 de
Sprigs	8	12.2	48.8	48.8	244.0	15.16 de
Sod	10	48.8	48.8	48.8	244.0	13.82 de
Sod	4	48.8	0	48.8	97.6	8.79 e
Sprigs	8	48.8	48.8	48.8	390.4	8.24 e
Sprigs	10	48.8	48.8	48.8	488.0	7.09 e

* Means with the same letter are not significantly different according to the LSD procedure at the 0.05 level of probability. LSD = 20.70
† Sod was fertilized on two week intervals beginning two weeks after planting
‡ Rainfall simulation – 63.5 mm hr^{-1}

Figure 2.3 Nitrogen regime† influence on 2000 rainfall simulator induced sediment surface runoff from bermudagrass established 4, 6, 8, and 10 weeks prior to rainfall simulation (WPRS)



*Means with the same letter are not significantly different according to the LSD procedure at the 0.05 level of probability. LSD=20.70

† ISP – 48,8 kg N ha^{-1} wk^{-1} LIN – 12.2 kg N ha^{-1} (weeks 1 – 4) and 48,8 kg N ha^{-1} (weeks 5 – 10)

SOD - 48,8 kg N ha^{-1} on two week intervals beginning two weeks after planting.

sediment, plot surface characteristics, and rain intensity are more influential factors to sediment movement. Establishment periods beyond four weeks showed remarkable consistency as variability decreased with the increase in sprig age and bermudagrass cover. Greater stoloneriferous growth as sprigs established, created a less amicable pathway for runoff movement, thus trapping suspended sediment.

Graphically the ISP and LIN regimes, were very similar, showing dramatic decreases in sediment loss as the sprigged plots aged. On the other hand, sodded treatments 4WPRS and 10WPRS were represented with lower sediment runoff of 8.79 and 13.82 g, respectively, regardless of the establishment period. Sprig establishments from 8WPRS and including 6WPRS for the LIN regime were statistically similar to the sodded treatments. Thus the development of bermudagrass offered greater resistance to sediment movement and sprigged bermudagrass can attain similar resistance to sediment movement rather quickly.

2001 Results and Discussion

Time until Runoff Initiation and Bermudagrass Establishment Period

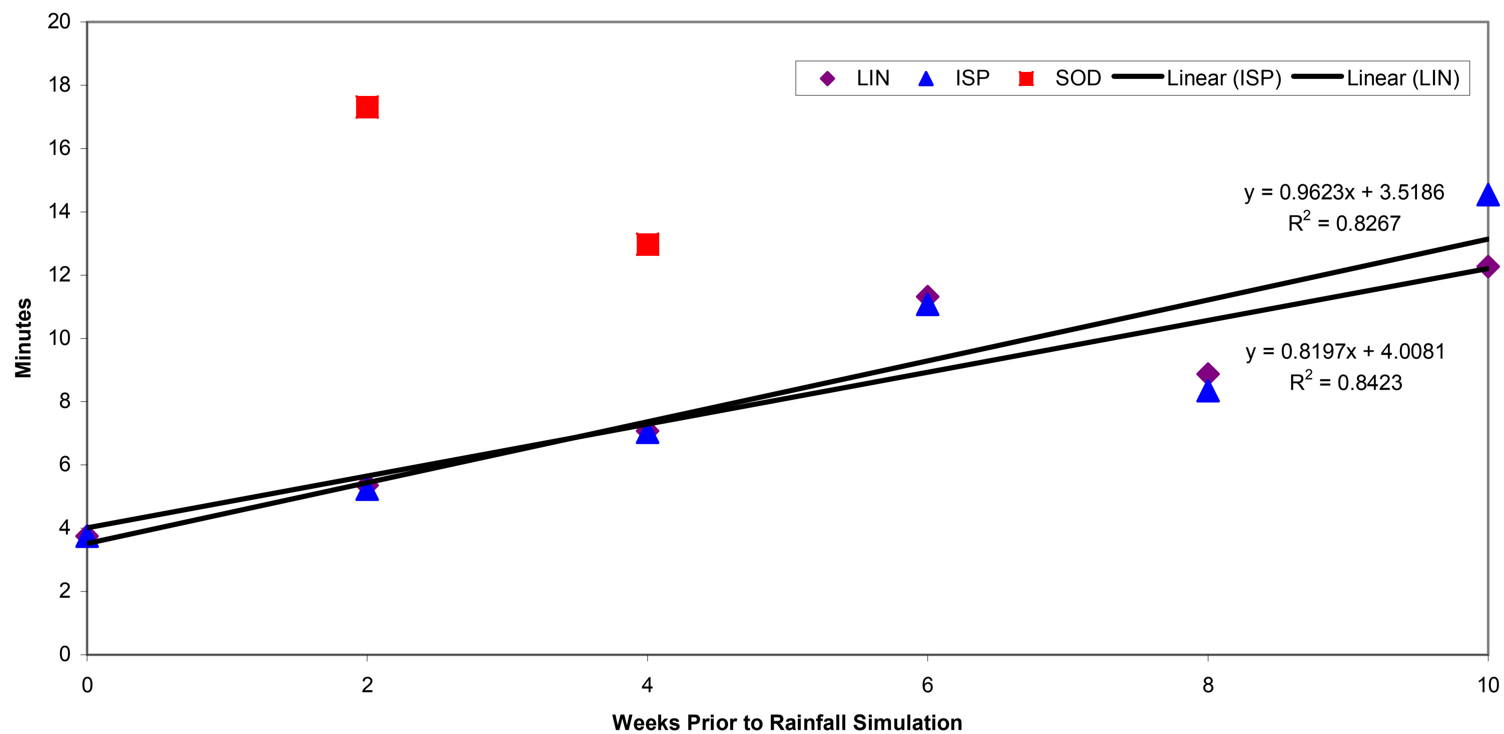
The time until surface runoff initiation for the ISP and LIN regimes shared similar positive linear relationships (Table 2.4 and Fig. 2.4). As the establishment period was extended, the resistance to surface runoff release was increased. Bare ground represented

Table 2.4 Nitrogen regime influence on 2001 time to initiation of rainfall simulator induced surface water runoff from bermudagrass established 2, 4, 6, 8, and 10 weeks prior to rainfall simulation (WPRS)

Vegetative Establishment		N Applied During Growth Period†		N Applied 30 minutes Prior to Rainfall Simulation	Total N Applied	Time Until Runoff*‡
Method	Period	Weeks 1 – 4	Weeks 5 – 10			
	----WPRS----	----------kg ha^{-1} wk^{-1}----------		------------- kg ha^{-1}------------	-- kg ha^{-1}--	--min--
Sod	2	48.8	0	48.8	48.8	17.31 a
Sprigs	10	48.8	48.8	48.8	488.0	14.54 ab
Sod	4	48.8	0	48.8	97.6	12.98 ab
Sprigs	10	12.2	48.8	48.8	341.6	12.27 abc
Sprigs	6	12.2	48.8	48.8	146.4	11.32 abc
Sprigs	6	48.8	48.8	48.8	292.8	11.08 abc
Sprigs	8	12.2	48.8	48.8	244.0	8.86 abc
Sprigs	8	48.8	48.8	48.8	390.4	8.35 abc
Sprigs	4	12.2	0	12.2	48.8	7.07 bc
Sprigs	4	48.8	0	48.8	195.2	7.03 bc
Sprigs	2	12.2	0	12.2	24.4	5.36 bc
Sprigs	2	48.8	0	48.8	97.6	5.23 bc
Bare	0	0	0	0	0	3.75 c

* Means with the same letter are not significantly different according to Duncan's Multiple range test at the 0.05 level of probability.
† Sod was fertilized on two week intervals beginning two weeks after planting
‡ Rainfall simulation – 63.5 mm hr^{-1}

Figure 2.4 Nitrogen regime† influence on 2001 time to initiation of rainfall simulator induced surface water runoff from bermudagrass established 2, 4, 6, 8, and 10 weeks prior to rainfall simulation (WPRS)



* Means with the same letter are not significantly different according to Duncan's multiple range test at the 0.05 level of probability.

† ISP – 48,8 kg N ha^{-1} wk^{-1} LIN – 12.2 kg N ha^{-1} (weeks 1 – 4) and 48,8 kg N ha^{-1} (weeks 5 – 10)

SOD - 48,8 kg N ha^{-1} on two week intervals beginning two weeks after planting.

the lowest time with 3.75 minutes. Lack of bermudagrass cover on untilled bare ground allowed further soil compaction and sealing from falling raindrops reducing the soils ability to handle intense rainfall, resulting in faster runoff release and higher volumes.

Sprigged treatments had no statistical differences between the ISP and LIN regimes for sprigs identical in age. In fact the positive linear relationships of both N regimes and insufficient differences in each establishment period, resulted in similar time until runoff values. Correlations of $r^2 = 0.8269$ and $r^2 = 0.8454$ for the ISP and LIN regimes respectively, offer further support through affirmation as to the strong relationship of the data. Increased establishment periods offered greater bermudagrass growth, likely resulting in retarding surface runoff occurrence through the creation of a tortuous pathway by stoloniferous growth and increased infiltration pathways developed by a fibrous root system.

Sodded treatments, though not significantly different from all sprigged treatments, took longer to produce runoff in respect to many sprigged treatments with times of 17.31 and 12.98 minutes at 2WPRS and 4WPRS, respectively. However, differences were not as large as those experienced in 2000. Interestingly, sprigs established 10WPRS under the ISP regime were able to show an increased time to runoff with 14.54 minutes, ranking above the 4WPRS sodded treatment. The 10WPRS ISP increased the time until runoff occurrence comparable to the 2 and 4 WPRS sodded treatments suggests that bermudagrass established by sprigs could retard water movement similar to that of sod once fully established.

Runoff Losses

Runoff losses were greatest for bermudagrass sprigs established 2 through 6 WPRS, including the bare ground control (Table 2.5 and Fig 2.5). Generally the bare ground had the greatest water runoff volumes. Runoff reduced as the sprigged treatments developed with age. However, treatments of the ISP at 2 and 6 WPRS had runoff quantities in excess of bare ground. The result of the 2WPRS sprigs under the ISP would not be as surprising given only a slight edge with immature sprig cover. The elevated level of 6WPRS sprigs under the ISP appeared the result of one particularly high plot runoff volume. This increase represents the variability that existed between plots. Factors concerning establishment or other anthropegenic conditions may have occurred allowing funneling of runoff, thereby reducing the ability of the sprigged bermudagrass to slow runoff momentum and aid soil infiltration capacity.

Sprigs established 8 and 10 WPRS displayed lower runoff volumes at 14.86 and 21.07 L, respectively, considerably less then the previous establishment period of 6WPRS. Sodded treatments were vastly different from one another. Sodded treatment 2WPRS had the lowest runoff volume with 9.86 L compared to a 26.26 L loss by 4WPRS. The difference between the two sodded treatments implies variability between establishment. The four week sod treatment may not have rooted properly, resulting in less vegetative involvement in the reduction of surface water runoff movement and infiltration; or funneling of surface water occurred.

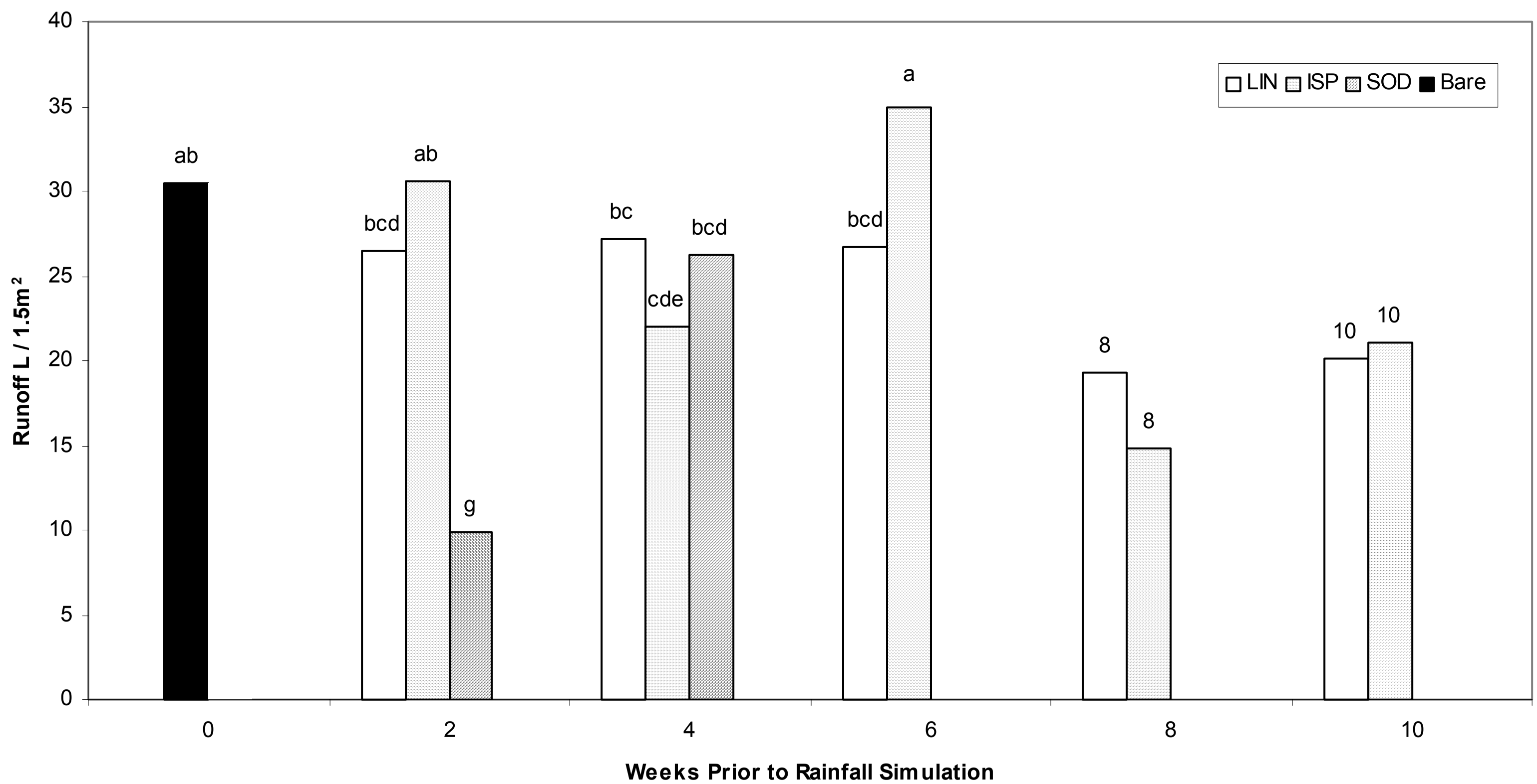
Both the ISP and LIN regimes shared similar characteristics with the reduction of runoff volumes as sprigged plots aged. In fact trend lines of both N regimes followed much the same path, indicating little difference in the effect of treatment. Rather,

Table 2.5 Nitrogen regime influence on 2001 rainfall simulator induced surface water runoff from bermudagrass established 2, 4, 6, 8, and 10 weeks prior to rainfall simulation (WPRS)

Vegetative Establishment		N Applied During Growth Period†		N Applied 30 minutes Prior to Rainfall Simulation	Total N Applied	Total Water Runoff*‡
Method	Period	Weeks 1 – 4	Weeks 5 – 10			
	----WPRS----	----------kg ha^{-1} wk^{-1}----------		------------- kg ha^{-1}------------	-- kg ha^{-1}--	-------L / 1.5 m^2-------
Sprigs	6	48.8	48.8	48.8	292.8	34.90 a
Sprigs	2	48.8	0	48.8	48.8	30.62 ab
Bare	0	0	0	0	0	30.45 ab
Sprigs	4	12.2	0	12.2	48.8	27.15 bc
Sprigs	6	48.8	48.8	48.8	292.8	26.74 bcd
Sprigs	2	12.2	0	12.2	24.4	26.43 bcd
Sod	4	48.8	0	48.8	97.6	26.26 bcd
Sprigs	4	48.8	0	48.8	195.2	22.03 cde
Sprigs	10	48.8	48.8	48.8	488.0	21.07 de
Sprigs	10	12.2	48.8	48.8	341.6	20.06 ef
Sprigs	8	12.2	48.8	48.8	244.0	19.29 ef
Sprigs	8	48.8	48.8	48.8	390.4	14.86 gf
Sod	2	48.8	0	48.8	24.4	9.86 g

* Means with the same letter are not significantly different according to the LSD procedure at the 0.05 level of probability. LSD = 5.67
† Sod was fertilized on two week intervals beginning two weeks after planting
‡ Rainfall simulation – 63.5 mm hr^{-1}

Figure 2.5 Nitrogen regime† influence on 2001 rainfall simulator induced surface water runoff from bermudagrass established 2, 4, 6, 8, and 10 weeks prior to rainfall simulation (WPRS).



*Means with the same letter are not significantly different according to the LSD procedure at the 0.05 level of probability. LSD = 5.67

† ISP – 48,8 kg N ha^{-1} wk^{-1} LIN – 12.2 kg N ha^{-1} (weeks 1 – 4) and 48,8 kg N ha^{-1} (weeks 5 – 10)

SOD - 48,8 kg N ha^{-1} on two week intervals beginning two weeks after planting.

vegetative cover and time were more influential factors on slowing runoff processes. As vegetative cover increased the amount of runoff sharply decreased with the lowest runoff volumes occurring with greater bermudagrass cover. Lowered water runoff volumes would be the result of matting growth by bermudagrass, weaving a tortuous pathway, which slows waters momentum and increases infiltration time. In addition, soil infiltration capacities may be enhanced with increased root growth through the formation of root channels as well as the possibility of channels formed through existing macrofauna activity (Merwin et al. 1996).

Sediment Runoff

Sediment loss over the ten week experimental period was greatest with bare ground, but was sharply reduced with increased bermudagrass cover. Bare ground exhibited the greatest sediment loss at 130.45 g (Table 2.6 and Fig 2.6). Consistency between replications was low (appendix 3). A pattern such as greater early losses followed by reduced sediment losses over the thirty minute runoff event was unable to be established for any treatment or regime.

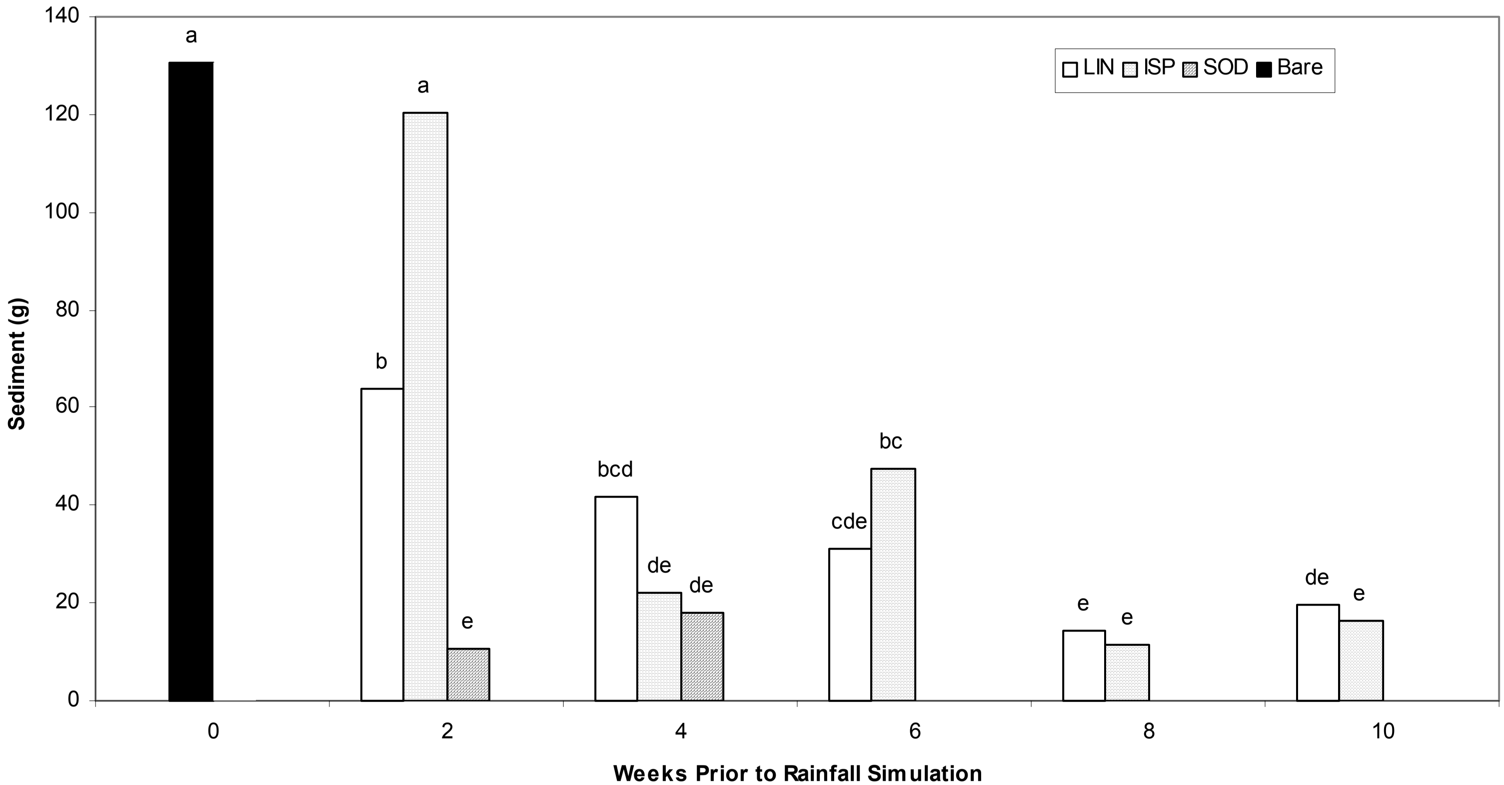
Sprigs established 2WPRS and 4WPRS for both N regimes displayed similar results as bare ground, in terms of consistency between five minute samples of the replications and lack of pattern. Sediment losses were reduced by sprigs except those established at 2WPRS under the ISP regime. Sprigs at 2WPRS under the ISP had the greastest sediment loss of any sprig treatment with 120.35 g compared to 63.98 g lost from 2WPRS (LIN). This difference demonstrated the variable effect of sprig placement and plots. The immaturity of sprigs between treatments would be similar, thus ruling out

Table 2.6 Nitrogen regime influence on 2001 rainfall simulator induced sediment surface runoff from bermudagrass established 2, 4, 6, 8 and 10 weeks prior to rainfall simulation (WPRS)

Vegetative Establishment		N Applied During Growth Period†		N Applied 30 minutes Prior to Rainfall Simulation	Total N Applied	Sediment Runoff*‡
Method	Period	Weeks 1 – 4	Weeks 5 – 10			
	----WPRS----	----------kg ha^{-1} wk^{-1}----------		------------- kg ha^{-1}------------	-- kg ha^{-1}--	------g / 1.5 m^2------
Bare	0	0	0	0	0	130.45 a
Sprigs	2	48.8	0	48.8	97.6	120.35 a
Sprigs	2	12.2	0	12.2	24.4	63.98 b
Sprigs	6	48.8	48.8	48.8	292.8	47.63 bc
Sprigs	4	12.2	0	12.2	48.8	41.89 bcd
Sprigs	6	12.2	48.8	48.8	146.4	30.92 cde
Sprigs	4	48.8	0	48.8	97.6	21.97 de
Sprigs	10	12.2	48.8	48.8	341.6	19.59 de
Sod	4	48.8	0	48.8	97.6	18.16 de
Sprigs	10	48.8	48.8	48.8	488.0	16.31 e
Sprigs	8	12.2	48.8	48.8	244.0	14.30 e
Sprigs	8	48.8	48.8	48.8	390.4	11.33 e
Sod	2	48.8	0	48.8	48.8	10.76 e

* Means with the same letter are not significantly different according to the LSD procedure at the 0.05 level of probability. LSD = 25.25
† Sod was fertilized on two week intervals beginning two weeks after planting
‡ Rainfall simulation – 63.5 mm hr^{-1}

Figure 2.6 Nitrogen regime† influence on 2001 rainfall simulator induced sediment surface runoff from bermudagrass established 2, 4, 6, 8 and 10 weeks prior to rainfall simulation (WPRS).



*Means with the same letter are not significantly different according to the LSD procedure at the 0.05 level of probability. LSD=25.25

† ISP – 48,8 kg N ha^{-1} wk^{-1} LIN – 12.2 kg N ha^{-1} (weeks 1 – 4) and 48,8 kg N ha^{-1} (weeks 5 – 10)

SOD - 48,8 kg N ha^{-1} on two week intervals beginning two weeks after planting.

growth influence as a major contributing factor in runoff and sediment losses. Instead these differences allow one to imply sprig establishment during the first two weeks is limited in its reduction of sediment movement depending heavily on shear random placement, amount of moveable sediment, and plot dynamics.

Establishment periods longer then two weeks resulted in dramatically reduced sediment loss. As bermudagrass establishment cover increased, sediment losses decreased. The stoloniferious growth habit aided the entrapment of suspended sediment. This is nowhere more evident than in the lowest sediment loss from the sodded 2WPRS treatment. Having a well developed thatch layer, the sod transplanted 2WPRS was able to prevent sediment movement more effectively than sprigged treatments, suggesting as sprigged treatments develop, the capabilities to hinder sediment movement would also increase.

As noted, the only difference between ISP and LIN regimes during the same week occurred at 2WPRS. The lack of differences among treatments of the same establishment period along with high correlations of $r^2 = 0.8378$ for the ISP and $r^2 = 0.9696$ for LIN regime trendlines, suggest losses of sediment from both N regimes were extremely similar. Therefore bermudagrass cover as influenced by length of sprig establishment or by sodding was the most influential factor in reducing sediment loss during rainfall events versus N regime effect.

Conclusion

The role of turfgrasses in reducing runoff and sediment losses for established stands have been well documented (Beard, 1994, Gross et al., 1990). It is believed that a tortuous pathway created by a spreading growth habit is most helpful in absorbing water droplet energy, slowing water movement, and trapping suspended sediment (Welterlen et al., 1989, Linde et al., 1995). Additionally, dense turfgrass canopies offer more highly developed fibrous root systems as well as environments conducive to macrofauna existence and development. Both have been recognized with their ability to enhance soil infiltration through the development of soil channels or pathways (Merwin et al., 1996).

It is evident that turfgrasses possess many characteristics capable of preventing or reducing runoff and sediment losses. However, the purpose of this study was to identify how time of establishment and ISP and LIN regimes influence time until water runoff occurrence as well as total water runoff and sediment losses. There were no apparent differences in surface runoff between sprigged bermudagrass treatments as affected by the two N regimes. This was supported through few statistical differences experienced during the same establishment periods for the three measurements of runoff losses. Bermudagrass cover and characteristics were also very similar under the ISP and LIN as discussed in Section 1. Similar growth patterns of the ISP and LIN treated sprigs resulted in similar times of runoff release, total water runoff volumes and sediment losses.

Therefore, it is more important to discuss the trends expressed by the period of bermudagrass cover, a function of establishment time (WPRS), was the most influential factor in determining initiation of surface runoff and quantities of runoff, if the plot and experimental factors such as rain intensity, soil moisture, and plot contours were similar. The data concerning time until runoff initiation for 2000 and 2001, showed few statistical differences among the sprigged treatments. However, the data did offer a trend that clearly demonstrated the resistance of older sprigged treatments (8 and 10 WPRS) to produce surface runoff compared to shorter establishment dates. This supports earlier studies such as Gross et al. (1991) who found increased seeding rates of turf type tall fescue allowed higher plant density, reducing the time to initiation of runoff as well as retarding water and sediment movement. Further analysis of time until runoff initiation between years, reveals a decrease for 2001 compared to the 2000 data. The drop in time is probably due to increases in initial soil moisture levels (appendices 12 and 13) and slope for the plots used in 2001 versus 2000. The increase in slope would facilitate runoff ultimately resulting in lowered initial runoff times (Balogh and Walker, 1992).

In addition to slowing the time to initiation of surface runoff, dense bermudagrass cover under older sprigged treatments exhibited lower total runoff volumes during the thirty minute rain simulation compared to younger establishment dates. This finding, in regard to established stands reducing surface runoff volume, were consistent with the earlier works of Linde et al (1997) and Cole et al. (1997). Slight differences were noted between N treatments during the same establishment period. These differences, as earlier discussed, could be the result of plot variation rather than treatment influence. The trends projected from the data indicated highly correlated trendlines similar in nature for both the ISP and LIN regimes.

Reduced runoff trends for ISP and LIN regimes during both 2000 and 2001, showed closely related sediment losses. During times of increased runoff volumes, sediment losses were higher. Bare ground (control) served as an important indicator to the influence of bermudagrass cover. As ground cover increased, sediment losses were greatly reduced as reported by Gross et al. (1991) on densities of various seeding rates of turf type tall fescues. Even with the erratic behavior between the 5 minute interval samples and lack of a pattern displayed from bare ground to 4WPRS, sediment loss reduction was apparent as bermudagrass sprigs knit into an established sod.

In the case of sod, regardless of the establishment date, time until runoff was greater than that of the sprigged treatments. Runoff volumes were greatly reduced resulting in less sediment movement off site. Hence sod represented a fully mature bermudagrass stand capable of impeding surface runoff occurrence and losses while reducing sediment losses. In comparison sprigged treatment surface runoff losses reduced as sprigs developed with age. However, sprigged treatments were eventually just as effective in reducing sediment runoff compared to sod.

Surface runoff initiation, total water and sediment losses are influenced by many factors other than vegetative cover. Rainfall intensity and duration, soil texture (e.g. infiltration), organic matter content, slope, and soil moisture can influence surface runoff (Balogh and Walker, 1992). These studies controlled rainfall intensity (63.5 mm hr^{-1}) and surface runoff duration (30 minutes) which presented less problems using the rainfall simulator. Other factors were more subject to variability such as soil texture, organic matter content, and soil moisture. The variability of these factors was limited through site selection and monitoring of soil moisture levels to reduce the variability between treatments.

Based on the statistical data, the lack differences in N treatments and similar growth pattern as discussed in section 1, warrant the reduction of nitrogen the first four weeks of establishment. The reduction of N under the LIN regime not only offers similar resistance to total water and sediment losses during surface runoff events as compared to ISP treated sprigs, but may potentially reduce the movement of surface runoff N through reduced application rates. The LIN would reduce N applied by 75% the first four weeks, a time of increased susceptibility to surface runoff, and 30% reduction of N for a ten week establishment period compared to the ISP regime.

Finally, the data concerning sprigs and sod allows a proposal for an alternative preventing surface water runoff and sediment losses on susceptible sites during bermudagrass sprig establishment. The combination of sod and sprig offer some advantages. Because of the high costs associated with sod installation, a suggestion for the use of bermudagrass would be reduced use of sod through sod strips lain across slopes with a distance of ten to fifteen meters apart for sprig establishment using the LIN regime. Use of sod in this manner would allow reduction of establishment costs while taking advantage of its greater ability to reduce runoff and sediment losses.

Section 3

Nitrogen and Phosphorus Surface Runoff Losses During Bermudagrass Sod and Sprig Establishment

Section three is concerned with N and P losses through surface runoff during simulated rainfall of bermudagrass sprigs established following the ISP and LIN regimes.

Objectives

The objectives of this study were to:

1. Determine the potential for N losses in surface runoff at different stages of bermudagrass sprig development under two post planting N regimes.

2. Determine the potential for P losses in surface runoff at various stages of bermudagrass sprig development.

Data Recorded

The experiment included examination of N losses in the forms of nitrate and ammonium as well as phosphorus in the inorganic and organic forms. The total nutrient losses are given as a mass basis in milligrams per 1.5 m^2.

The five minute interval samples from the thirty minute surface runoff rainfall simulation were analyzed using the automated ion analyzer (Lachet Instruments) to evaluate nitrate and ammonium losses. The process for nitrate quantification involves reducing nitrate to nitrite through a copperized cadmium column. The nitrite is diazotized using sulfanilamide followed by coupling with N – naphthllethylenediamine dihydrochloride. This results in a magenta color which can be observed at 520 nm to disconcern nitrite amounts and thus nitrate concentrations. Ammonium concentrations are determined simultaneously through the heating of the water sample with salicylate and hypochlorite in an alkaline phosphate buffer. The reaction leads to an emerald green color whose intensity varies according to ammonia concentration (USEPA, 1992).

Phosphorus concentrations were determined using the spectrophometer (Hitachi), Inductively Coupled Argon Plasma (ICAP), and automated analyzer (lachat) for total phosphorus (TKP). Dissolved Reactive P (DRP) was analyzed using ammonium molybdate and ascorbic acid reactions to form a blue colored solution. Based on the intensity of the color the DRP concentration was determined through comparison to known phosphorus concentrations (Murphy and Reilly, 1962). The ICAP and TKP results following the procedures as outlined by Pierzynski in the "Methods of P Analyses for Water and Soil" are presented in the appendices (Pierzynski, 2000).

Individual analysis of the runoff samples for the specified nutrients allowed calculation and comparison of total nutrient loads between WPRS establishment dates, comparison of variability between runoff time intervals between the same treatments of the replications, as well as aid in the establishment of any nutrient surface runoff loss patterns.

The statistical design was a randomized complete block design with three replications in 2000 and four replications in 2001. Statistical analyses were performed using the program SAS (Statistical Analysis System) (SAS, 1985). N and P measurements were analyzed using repeated measure commands with subsampling used as a complete randomized design for total nutrient surface runoff losses mean separation. LSD (Least significant differences) was the mean separation procedure followed for the subsamples at the 0.05 alpha level.

2000 Results and Discussion

Nitrate Surface Runoff Losses

Nitrate losses in surface runoff between the industry standard practice (ISP) and lower initial N (LIN) regime were not different for any WPRS establishment period (Table 3.1 and Figure 3.1). Beginning with the bare ground treatment, with no N application, the lowest amount of N loss, 68.82 mg NO_3-N, was recorded during the thirty minute rainfall simulated surface runoff event. Both the ISP and LIN regimes nitrate losses in surface runoff increased with WPRS establishment periods. Nitrate losses peaked at 6WPRS as seen with ISP and LIN with losses of 614.47 and 468.03 mg NO_3-N, respectively. Additionally, the 6WPRS established turf represented the greatest difference between N treatments.

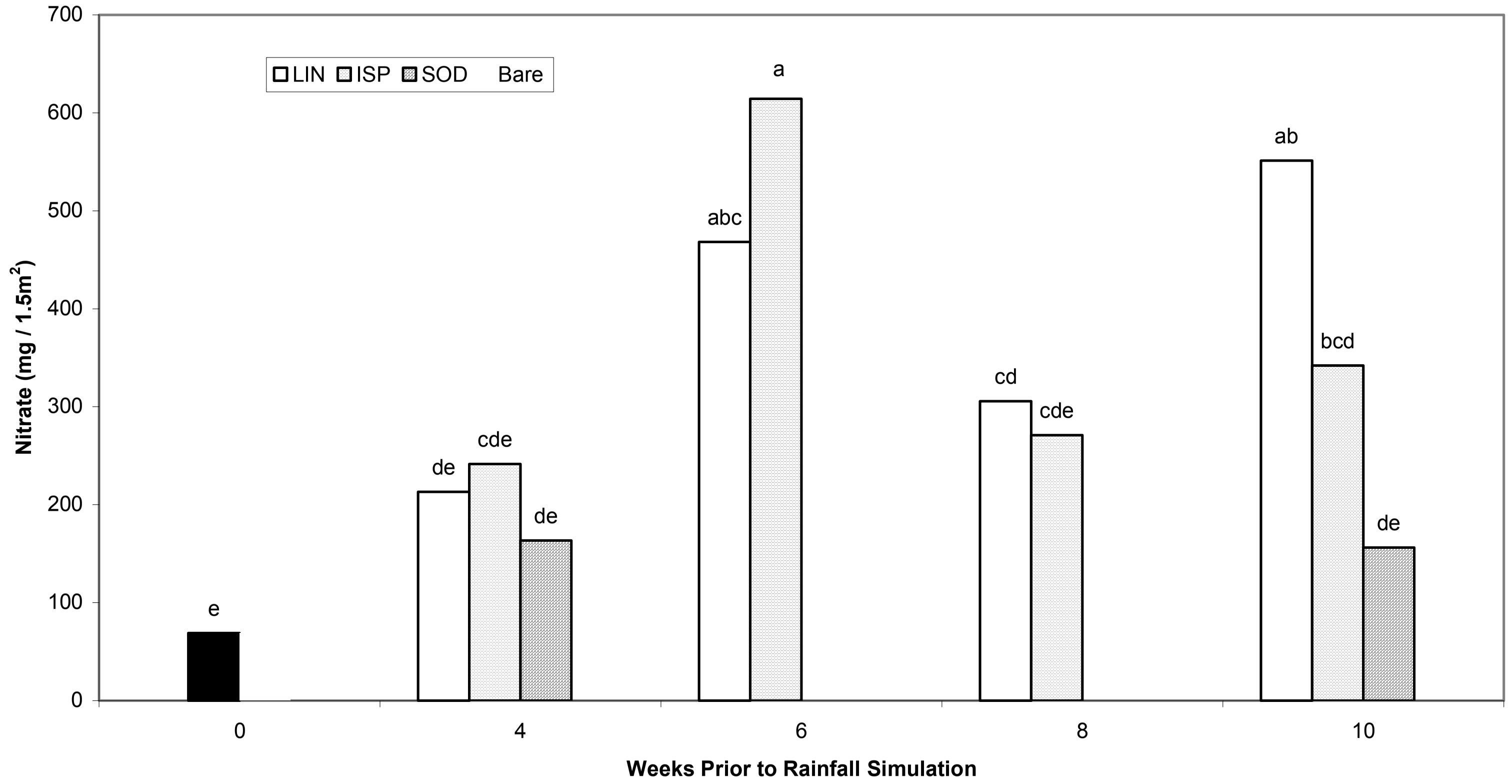
It was suspected that nitrate levels in the soil and therefore losses from surface runoff would increase as establishment (WPRS) period increased and N rates increased, until adequate bermudagrass cover could be established (Gross et al., 1990). One would further hypothesize reduced nitrate losses from surface runoff during the first four weeks following LIN compared to the ISP, because of similar bermudagrass sprig development (Section 1) during the initial four weeks and slower N concentration buildup within the

Table 3.1 Nitrogen regime influence on 2000 nitrate losses through rainfall simulator induced surface runoff from bermudagrass established 4, 6, 8 and 10 weeks prior to rainfall simulation (WPRS)

Vegetative Establishment Method	Vegetative Establishment Period	N Applied During Growth Period† Weeks 1 – 4	N Applied During Growth Period† Weeks 5 – 10	N Applied 30 minutes Prior to Rainfall Simulation	Total N Applied	NO_3-N Runoff*‡
	----WPRS----	----------kg ha^{-1} wk^{-1}----------		------------- kg ha^{-1}------------	-- kg ha^{-1}--	-----mg / 1.5 m^2-----
Sprigs	6	48.8	48.8	48.8	292.8	614.47 a
Sprigs	10	12.2	48.8	48.8	341.6	551.13 ab
Sprigs	6	12.2	48.8	48.8	146.4	468.03 abc
Sprigs	10	48.8	48.8	48.8	488.0	342.08 bcd
Sprigs	8	12.2	48.8	48.8	244.0	305.56 cd
Sprigs	8	48.8	48.8	48.8	390.4	271.15 cde
Sprigs	4	48.8	0	48.8	195.2	241.74 cde
Sprigs	4	12.2	0	12.2	146.4	213.23 de
Sod	4	48.8	0	48.8	97.6	163.54 de
Sod	10	48.8	48.8	48.8	244.0	156.32 de
Bare	0	0	0	0	0	68.83 e

* Means with the same letter are not significantly different according to the LSD procedure at the 0.05 level of probability. LSD = 243.35
† Sod was fertilized on two week intervals beginning two weeks after planting
‡ Rainfall simulation – 63.5 mm hr^{-1}

Figure 3.1 Nitrogen regime† influence on 2000 nitrate losses through rainfall simulator induced surface runoff from bermudagrass established 4, 6, 8 and 10 weeks prior to rainfall simulation (WPRS).



*Means with the same letter are not significantly different according to the LSD procedure at the 0.05 level of probability. LSD =243.35

† ISP – 48,8 kg N ha^{-1} wk^{-1} LIN – 12.2 kg N ha^{-1} (weeks 1 – 4) and 48,8 kg N ha^{-1} (weeks 5 – 10)

SOD - 48,8 kg N ha^{-1} on two week intervals beginning two weeks after planting.

soil (Gross et al., 1990). Little difference existed in nitrate runoff at 4WPRS for ISP and LIN regimes at 241.74 and 213.23 mg NO_3-N respectively. Therefore the raw data was evaluated as well as visual and runoff data to develop an understanding as to the causes of the similar results for 4WPRS. In doing so, one finds that the ISP and LIN at 4WPRS were statistically similar in cover, quality, biomass (Section 1), and runoff characterization (Section 2). This initiated investigation into the nitrate surface runoff raw data, which displayed fairly consistent results for 4WPRS following ISP, but saw 4WPRS for LIN inflated by one particularly high surface runoff nitrate loss (Appendix 4). Taking into account the inflated average of 4WPRS of LIN, nitrate surface runoff losses could possibly be reduced during earlier weeks with the use of lower initial N rates compared to the ISP of 48.8 kg N ha^{-1} wk^{-1}. However in order to substantiate the proposed hypothesis, inclusion of additional replications are needed. These results are further hindered from fully supporting differences between the ISP and LIN N regimes during the first four weeks without the 2WPRS establishment period results.

The 8WPRS treatments, with increased bermudagrass cover, exhibited greatly reduced nitrate runoff levels following either ISP or LIN compared to the high nitrate losses of 6WPRS for both ISP and LIN. In contrast to 8WPRS, the 10WPRS had increased nitrate losses for both N regimes. Once again a large difference between treatments existed. The 10WPRS treatment following the LIN regime had runoff losses of 551.10 mg NO_3-N compared to 342.06 mg NO_3-N lost by ISP. Though not statistically different, this represented a difference in nitrate losses for bermudagrass stands that were visually and cover wise extremely similar. Much like the difference in the 4WPRS treatments following the LIN, one particular plot inflated the mean.

The lack of differences between the ISP and LIN treated sprigs does emphasize the importance of N application timing in regards to potential surface runoff loss. With the onset of cooler temperatures in Blacksburg during the month of September (Appendix 1), one would expect a period of transitioning in the plant toward dormancy (Duble, 1996). Therefore, the bermudagrass N uptake may have been less, resulting in higher soil N concentrations.

Sodded plots showed the greatest similarity with losses of 163.56 mg and 156.30 mg NO_3-N for 4WPRS and 10WPRS, respectively. Sodded plots were lower in N runoff and similar to all sprigged treatments with the exception of 6WPRS for both ISP and LIN and 10WPRS for LIN. It is believed the increased number of bermudagrass plants associated with sod, were able to reestablish rather quickly; utilizing the available N while also creating a less than amicable canopy for surface runoff, reducing nitrate concentration and ability to move offsite.

Not only was a pattern of peaked nitrate losses obvious for the 6WPRS establishment treatments, but a pattern of high early losses followed by substantially lower concentrations was recognized from the five minute samples during the thirty minute rainfall event for all three N regimes (Appendix 4). Nitrate losses were consistent between many samples with the most variability taking place in the first five to ten minute intervals between replications.

Ammonium Surface Runoff Losses

Ammonium losses from surface runoff during the ten week establishment period prior to rainfall simulation appeared closely aligned to the results for by nitrate surface runoff losses. As bermudagrass established itself, ammonium losses though not statistically different between weeks, increased as seen with bare ground to 6WPRS. The 6WPRS period represented the highest ammonium surface runoff loss for both ISP and LIN regimes (Table 3.2 and Figure 3.2). In addition to representing the apex of ammonium surface runoff, 6WPRS had the greatest separation during the same week between the higher ISP and lower LIN as seen with a 117.96 mg NH_3-N difference.

In the weeks following, the 8WPRS of ISP and LIN regimes showed similar losses with 215.16 and 248.16 mg NH_3-N respectively, a dramatic reduction in comparison to the elevated levels experienced at 6WPRS. This marked a time period where increased bermudagrass cover was able to use available N; or excessive N in the form of ammonium was able to adsorb to charged soil or organic particles. Like nitrate, ammonium surface runoff losses were higher at 10WPRS with sprigs following LIN regime showing a greater loss than the moderate increase under the ISP. Though not statistically different, one would expect ammonium losses to be close for both ten week treatments with similar coverage, plant and runoff characteristics (Chapter 1 and 2). Once again the raw data exposed a replication for 10WPRS following LIN regime that experienced a much higher ammonium loss, inflating the mean total ammonium surface runoff loss.

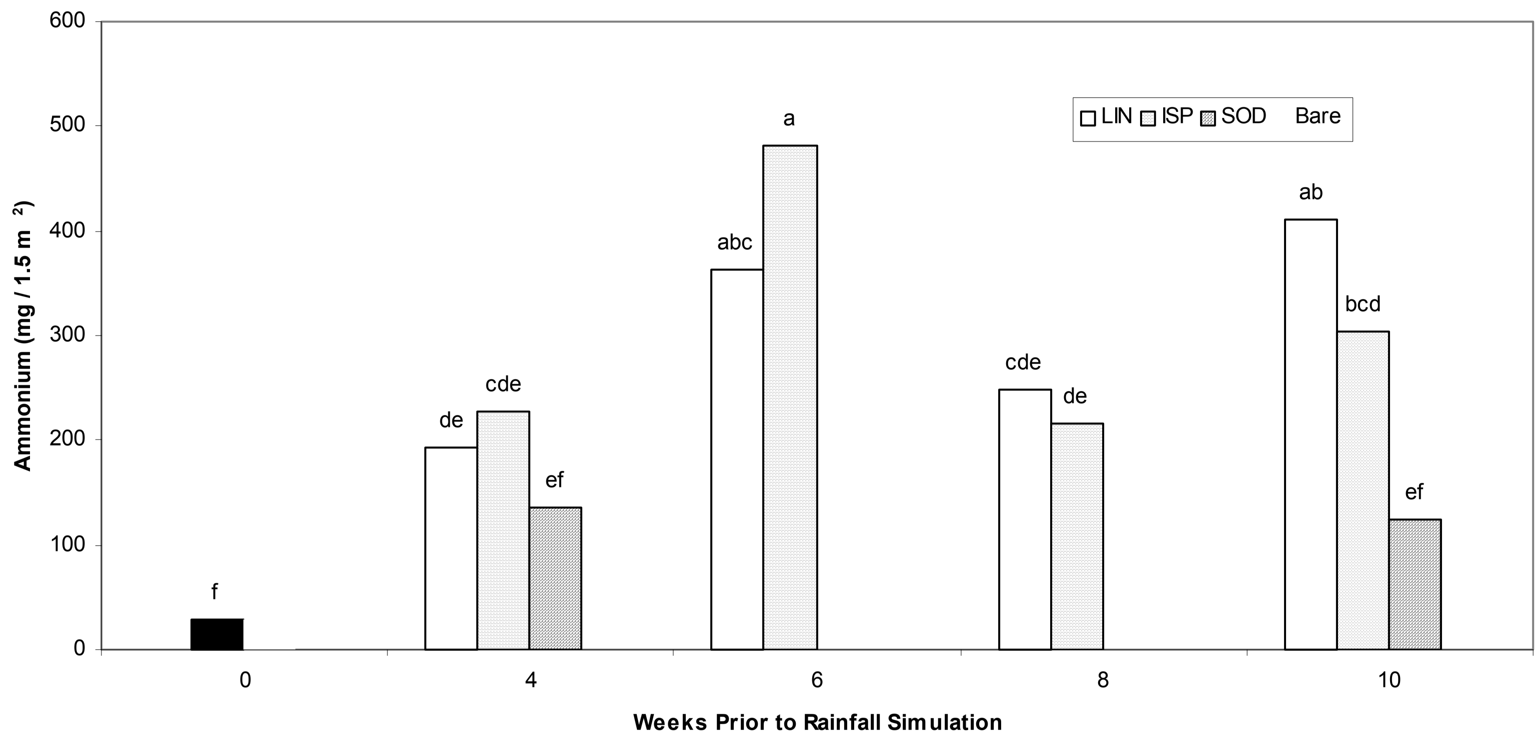
Interestingly, the ammonium losses also displayed a distinguishable pattern for individual concentrations of ammonium in surface runoff of plots. The ammonium loss concentrations were high early followed by reduced concentration losses the remainder of the thirty minute surface runoff rainfall simulation (Appendix 6). Variation of the five

Table 3.2 Nitrogen regime influence on 2000 ammonium losses through rainfall simulator induced surface runoff from bermudagrass established 4, 6, 8 and 10 weeks prior to rainfall simulation (WPRS)

Vegetative Establishment		N Applied During Growth Period†		N Applied 30 minutes Prior to Rainfall Simulation	Total N Applied	NH_3-N Runoff*‡
Method	Period	Weeks 1 – 4	Weeks 5 – 10			
	----WPRS----	----------kg ha^{-1} wk^{-1}----------		------------- kg ha^{-1}------------	-- kg ha^{-1}--	-----mg / 1.5 m^2--
Sprigs	6	48.8	48.8	48.8	292.8	481.80 a
Sprigs	10	12.2	48.8	48.8	341.6	410.71 ab
Sprigs	6	12.2	48.8	48.8	146.4	363.82 abc
Sprigs	10	48.8	48.8	48.8	488.0	303.79 bcd
Sprigs	8	12.2	48.8	48.8	244.0	248.18 cde
Sprigs	4	48.8	0	48.8	195.2	226.48 cde
Sprigs	8	48.8	48.8	48.8	390.4	215.18 de
Sprigs	4	12.2	0	12.2	146.4	192.95 de
Sod	4	48.8	0	48.8	97.6	136.16 ef
Sod	10	48.8	48.8	48.8	244.0	124.04 ef
Bare	0	0	0	0	0	28.75 e

* Means with the same letter are not significantly different according to the LSD procedure at the 0.05 level of probability. LSD = 145.53
† Sod was fertilized on two week intervals beginning two weeks after planting
‡ Rainfall simulation – 63.5 mm hr^{-1}

Figure 3.2 Nitrogen regime† influence on 2000 ammonia losses through rainfall simulator induced surface runoff from bermudagrass established 4, 6, 8 and 10 weeks prior to rainfall simulation (WPRS).



* Means with the same letter are not significantly different according to the LSD procedure at the 0.05 level of probability. LSD = 145.53

† ISP – 48,8 kg N ha^{-1} wk^{-1} LIN – 12.2 kg N ha^{-1} (weeks 1 – 4) and 48,8 kg N ha^{-1} (weeks 5 – 10)

SOD - 48,8 kg N ha^{-1} on two week intervals beginning two weeks after planting.

minute samples between replications of the same treatment existed at the five and ten minute intervals with less variation the remainder of the thirty minute runoff event.

Sodded plots unlike many of the sprigged treatments represented relatively mature turfgrass stands able to utilize applied N. Statistically the two sodded plots were no different than the losses experienced under bare ground as seen with losses of 136.16 and 124.04 mg NH_3-N for 4WPRS and 10WPRS respectively. Thus sodded bermudagrass offered greater resistance to ammonium losses in surface runoff during rainfall simulation compared to sprigged treatments regardless the age. The reduced losses may be attributed to the quick establishment of bermudagrass sod and the retardation of runoff and thus quantity, as well as the combination of less N applied at the rate of 48.8 kg N ha^{-1} every other week.

Dissolved Reactive Phosphorus (DRP) Surface Runoff Losses

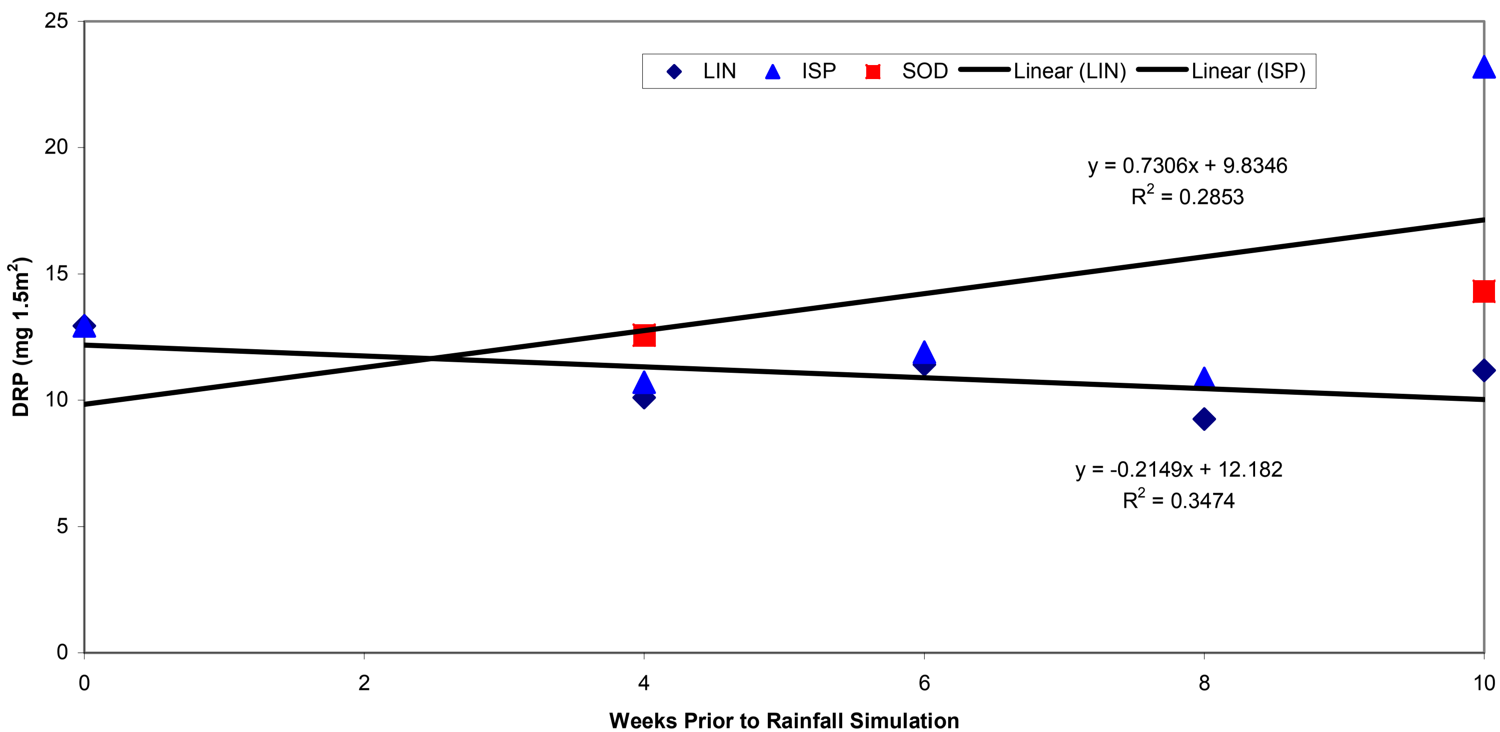
Dissolved reactive P surface runoff, a measurement of dissolved inorganic forms of phosphorus ($H_2PO_4^-$ and HPO_4^{-2}), losses were extremely inconsistent between replications and sampling during the five minute time intervals (Table 3.3, Figure 3.3, and Appendix 8). A pattern between sprig establishment WPRS for both ISP and LIN regimes effects resulted in poor linear correlations of $r^2 = 0.2853$ and $r^2 = 0.3474$, respectively. One must note that the data from DRP is evaluated for N influence and not the result of any phosphorus application.

Table 3.3 Nitrogen regime influence on 2000 dissolved reactive phosphorus (DRP) losses through rainfall simulator induced surface runoff from bermudagrass established 4, 6, 8 and 10 weeks prior to rainfall simulation (WPRS)

Vegetative Establishment		N Applied During Growth Period†		N Applied 30 minutes Prior to Rainfall Simulation	Total N Applied	DRP Runoff*‡
Method	Period	Weeks 1 – 4	Weeks 5 – 10			
	----WPRS----	----------kg ha^{-1} wk^{-1}----------		------------- kg ha^{-1}------------	-- kg ha^{-1}--	----mg / 1.5 m^2---
Sprigs	10	48.8	48.8	48.8	488.0	23.20 a
Sod	10	48.8	48.8	48.8	244.0	14.31 b
Bare	0	0	0	0	0	12.95 bc
Sod	4	48.8	0	48.8	97.6	12.58 bcd
Sprigs	6	48.8	48.8	48.8	292.8	11.91 bcde
Sprigs	6	12.2	48.8	48.8	146.4	11.41 cde
Sprigs	10	12.2	48.8	48.8	341.6	11.18 cde
Sprigs	8	48.8	48.8	48.8	390.4	10.86 cde
Sprigs	4	48.8	0	48.8	195.2	10.71 cde
Sprigs	4	12.2	0	12.2	48.8	10.10 de
Sprigs	8	12.2	48.8	48.8	244.0	9.25 e

* Means with the same letter are not significantly different according to the LSD procedure at the 0.05 level of probability. LSD = 2.76
† Sod was fertilized on two week intervals beginning two weeks after planting
‡ Rainfall simulation – 63.5 mm hr^{-1}

Figure 3.3 Nitrogen regime† influence on 2000 dissolved reactive phosphorus (DRP) losses through rainfall simulator induced surface runoff from bermudagrass established 4, 6, 8 and 10 weeks prior to rainfall simulation (WPRS).



* Means with the same letter are not significantly different according to the LSD procedure at the 0.05 level of probability. LSD = 2.76

† ISP – 48,8 kg N ha^{-1} wk^{-1} LIN – 12.2 kg N ha^{-1} (weeks 1 – 4) and 48,8 kg N ha^{-1} (weeks 5 – 10)

SOD - 48,8 kg N ha^{-1} on two week intervals beginning two weeks after planting.

There are points of concern with the DRP sprig treatment data. There was a substantially higher loss exhibited under treatment 10WPRS following the ISP at 23.20 mg DRP compared to any other treatment, sprig or sod. There was also a positive slope of the ISP trendline. The increased DRP losses experienced under the 10WPRS for the ISP caused review of the raw data, which calmed suspicion of an inflated average with higher then expected loss by all three replications. Because clippings were returned throughout the study, it is possible phosphorus extracted from the soil by the plant was released on the soil surface with clipping decomposition. Increased levels of phosphorus at the soil surface would allow greater susceptibility to movement from surface runoff events as reported from earlier studies concerning the range of phosphorus and surface runoff interaction during rainfall events as DRP (Sharpley, 1985).

The concern with the difference in trendline slopes was answered through investigation of the increased DRP loss of ISP for 10WPRS. The higher then expected DRP loss influenced the ISP trendline to result in a positive slope, suggesting unexpected higher losses over time with increased N applications or bermudagrass growth. However, without applications of phosphorus, the amount of available phosphorus in the soil would be expected to diminish over time (Tisdale et al., 1993).

Sodded treatments did show similar and statistical total DRP losses with 12.58 and 14.31 mg DRP for 4WPRS and 10WPRS. Inconsistencies were observed between the five minute samples taken during the thirty minute runoff period (Appendix 8). Little in regard to cause and effect could be related to sod or sprig treatments when analyzed. Sod appeared just as susceptible of DRP surface runoff occurrence to that of bermudagrass established by sprigging; and the amounts of DRP lost from surface runoff for many of the treatments, ranging in 0.16 to 0.98 ppm, existed under moderate levels of soil phosphorus at 25 ppm.

2001 Results and Discussion

Nitrate Surface Runoff Losses

Increased nitrate losses in surface runoff from bermudagrass sprigs during the thirty minute post simulated rainfall, showed increased nitrate runoff losses following the industry standard practice (ISP) to that of lower initial N rates (LIN) during 2WPRS, 4WPRS, and 6WPRS (Table 3.4 and Figure 3.4). Bare ground, with no N applications, represented the lowest nitrate surface runoff loss at 34.59 mg NO_3-N. Bermudagrass sprig establishment periods of 2WPRS, 4WPRS, and 6WPRS for ISP and LIN regimes with the addition of 8WPRS displayed sequential increased nitrate losses, with 6WPRS for ISP and LIN at 8WPRS representing the highest nitrate losses.

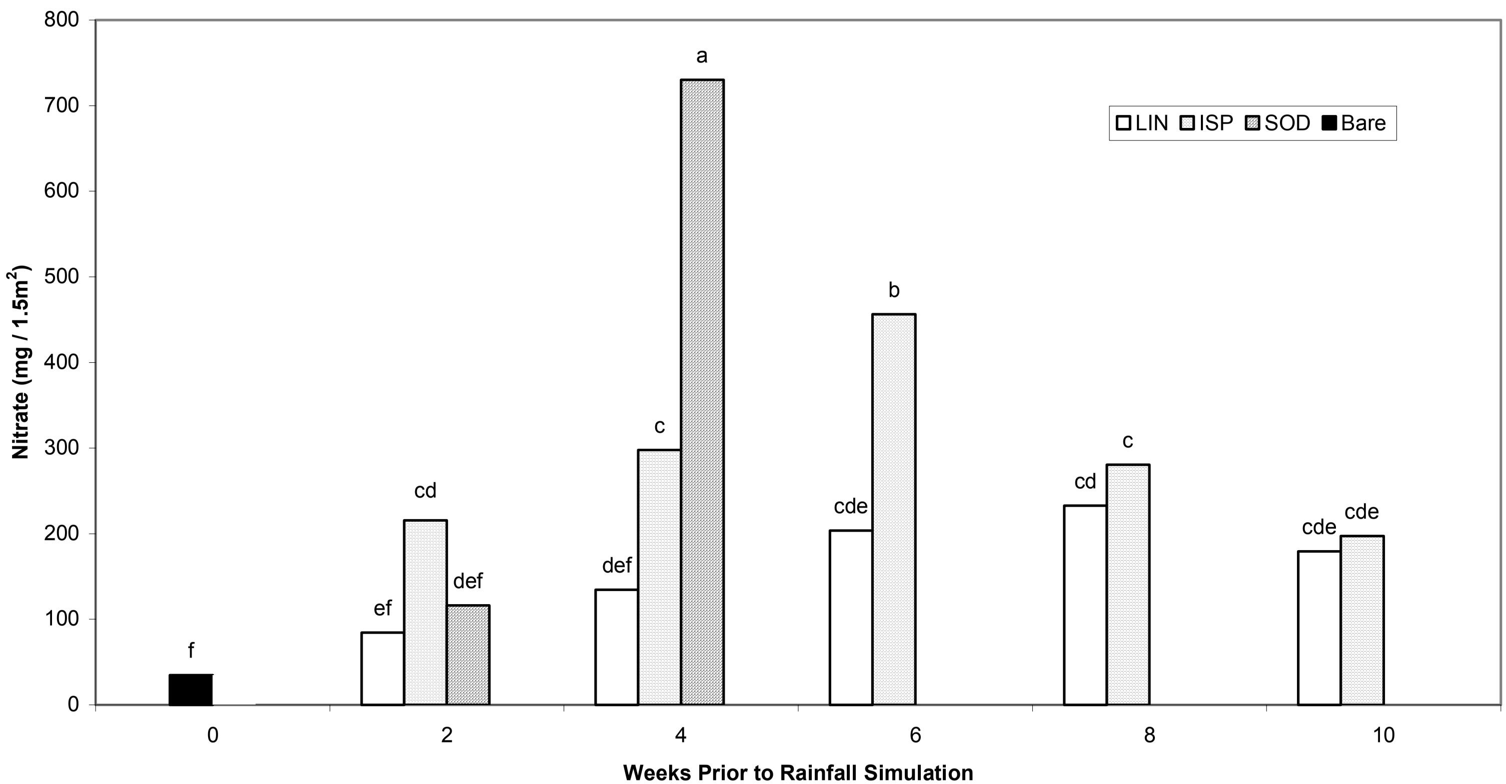
Though similar in the progression of nitrate loss until 6 or 8 WPRS, bermudagrass sprigs established following ISP and LIN regimes experienced very different quantities of nitrate lost via surface runoff. The LIN regime at 2WPRS had a nitrate surface runoff loss of 84.42 mg NO_3-N, a 61% reduction, when compared to a 215.62 mg NO_3-N loss of 2WPRS following ISP. Increased ISP nitrate surface runoff losses was again greater at 4WPRS, compared to sprigs under the LIN. Nitrate losses of sprigs at 6WPRS at 456.12 mg NO_3-N of the ISP was much higher than the 203.69 mg NO_3-N for LIN, resulting in a difference of 252.43 mg NO_3-N, a reduction of more than fifty percent by LIN regime from ISP. A difference in nitrate loss in surface runoff from the higher ISP to that of the

Table 3.4 Nitrogen regime influence on 2001 nitrate losses through rainfall simulator induced surface runoff from bermudagrass established 2, 4, 6, 8 and 10 weeks prior to rainfall simulation (WPRS)

Vegetative Establishment		N Applied During Growth Period†		N Applied 30 minutes Prior to Rainfall Simulation	Total N Applied	NO_3-N Runoff*‡
Method	Period	Weeks 1 – 4	Weeks 5 – 10			
	----WPRS----	----------kg ha^{-1} wk^{-1}----------		------------- kg ha^{-1}------------	-- kg ha^{-1}--	-----mg / 1.5 m^2----
Sod	4	48.8	0	48.8	97.6	730.16 a
Sprigs	6	48.8	48.8	48.8	292.8	456.12 b
Sprigs	4	48.8	0	48.8	195.2	297.92 c
Sprigs	8	48.8	48.8	48.8	390.4	280.54 c
Sprigs	8	12.2	48.8	48.8	244.0	232.74 cd
Sprigs	2	48.8	0	48.8	97.6	215.62 cd
Sprigs	6	12.2	48.8	48.8	146.4	203.69 cde
Sprigs	10	48.8	48.8	48.8	488.0	197.35 cde
Sprigs	10	12.2	48.8	48.8	341.6	179.19 cde
Sprigs	4	12.2	0	12.2	48.8	134.51 def
Sod	2	48.8	0	48.8	48.8	116.28 def
Sprigs	2	12.2	0	12.2	24.4	84.42 ef
Bare	0	0	0	0	0	34.59 f

* Means with the same letter are not significantly different according to the LSD procedure at the 0.05 level of probability. LSD = 125.36
† Sod was fertilized on two week intervals beginning two weeks after planting
‡ Rainfall simulation – 63.5 mm hr^{-1}

Figure 3.4 Nitrogen regime† influence on 2001 nitrate losses through rainfall simulator induced surface runoff from bermudagrass established 2, 4, 6, 8 and 10 weeks prior to rainfall simulation (WPRS).



* Means with the same letter are not significantly different according to the LSD procedure at the 0.05 level of probability. LSD = 125.36

† ISP – 48,8 kg N ha^{-1} wk^{-1} LIN – 12.2 kg N ha^{-1} (weeks 1 – 4) and 48,8 kg N ha^{-1} (weeks 5 – 10)

SOD - 48,8 kg N ha^{-1} on two week intervals beginning two weeks after planting.

LIN regime during the same week supported the hypothesis of increased probability of N movement during early excessive fertilization of bermudagrass sprigs such as the industry standard practice.

Sprigs established 8 and 10 WPRS following the ISP and 10WPRS for LIN regime had lower nitrate losses compared to sprigs 6WPRS. The LIN regime at 8WPRS was the apex of surface runoff nitrate loss at 232.74 mg NO_3-N and was extremely similar to the losses experienced by the ISP sprigs 8WPRS, which was less compared to 6WPRS following the ISP, at 280.56 mg NO_3-N. The delayed maturity of 8WPRS under LIN regime, as shown through percent cover, visual quality, and biomass data from 2001 (Section 1), suggests a reduced number of bermudagrass plants, lacking a substantial bermudagrass population able to effectively utilize available soil nitrate compared to bermudagrass sprigs following the ISP regime; or that reduced coverage prohibited nitrate movement downward in the soil through root channels and thus unavailable during surface runoff occurrence.

A pattern regarding nitrate surface runoff losses for individual plots during the thirty minute simulated surface runoff event was observed (Appendix 7). Nitrate surface runoff losses were highest during the first five and ten minute interval runoff samples and decreased over the rest of the thirty minute rainfall simulation induced rainfall. The five and ten minute interval samples also demonstrated the highest variability between replications, indicating variability is closely tied to the runoff characteristics of the plot.

Sodded treatments were not as consistent in nitrate losses as those seen in 2000. The 2WPRS had nitrate losses of 116.28 mg NO_3-N compared to a surprising 730.16 mg NO_3-N from 4WPRS. Not only did 4WPRS represent a substantial higher loss of nitrate through surface runoff, but was the highest loss for any treatment sod or sprig. Raw data from the four replications of the sodded 4WPRS showed high marks for three of the four replications, requiring further investigation as to the leading cause. It was found the location in which the sod was harvested had portions of the area fertilized in preparation for another experiment. When the sod was transplanted from one site to the other, residual N accompanied the bermudagrass sod, and likely influenced nitrate and ammonium surface runoff losses. However, the 2WPRS sodded treatment did display a low nitrate surface runoff loss compared to many of the sprigged treatments. Judging from the low nitrate surface runoff losses of sod established 4WPRS in 2000 and sodded treatment in 2001 at 2WPRS, sod offers an instant cover capable of preventing and reducing surface runoff and nitrate movement at applied N applications.

Ammonium Surface Runoff Losses

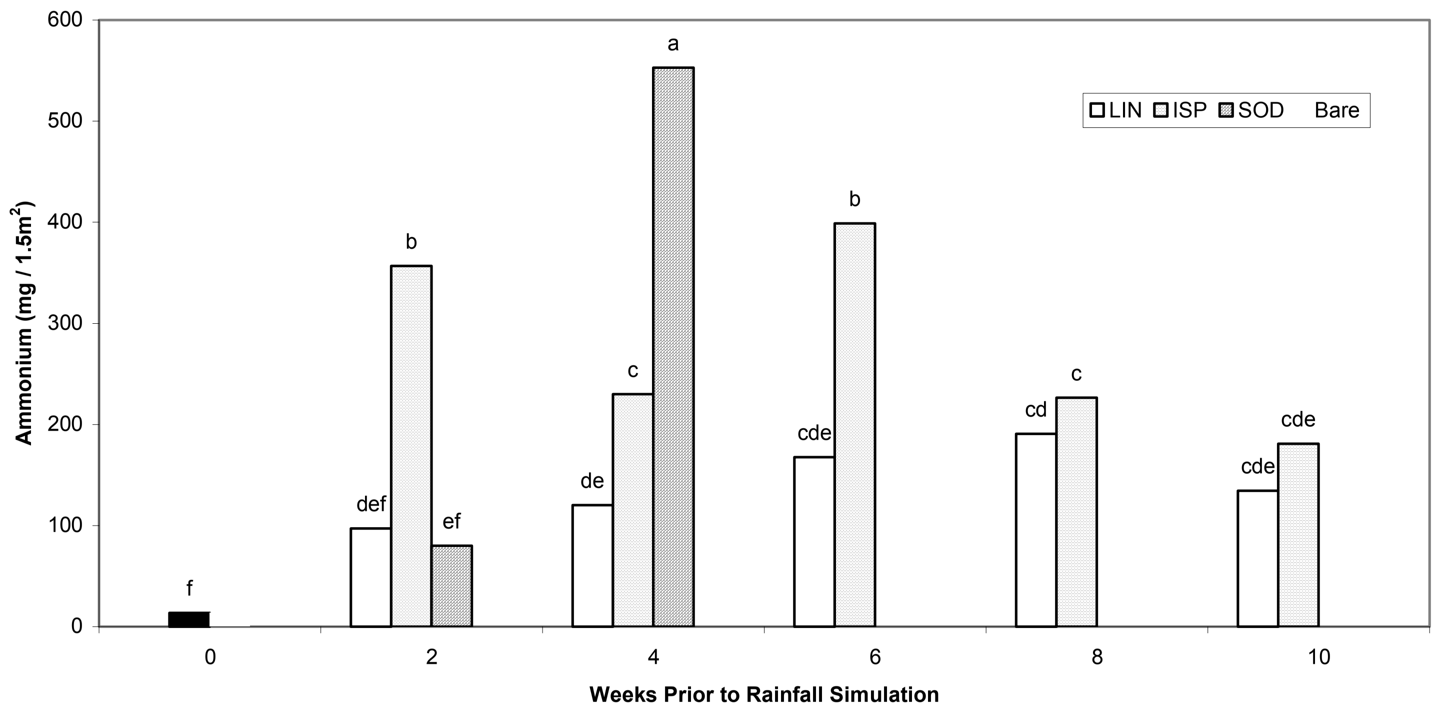
Ammonium surface runoff losses from the thirty minute surface runoff rainfall simulation followed a similar pattern to that of nitrate surface runoff losses for each establishment period. The bare ground represented the lowest total ammonium surface runoff loss of 13.51 mg NH_3-N (Table 3.5 and Figure 3.5). The 2, 4, and 6 WPRS establishment periods had greater ammonium surface runoff for the ISP than the LIN treated sprigs. The only exception to the increases was observed for 4WPRS following the ISP, which decreased to 229.98 mg NH_3-N compared to higher ammonium surface runoff losses of 2WPRS and 6WPRS at 356.67 mg NH_3-N and 398.87 mg NH_3-N both following the ISP.

Table 3.5 Nitrogen regime influence on 2001 ammonium losses through rainfall simulator induced surface runoff from bermudagras established 2, 4, 6, 8 and 10 weeks prior to rainfall simulation (WPRS)

Vegetative Establishment Method	Vegetative Establishment Period	N Applied During Growth Period† Weeks 1 – 4	N Applied During Growth Period† Weeks 5 – 10	N Applied 30 minutes Prior to Rainfall Simulation	Total N Applied	NH_3-N Runoff*‡
	----WPRS----	----------kg ha^{-1} wk^{-1}----------		------------- kg ha^{-1}------------	-- kg ha^{-1}--	-----mg / 1.5 m^2----
Sod	4	48.8	0	48.8	97.6	552.94 a
Sprigs	6	48.8	48.8	48.8	292.8	398.97 b
Sprigs	2	48.8	0	48.8	97.6	356.67 b
Sprigs	4	48.8	0	48.8	195.2	229.98 c
Sprigs	8	48.8	48.8	48.8	390.4	226.54 c
Sprigs	8	48.8	48.8	48.8	244.0	190.76 cd
Sprigs	10	48.8	48.8	48.8	488.0	180.78 cde
Sprigs	6	12.2	48.8	48.8	146.4	167.60 cde
Sprigs	10	12.2	48.8	48.8	341.6	134.42 cde
Sprigs	4	12.2	0	12.2	48.8	120.06 de
Sprigs	2	12.2	0	12.2	24.4	97.20 def
Sod	2	48.8	0	48.8	48.8	80.07 ef
Bare	0	0	0	0	0	13.51 f

* Means with the same letter are not significantly different according to the LSD procedure at the 0.05 level of probability. LSD = 103.35
† Sod was fertilized on two week intervals beginning two weeks after planting
‡ Rainfall simulation – 63.5 mm hr^{-1}

Figure 3.5 Nitrogen regime† influence on 2001 ammonia losses through rainfall simulator induced surface runoff from bermudagrass established 2, 4, 6, 8 and 10 weeks prior to rainfall simulation (WPRS).



* Means with the same letter are not significantly different according to the LSD procedure at the 0.05 level of probability. LSD = 103.35

† ISP – 48,8 kg N ha^{-1} wk^{-1} LIN – 12.2 kg N ha^{-1} (weeks 1 – 4) and 48,8 kg N ha^{-1} (weeks 5 – 10)

SOD - 48,8 kg N ha^{-1} on two week intervals beginning two weeks after planting.

The largest difference between ISP and LIN, 73% (259.47 mg NH_3-N), occurred at 2WPRS with ISP being greater. The 6WPRS treatment for both ISP and LIN showed similar results to that experienced between 2WPRS treatments with a 231.27 mg NH_3-N or 58% increase for the ISP. The statistical separation in ammonium losses between the two N regimes is thought to rely heavily on available ammonium. Continued use of ammonium based fertilizer at higher rates like those used in the standard industry practice could have increased ammonium concentration in the soil, resulting in its increase probability to move off site through surface runoff.

Establishment periods of 8WPRS and 10WPRS for both N regimes had no statistical differences in ammonium surface runoff losses. In fact the differences in quantities of ammonium lost between ISP and LIN at 8WPRS and 10WPRS were 35.78 mg NH_3-N and 46.36 mg NH_3-N, respectively. The bermudagrass stands for 8WPRS and 10WPRS were also similar in many visual and runoff characteristics.

Sodded treatments, like that of the 2001 nitrate surface runoff losses, showed a great disparity between 2WPRS and 4WPRS. The 2WPRS had the lowest ammonium surface runoff quantity lost at 80.07 mg NH_3-N, statistically comparable to that of the non-treated bare ground. The 4WPRS treatment, on the other hand, displayed the highest ammonium loss of any treatment, sod or sprig, at 552.94 mg NH_3-N. As discussed in the results of nitrate surface runoff losses in 2001, sod was influenced by additional fertilizer.

Bermudagrass cover was an influential factor in increasing resistance to surface runoff timing, lowering the quantity of surface water runoff, and reducing ammonium lost during simulated rainfall induced surface runoff. Additionally, patterns regarding ammonium surface runoff losses for individual treatments were uncovered through analysis of the five minute samples (Appendix 7). Ammonium surface runoff concentrations were greater the first five minutes and reduced over the duration of the thirty minute sampling period. The high levels of ammonium lost during the initial five minutes was highly variable between replications. Variability decreased with the progression of the thirty minute surface runoff collection period.

Dissolved Reactive Phosphorus (DRP) Surface Runoff Losses

Dissolved Reactive P was extremely variable between all establishment dates and sampling time intervals for all N regimes (Appendix 9). No pattern regarding DRP loss was discovered for ISP and LIN regimes, resulting in uncorrelated loss of DRP from both the sprigged and sodded treatments (Table 3.6 and Figure 3.6) . No phosphorus treatment was applied to any of the plots. Data was collected to determine the effect of N applications on dissolved reactive phosphorus release during surface runoff events.

Linear regression lines for ISP and LIN N regimes had poor correlations of r^2 = 0.3047 and r^2 = 0.1551 respectively. However, 2001 trendlines followed similar downward sloped paths. The reduction of DRP may be the result of increased use of phosphorus by bermudagrass during establishment. It has been well documented a plant's increased need for available P during seeding and vegetative establishment of plants, but with poor correlations further studies are warranted (Turner and Hummel, 1992).

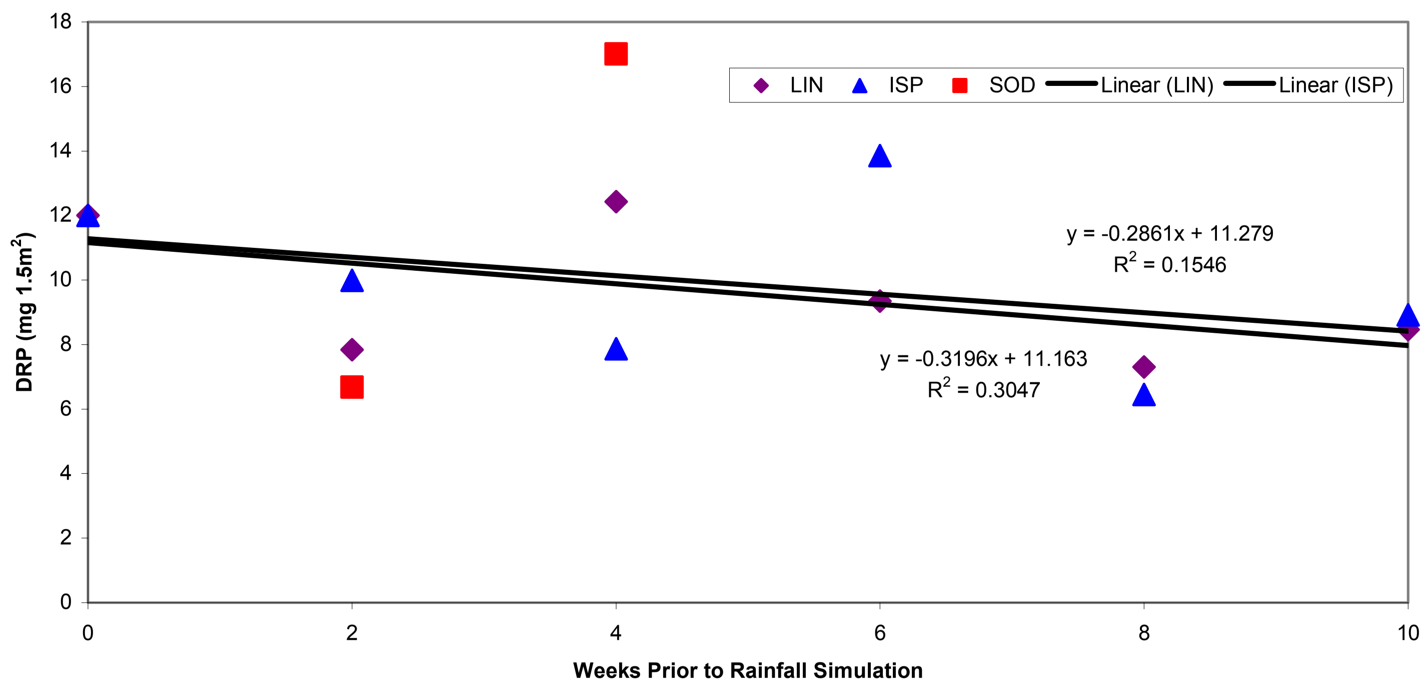
Sodded treatments showed very different results between each other with 2WPRS being lower compared to 4WPRS. This difference is believed to be the result of misapplied fertilizer in preparation for another experiment. Sod was harvested

Table 3.6 Nitrogen regime influence on 2001 dissolved reactive phosphorus (DRP) losses through rainfall simulator induced surface runoff from bermudagrass established 2, 4, 6, 8 and 10 weeks prior to rainfall simulation (WPRS)

Vegetative Establishment		N Applied During Growth Period†		N Applied 30 minutes Prior to Rainfall Simulation	Total N Applied	DRP Runoff*‡
Method	Period	Weeks 1 – 4	Weeks 5 – 10			
	----WPRS----	----------kg ha^{-1} wk^{-1}----------		------------- kg ha^{-1}------------	-- kg ha^{-1}--	----mg / 1.5 m^{2}---
Sod	4	48.8	0	48.8	97.6	17.01 a
Sprigs	6	48.8	48.8	48.8	292.8	13.86 b
Sprigs	4	12.2	0	12.2	48.8	12.43 bc
Bare	0	0	0	0	0	12.00 bc
Sprigs	2	48.8	0	48.8	97.6	9.99 cd
Sprigs	6	12.2	48.8	48.8	146.4	9.35 de
Sprigs	10	48.8	48.8	48.8	488.0	8.92 def
Sprigs	10	12.2	48.8	48.8	341.6	8.46 def
Sprigs	4	48.8	0	48.8	195.2	7.87 def
Sprigs	2	12.2	0	12.2	24.4	7.84 def
Sprigs	8	12.2	48.8	48.8	244.0	7.31 ef
Sod	2	48.8	0	48.8	48.8	6.68 f
Sprigs	8	48.8	48.8	48.8	390.4	6.45 f

* Means with the same letter are not significantly different according to the LSD procedure at the 0.05 level of probability. LSD = 2.55
† Sod was fertilized on two week intervals beginning two weeks after planting
‡ Rainfall simulation – 63.5 mm hr^{-1}

Figure 3.6 Nitrogen regime† influence on 2001 dissolved reactive phosphorus(DRP) losses through rainfall simulator induced surface runoff from bermudagrass established 2, 4, 6, 8 and 10 weeks prior to rainfall simulation (WPRS).



* Means with the same letter are not significantly different according to the LSD procedure at the 0.05 level of probability. LSD = 2.55

† ISP – 48,8 kg N ha^{-1} wk^{-1} LIN – 12.2 kg N ha^{-1} (weeks 1 – 4) and 48,8 kg N ha^{-1} (weeks 5 – 10)

SOD - 48,8 kg N ha^{-1} on two week intervals beginning two weeks after planting.

unknowingly for the 4WPRS, and used within this specific experiment. Thus levels of phosphorus availability differed resulting in high DRP losses for treatment 4WPRS. The 2WPRS sod treatment did display a low DRP surface runoff quantity of 6.68 mg compared to many of the sprigged treatments and may offer a suitable alternative.

Conclusion

Nitrate and ammonium surface runoff losses from sprigs established under the ISP and LIN regimes demonstrated a consistent overall loss pattern for both 2000 and 2001. Nitrate losses were greater in comparison to ammonium during both years. Differences may be related the denitrification of ammonium or adsorption to charged soil and organic surfaces (Petrovic, 1990). However, the runoff patterns established by nitrate and ammonium losses over the treatments (WPRS) were closely aligned, allowing nitrate and ammonium losses to be discussed simply as N.

Nitrate and ammonium losses, for the thirty minute simulated rainfall after surface runoff initiation, over the establishment ages were greatest at 6WPRS for ISP and LIN during 2000 and the 6WPRS under the ISP for 2001. LIN surface runoff N losses were greatest at 8WPRS in 2001. The increase in N losses over the establishment periods could have exposed a buildup of N within the soil (Tisdale et al., 1993). Repeated N applications of the ISP and LIN regimes could have increased soil N concentrations. The longer the establishment period the more N applied. Therefore, longer establishment periods probably contained higher N concentrations within the upper few centimeters of the soil. The increased levels of N and placement on the soil, could allow greater interaction between the runoff water and N; unless the N was reduced in the soil or was able to move deeper within the soil and out of range from surface runoff water reactions. This type of interaction, first observed with phosphorus (DRP), would explain increased levels of N lost via surface runoff with repeated N applications as found with longer establishment periods. However, this does not take into account the influence of vegetative cover on N levels or resistance to surface runoff.

Bermudagrass has an aggressive growth habit that retards surface runoff initiation as well as reduces water runoff volumes (Cole et al., 1997). As the bermudagrass sprigs grew and developed, greater cover was achieved while reducing available N through plant uptake. As seen with sprigs 8WPRS under the ISP in 2000 and 2001 and LIN regime in 2000, N losses from surface runoff were reduced with greater ground cover and lower runoff volumes. In 2001, sprigs under the LIN did see greater loss of N compared to sprigs 6WPRS (LIN). However establishment took ten weeks in 2001.

Based on the relationship of bermudagrass cover, runoff characterization, and N application rates, sprigs were most susceptible to N loss through surface runoff prior to full establishment. N regimes affected sprig growth and runoff characterization similarly. It is no surprise that the lower initial N (LIN) rate was able to reduce N surface runoff losses by simply reducing early excessive N at a time sprigs were too morphologically immature to utilize available N. This was clearly demonstrated in 2001, when the LIN treated sprigs were able to reduce N losses by as much as 50% compared to sprigs established 2, 4, and 6 WPRS under the ISP.

It is important to note that in 2000 the differences in N losses between the two regimes were not significant. However, the surface runoff trend for ISP treated sprigs at the 4 and 6 WPRS establishment periods were greater compared to the LIN treated sprigs. Differences between the years are believed to be heavily influenced by weather conditions (Appendix 1). The 2000 experiment took place in the months of July, August, and September compared to June, July, and August for 2001. Weather in September had cooler temperatures, slowing bermudagrass growth and therefore reducing its N requirement. In the weeks leading up to rainfall simulation during September, N would have been applied on less aggressive plants, probably resulting in higher soil N concentrations. Unlike 2000, 2001 rainfall simulation took place the month of August when summer temperatures are at their highest. Bermudagrass growth would be at its most aggressive state and was better able to utilize available N in the weeks leading up to rain simulation.

Even taking into account the different weather conditions of 2000 and 2001, sod reduced N runoff compared to sprigged treatments. In 2000 both 4WPRS and 10WPRS had extremely low N runoff values along with 2WPRS in 2001. Sod represented an instant cover, with many of the characteristics necessary to prevent or reduce surface runoff losses.

In regard to a pattern for N release during surface runoff over the thirty minute surface runoff rainfall simulation, it is clearly evident N levels are highest during initial runoff and reduced over the thirty minute simulated runoff period (Appendices 4 – 7). This type of N runoff pattern has been established in several previous studies, indicating N losses are highest in the initial runoff amounts and N and phosphorus are most susceptible to surface runoff soon after application (Kelling and Peterson, 1975, Morten et al., 1980, Gross et al., 1990, 1991). In addition to the establishment of N runoff loss patterns per plot, variability between treatments was greatest for the first five and ten minute interval runoff samples and decreased for the 15, 20, 25, and 30 minute collections. This type of variation demonstrates the vast differences that may occur between plots as a result of vegetative growth and/or surface topography which influence surface runoff timing and quantities. One is limited in the ability to reduce the variability through addition of replications, because of the intense labor requirement and timing component. Therefore variability in this study may be higher when compared to other studies.

Based on all the data and consideration of weather and planting time, reducing rates of N as much as 75% during the initial four weeks (LIN) for bermudagrass sprig establishment appears warranted in all cases, if sod cannot be used. Soil N concentrations have a tendency to increase with repeated N applications, increasing the amount of N available to leave the site as surface runoff during intense rainfall. Decreasing the amounts of N applied the first four weeks reduces the chance of excessive build up of soil N throughout the establishment period compared to the ISP. Delaying heavier N applications until after the fourth week not only decreases soil available N; but gives the immature sprigs time to develop, ultimately aiding in the reduction of soil available N through plant uptake or decrease of N runoff through greater surface runoff resistance. Also, increased rooting can aid in the downward movement of N into the soil, to a depth beyond surface runoff movement. Therefore LIN bermudagrass sprigs provide similar cover, visual quality, and biomass to that of ISP treated sprigs using 30% less N for 10 week establishment periods, while reducing the amount of N leaving the site through surface runoff.

Phosphorus surface runoff loses in the form of DRP offered little as regards its relationship to N regime for both 2000 and 2001. In fact, the correlations for DRP as affected by N applications were extremely poor. Because of no phosphorus treatment and lack of relationship with N regime, one can only conclude that DRP surface runoff does occur on both sprigged and sod bermudagrass established plots for any period of establishment and that further study is warranted.

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Summary

Bermudagrass is a popular turfgrass used throughout the Southeast. Its aggressive growth and tolerances to traffice, heat, drought, and various soil conditions prove an excellent choice for many maintenance situations. Unlike the seeded cool season turfgrasses, improved bermudagrass varieties are established primarily through vegetative means including sod and sprig. Due to its higher price and short supply, other methods of bermudagrass establishment are often employed. Sprigs, shredded segments of sod, are an alternative to sod that use much less plant material, relying on the aggressive stoloniferious growth habit of the bermudagrass to create a dense turf canopy. During the establishment period inputs of irrigation and fertilizer are increased. Fertilization rates as high as 48.8 kg N ha^{-1} wk^{-1} are applied to ensure dense growth. The combination of high fertilization rates and continually moist soils make sprig establishment more susceptible to nutrient and sediment losses via surface runoff. This research attempts to examine the relationship of bermudagrass sprig establishment age under different N regimes and how this impacts water, sediment, and nutrient movement during surface runoff events.

Chapter 1

Sprigs fertilized following the current industry standard practice (ISP) at 48.8 kg N ha^{-1} wk^{-1} proved to be only moderately faster in establishment compared to the lower initial N regime of 12.2 kg N ha^{-1} wk^{-1} the initial four weeks followed by the ISP the remaining weeks. ISP fertilized sprigs did display greater ground cover, visual quality ratings, and biomass production for many of the establishment periods; but without being

statistically better than the LIN regime treated sprigs. Sprigs achieved full establishment with 8 weeks growth under the ISP compared to eight or ten weeks for the LIN, while sod provided an instant ground cover. Therefore, if sod is unable to be used, a one to two week establishment delay was considered acceptable if a decrease in 75% N is followed (LIN) the first four weeks after establishment.

The procedures involving the timing of sprig establishments prevented proper comparison between fertilization rates over a ten week establishment period. Therefore only simple points could be derived from the data. The lack of differences in sprig growth after the initial four weeks for both 2000 and again in 2001, suggested N requirements could be reduced during the first four weeks of establishment; and the majority of sprig growth occurred after four weeks of establishment.

Chapters 2

Time until surface water runoff initiation and total water and sediment losses were heavily influenced by bermudagrass cover rather than N regime. The bare ground exhibit the lowest time until surface runoff release as well as higher water and sediment losses compared to sprig or sodded treatments. As sprigged bermudagrass ground cover increased in correlation to longer establishment periods, resistance to surface runoff increased and water and sediment losses decreased. Older bermudagrass sprigs were able to: absorb energy associated with falling rain droplets preventing soil compaction and sealing, formed a tortuous pathway from aggressive stoloniferious growth to slow lateral water flow, and increased soil infiltration through vertical drainage pathways created by a fibrous root system. Sod represented a vegetative establishment method capable of increasing time until surface runoff initiation and reducing water and sediment losses regardless of establishment period.

Therefore sprigs established using 75% less N (LIN) during the initial weeks after planting could attain similar resistance to surface runoff and reduced total water and sediment losses as effectively as sprigs established following the ISP.

Chapter 3

Nitrate and ammonium losses through surface runoff over the establishment periods were similar. A pattern of N losses increased from bare ground until six or eight weeks after establishment for the ISP and LIN regimes. The increase in N losses was thought to be a combination of repeated N applications, resulting in higher soil N concentrations; and limited ground cover of younger sprigs, allowing faster runoff release and higher volumes. As the sprigs reached full cover (8 and 10 WPRS), nitrate losses were reduced through plant uptake and prevention and/or reduction of surface runoff and volumes.

In 2001, sprigs established 2, 4, and 6 WPRS demonstrated a more than 50% reduction in N surface runoff loss compared to sprigs under the ISP. Differences in N regimes for sprigs established 4 and 6 WPRS were not as pronounced in 2000, even though the ISP sprigs has greater losses 4 and 6 WPRS compared to sprigs under the LIN regime. The results were thought to be influenced by cooler temperatures. Therefore, the LIN regime versus the ISP should be followed to reduce potential movement of N via surface runoff in the initial weeks during vegetative establishment of bermudagrass.

Appendices

Appendix 1: Weather data for Blacksburg, Virginia in 2000 and 2001.

Month	Year	Temperature			Precipitation
		High	Low		
		^{0}C			(cm)
July	2000	25	16		9.7
August	2000	26	15		10.7
September	2000	24	13		5.7
Average		25	15	Total	26.1
June	2001	26	14		7.7
July	2001	26	15		12.4
August	2001	29	17		4.3
Average		27	15	Total	24.4

Provided by the National Weather Service located in Blacksburg, VA

Appendix 2: Rainfall simulation induced sediment surface runoff concentrations over a thirty minute period from sprigged and sodded bermudagrasss established 4, 6, 8, and 10 WPRS under three nitrogen regimes in 2000

Bare Ground - (bare soil - 10wks - 0 kg N ha^{-1})

	Sediment from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	g
5	8540.00	62.59	1332.50	2.65	3557.50	15.98	
10	5567.50	45.46	980.00	4.52	1875.00	14.18	
15	2325.00	17.93	1800.00	11.25	3462.50	22.49	
20	2620.00	19.97	2475.00	14.97	7940.00	58.35	
25	3292.50	28.65	1700.00	12.21	2767.50	17.48	
30	2290.00	13.35	2552.50	15.49	3007.50	20.33	
Total		187.94		61.09		148.81	132.61

4WPRS- ISP - (sprigs - 4 wks - 195.2 kg N ha^{-1})

	Sediment from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	g
5	1960.00	2.73	1687.50	2.40	4927.50	18.01	
10	2015.00	7.89	1900.00	5.82	5097.50	16.67	
15	1797.50	11.54	1427.50	6.50	3430.00	21.70	
20	1070.00	5.82	1315.00	7.02	2287.50	6.93	
25	1582.50	12.27	2142.50	18.49	4130.00	29.36	
30	2307.50	10.85	1607.50	13.55	4995.00	35.55	
Total		51.11		53.78		128.21	77.70

4WPRS - LIN - (sprigs - 4 wks - 48.8 kg N ha^{-1})

	Sediment from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	g
5	1987.50	3.47	1610.00	4.76	2957.50	5.00	
10	1417.50	3.48	1610.00	9.73	1927.50	5.52	
15	1460.00	6.14	1482.50	7.08	2365.00	12.92	
20	672.50	3.19	1237.50	6.14	1832.50	13.03	
25	327.50	1.74	840.00	4.77	2777.50	21.82	
30	1457.50	7.80	1377.50	7.42	1767.50	13.65	
Total		25.82		39.90		71.94	45.89

4WPRS - SOD - (sod - 4 wks - 97.6 kg N ha^{-1})

	Sediment from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	g
5	1607.50	2.41	1205.00	3.33	622.50	1.31	
10	720.00	0.83	482.50	1.74	350.00	1.41	
15	712.50	0.86	172.50	0.55	297.50	1.18	
20	1972.50	3.65	180.00	0.76	5.00	0.02	
25	1390.00	2.70	237.50	0.92	162.50	0.73	
30	1672.50	2.77	195.00	0.69	102.50	0.51	
Total		13.22		7.99		5.16	8.79

6WPRS - ISP - (sprigs - 6 wks - 292.8 kg N ha^{-1})

	Sediment from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	g
5	1805.00	6.11	1037.50	3.87	2060.00	9.33	
10	1210.00	5.81	865.00	4.07	1140.00	6.93	
15	1307.50	5.56	992.50	4.81	797.50	3.55	
20	1432.50	7.61	800.00	2.81	790.00	4.96	
25	985.00	5.26	987.50	4.31	875.00	4.83	
30	967.50	4.83	850.00	2.29	882.50	5.54	
Total		35.17		22.17		35.14	30.82

6WPRS - ISP - (sprigs - 6 wks - 292.8 kg N ha^{-1})

	Sediment from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	g
5	1347.50	7.34	700.00	1.88	3985.00	8.06	
10	1272.50	3.61	705.00	1.07	1487.50	6.97	
15	975.00	4.21	402.50	1.70	1365.00	7.68	
20	615.00	1.79	142.50	0.72	807.50	4.28	
25	772.50	3.13	242.50	1.27	1857.50	12.26	
30	840.00	3.59	295.00	1.38	1440.00	8.81	
Total		23.68		8.02		48.06	26.59

Appendix 2: continued

8WPRS - ISP - (sprigs - 8 wks - 390.4 kg N ha^{-1})

	Sediment from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	g
5	475.00	0.73	522.50	1.20	455.00	1.24	
10	442.50	1.32	225.00	0.84	275.00	1.34	
15	190.00	0.62	292.50	1.21	247.50	1.56	
20	275.00	1.14	207.50	0.83	307.50	2.18	
25	292.50	1.39	170.00	1.21	300.00	1.67	
30	725.00	3.07	337.50	1.65	217.50	1.51	
Total		8.27		6.95		9.50	8.24

8WPRS - LIN - (sprigs - 8 wks - 244.0 kg N ha^{-1})

	Sediment from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	g
5	372.50	1.20	1232.50	2.11	1902.50	3.57	
10	897.50	3.24	732.50	1.88	1260.00	4.03	
15	300.00	1.24	397.50	0.75	1010.00	4.05	
20	537.50	2.38	427.50	0.81	907.50	2.71	
25	380.00	1.70	365.00	1.10	897.50	5.75	
30	707.50	3.09	450.00	1.22	1257.50	4.64	
Total		12.85		7.86		24.76	15.16

Appendix 2: continued

10WPRS - ISP - (sprigs - 10 wks - 488.0 kg N ha^{-1})

	Sediment from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	g
5	525.00	1.80	567.50	2.19	682.50	2.80	
10	287.50	0.81	232.50	0.82	210.00	0.99	
15	140.00	0.80	360.00	1.35	310.00	1.77	
20	285.00	0.87	415.00	1.68	132.50	0.78	
25	2.50	0.01	140.00	0.64	172.50	0.95	
30	182.50	0.93	245.00	1.26	132.50	0.79	
Total		5.23		7.94		8.10	7.09

10WPRS - LIN - (sprigs - 10 wks - 341.6 kg N ha^{-1})

	Sediment from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	g
5	982.50	3.32	1215.00	5.49	1770.00	4.34	
10	1070.00	2.31	325.00	2.51	1980.00	5.74	
15	295.00	0.61	482.50	2.44	1500.00	5.53	
20	545.00	1.37	240.00	1.52	530.00	2.31	
25	332.50	0.81	415.00	2.68	392.50	1.77	
30	262.50	0.61	120.00	0.75	382.50	1.75	
Total		9.03		15.39		21.45	15.29

Appendix 2: continued

10WPRS - SOD - (sod - 10wks - 244 kg N ha^{-1})

	Sediment from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	g
5	1410.00	7.91	685.00	0.94	2897.50	4.85	
10	580.00	3.15	542.50	1.64	2287.50	2.50	
15	510.00	1.60	185.00	0.75	1457.50	2.08	
20	845.00	2.86	222.50	0.89	625.00	0.84	
25	727.50	3.85	207.50	0.96	407.50	0.43	
30	857.50	4.56	242.50	1.23	315.00	0.40	
Total		23.92		6.42		11.10	13.82

Appendix 3: Rainfall simulated induced sediment surface runoff concentrations over a thiry minute period from sprigged and sodded bermudagrass established 2, 4, 6, 8, and 10 WPRS under three nitrogen regimes in 2001.

Bare Ground - (bare soil - 10wks - 0 kg N ha^{-1})

	Sediment from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	ppm	g	g
5	1545.00	8.52	46927.50	63.67	5867.50	25.53	6655.00	17.79	
10	1882.50	11.30	3120.00	8.03	6197.50	40.75	7075.00	45.39	
15	2495.00	4.94	5530.00	17.12	3752.50	26.01	367.50	2.91	
20	1895.00	20.81	4057.50	12.35	3800.00	27.85	4887.50	29.31	
25	2515.00	8.37	5405.00	17.06	3020.00	22.83	5002.50	21.95	
30	2775.00	18.39	5200.00	21.58	5772.50	35.93	3222.50	13.39	
Total		72.33		139.82		178.89		130.73	130.44

2WPRS- ISP - (sprigs - 2 wks - 97.6 kg N ha^{-1})

	Sediment from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	ppm	g	g
5	3942.50	1.27	207.50	0.37	3370.00	7.42	15087.50	77.65	
10	3067.50	3.53	3732.50	16.99	3377.50	18.17	4775.00	24.83	
15	1640.00	2.78	7057.50	43.05	2925.00	19.30	6367.50	40.77	
20	2762.50	11.87	497.50	2.73	2670.00	19.08	4817.50	37.73	
25	2940.00	13.43	497.50	3.40	3625.00	23.85	3202.50	26.08	
30	1260.00	6.50	6792.50	42.36	4750.00	34.03	600.00	4.21	
Total		39.38		108.89		121.83		211.28	120.35

Appendix 3: continued

2WPRS - LIN - (sprigs - 2wks - 24.4 kg N ha^{-1})

	Sediment from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	ppm	g	g
5	2692.50	9.10	2815.00	2.53	9310.00	7.21	2117.50	2.44	
10	450.00	1.49	1910.00	2.62	2830.00	5.65	2185.00	1.73	
15	2795.00	14.42	2462.50	5.08	1202.50	1.75	525.00	0.72	
20	2192.50	17.36	1695.00	4.00	332.50	20.71	3367.50	9.85	
25	2482.50	31.36	125.00	0.33	3430.00	17.76	3617.50	9.15	
30	2825.00	50.21	302.50	0.86	3082.50	20.94	4420.00	18.66	
Total		123.94		15.43		74.01		42.54	63.98

2WPRS - SOD - (sod - 2wks - 48.8 kg N ha^{-1})

	Sediment from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	ppm	g	g
5	287.50	0.10	3132.50	6.36	260.00	0.31	3690.00	1.22	
10	247.50	0.12	440.00	1.17	52.50	0.09	332.50	0.32	
15	627.50	0.40	390.00	1.33	2995.00	4.91	200.00	0.24	
20	200.00	0.14	337.50	1.31	2845.00	4.88	102.50	0.13	
25	45.00	0.03	3460.00	13.66	2735.00	4.82	137.50	0.19	
30	240.00	0.26	242.50	0.79	25.00	0.04	130.00	0.20	
Total		1.06		24.60		15.06		2.30	10.76

Appendix 3: continued

4WPRS - ISP - (sprigs - 4 wks - 195.2 kg N ha^{-1})

	Sediment from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	ppm	g	g
5	1590.00	2.13	1572.50	0.44	932.50	3.08	1755.00	2.26	
10	1297.50	2.63	1532.50	1.04	692.50	4.13	1155.00	5.62	
15	1327.50	2.69	1767.50	2.39	1057.50	6.35	1320.00	7.55	
20	205.00	0.53	1510.00	2.50	255.00	1.59	287.50	1.81	
25	477.50	1.00	1140.00	1.97	1102.50	7.96	1565.00	11.68	
30	1162.50	2.90	1427.50	2.41	500.00	3.40	1385.00	9.83	
Total		11.88		10.75		26.50		38.76	21.97

4WPRS - LIN - (sprigs - 4 wks - 48.8 kg N ha^{-1})

	Sediment from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	ppm	g	g
5	1570.00	1.35	337.50	1.08	1712.50	1.19	1570.00	6.86	
10	1297.50	3.24	3932.50	16.63	1200.00	3.14	1587.50	7.73	
15	615.00	1.91	157.50	0.87	657.50	2.73	207.50	1.05	
20	1127.50	4.17	3817.50	20.42	622.50	3.04	1652.50	8.29	
25	1292.50	4.67	3255.00	22.91	320.00	1.52	1605.00	13.40	
30	507.50	2.26	3550.00	25.25	775.00	5.09	1295.00	8.73	
Total		17.61		87.16		16.72		46.07	41.89

4WPRS - SOD - (sod - 4 wks - 97.6 kg N ha^{-1})

	Sediment from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	ppm	g	g
5	1345.00	1.29	275.00	0.14	125.00	0.34	467.50	2.10	
10	1795.00	17.60	275.00	0.33	735.00	2.36	544.25	4.19	
15	1642.50	11.70	335.00	0.35	287.50	1.03	560.00	3.79	
20	1280.00	8.92	135.00	0.09	340.00	1.28	37.50	0.28	
25	1000.00	5.53	207.50	0.13	35.00	0.13	367.50	2.98	
30	792.50	6.23	172.50	0.09	210.00	0.85	130.00	0.86	
Total		51.27		1.14		5.99		14.21	18.15

6WPRS - ISP - (sprigs - 6 wks - 292.8 kg N ha^{-1})

	Sediment from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	ppm	g	g
5	1380.00	3.67	4505.00	12.44	32.50	0.17	905.00	0.92	
10	2287.50	26.43	2655.00	11.65	597.50	3.54	182.50	0.18	
15	2275.00	25.85	2670.00	13.59	75.00	0.49	347.50	1.08	
20	322.50	4.17	2277.50	9.85	65.00	0.44	445.00	1.03	
25	1707.50	22.51	2190.00	12.71	700.00	4.73	397.50	0.76	
30	1892.50	21.14	2495.00	12.05	47.50	0.34	367.50	0.77	
Total		103.76		72.29		9.71		4.73	47.63

Appendix 3: continued

6WPRS - ISP - (sprigs - 6 wks - 292.8 kg N ha^{-1})

	Sediment from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	ppm	g	g
5	1440.00	0.21	5140.00	6.69	1617.50	6.41	900.00	2.34	
10	962.50	1.08	4760.00	21.43	740.00	4.90	1237.50	5.02	
15	867.50	1.07	1265.00	8.02	575.00	3.60	1312.50	6.17	
20	500.00	0.80	1515.00	10.90	1102.50	6.14	577.50	1.79	
25	202.50	0.33	1165.00	7.89	822.50	6.49	570.00	3.46	
30	705.00	1.43	980.00	5.71	870.00	7.62	540.00	4.21	
Total		4.92		60.63		35.15		22.99	30.92

8WPRS - ISP - (sprigs - 8 wks - 390.4 kg N ha^{-1})

	Sediment from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	ppm	g	g
5	647.50	0.71	3142.50	3.22	617.50	1.48	2647.50	2.03	
10	817.50	0.96	372.50	0.40	357.50	1.38	740.00	1.33	
15	740.00	1.54	4377.50	4.63	725.00	2.75	585.00	1.97	
20	150.00	0.38	6517.50	6.53	392.50	2.03	150.00	0.44	
25	832.50	2.13	1522.50	1.82	420.00	1.84	420.00	1.37	
30	732.50	2.15	1225.00	2.13	170.00	0.78	362.50	1.35	
Total		7.86		18.73		10.25		8.49	11.33

8WPRS - LIN - (sprigs - 8 wks - 244.0 kg N ha^{-1})

	Sediment from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	ppm	g	g
5	745.00	0.51	980.00	1.00	840.00	1.56	585.00	1.75	
10	630.00	0.40	845.00	1.48	402.50	1.73	1247.50	5.49	
15	457.50	0.22	810.00	3.26	467.50	1.90	632.50	4.06	
20	487.50	0.51	665.00	1.59	272.50	0.90	1100.00	7.37	
25	240.00	0.28	715.00	2.93	1040.00	3.35	507.50	3.62	
30	225.00	0.22	510.00	1.74	900.00	2.79	1022.50	8.54	
Total		2.14		12.00		12.23		30.82	14.30

10WPRS - ISP - (sprigs - 10 wks - 488.0 kg N ha^{-1})

	Sediment from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	ppm	g	g
5	557.50	0.05	207.50	0.65	1107.50	4.20	2902.50	2.95	
10	572.50	0.15	675.00	3.36	442.50	2.27	187.50	0.37	
15	830.00	0.22	482.50	2.88	622.50	3.43	310.00	0.72	
20	285.00	0.05	620.00	4.19	237.50	1.39	115.00	0.32	
25	1647.50	0.97	3945.00	28.36	265.00	1.75	705.00	2.32	
30	365.00	0.17	220.00	1.68	97.50	0.52	677.50	2.25	
		1.62		41.12		13.57		8.94	16.32
Total									

Appendix 3: continued

10WPRS - LIN - (sprigs - 10 wks - 341.6 kg N ha^{-1})

	Sediment from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	ppm	g	g
5	885.00	2.30	3922.50	9.78	4157.50	1.58	825.00	0.32	
10	335.00	1.63	185.00	0.72	1115.00	0.86	722.50	1.65	
15	820.00	3.81	405.00	2.11	1132.50	0.95	590.00	1.80	
20	320.00	1.85	132.50	0.77	605.00	0.55	600.00	1.94	
25	497.50	3.17	312.50	1.92	660.00	0.61	192.50	0.63	
30	2882.50	18.57	3417.50	19.53	1157.50	0.94	95.00	0.35	
Total		31.34		34.84		5.49		6.68	19.59

Appendix 4: Rainfall simulation induced nitrate surface runoff concentrations over a thirty minute period from sprigged and sodded bermudagrass established 4, 6, 8, and 10 WPRS under three nitrogen regimes in 2000

Bare Ground - (bare soil - 10wks - 0 kg N ha^{-1})

	Nitrate from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	g	ppm	g	ppm	g	mg
5	3.59	26.28	5.42	10.77	3.66	16.44	
10	2.09	17.03	2.44	11.26	1.49	11.25	
15	1.21	9.32	2.18	13.60	1.08	7.01	
20	1.17	8.94	2.32	14.01	0.97	7.16	
25	1.09	9.44	2.11	15.16	1.02	6.45	
30	0.99	5.78	1.61	9.78	1.00	6.78	
Total		76.79		74.59		55.10	68.83

4WPRS- ISP - (sprigs - 4 wks - 195.2 kg N ha^{-1})

	Nitrate from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	32.32	45.07	15.79	22.43	3.52	12.85	
10	21.92	85.87	10.67	32.69	5.28	17.25	
15	14.53	93.23	6.03	27.48	7.48	47.31	
20	11.21	60.95	4.70	25.11	8.89	26.94	
25	8.77	68.00	1.66	14.35	7.43	52.83	
30	6.68	31.40	3.58	30.15	4.40	31.29	
Total		384.52		152.21		188.47	241.74

Appendix 4: continued

4WPRS - LIN - (sprigs - 4 wks - 48.8 kg N ha^{-1})

	Nitrate from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	4.45	7.77	45.11	133.37	12.87	21.76	
10	2.74	6.72	19.63	118.61	7.58	21.71	
15	2.52	10.61	11.15	53.24	5.66	30.91	
20	2.58	12.27	8.14	40.43	4.64	32.98	
25	2.59	13.76	6.55	37.20	3.64	28.58	
30	2.31	12.37	5.62	30.25	3.52	27.16	
Total		63.49		413.10		163.09	213.23

4WPRS - SOD - (sod - 4 wks - 97.6 kg N ha^{-1})

	Nitrate from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	6.42	9.64	10.86	30.01	14.82	31.08	
10	4.67	5.39	11.26	40.58	15.02	60.41	
15	3.86	4.63	6.61	21.09	13.47	53.47	
20	3.32	6.14	8.37	35.41	11.77	51.83	
25	2.77	5.37	6.89	26.75	9.95	44.82	
30	2.22	3.68	4.57	16.06	8.90	44.26	
Total		34.85		169.89		285.89	163.54

Appendix 4: continued

6WPRS - ISP - (sprigs - 6 wks - 292.8 kg N ha^{-1})

	Nitrate from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	91.87	310.88	46.39	172.96	27.58	124.95	
10	47.04	226.00	30.46	143.29	19.32	117.40	
15	21.42	91.01	20.91	101.42	13.69	60.94	
20	14.15	75.15	16.15	56.71	12.90	80.94	
25	10.41	55.55	11.71	51.08	11.03	60.87	
30	6.73	33.57	10.30	27.79	8.42	52.89	
Total		792.17		553.26		497.99	614.47

6WPRS - LIN - (sprigs - 6 wks - 146.4 kg N ha^{-1})

	Nitrate from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	66.02	359.79	70.65	190.24	9.18	18.57	
10	37.76	107.24	39.28	59.40	7.85	36.79	
15	21.52	92.90	21.25	89.70	6.23	35.05	
20	16.04	46.75	14.72	74.46	5.33	28.22	
25	12.62	51.17	11.56	60.40	4.86	32.05	
30	11.56	49.45	9.89	46.24	4.20	25.68	
Total		707.30		520.44		176.36	468.03

8WPRS - ISP - (sprigs - 8 wks - 390.4 kg N ha^{-1})

	Nitrate from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	18.21	27.88	55.58	128.08	6.42	17.50	
10	14.29	42.59	22.50	84.45	7.60	37.06	
15	11.21	36.80	14.90	61.44	7.05	44.33	
20	8.67	35.87	10.04	40.32	6.37	45.23	
25	7.38	35.07	8.06	57.53	5.52	30.78	
30	6.45	27.30	5.43	26.54	5.01	34.68	
Total		205.50		398.35		209.58	271.15

8WPRS - LIN - (sprigs - 8 wks - 244.0 kg N ha^{-1})

	Nitrate from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	43.80	140.58	31.57	54.06	17.02	31.95	
10	29.19	105.30	23.38	59.87	13.12	41.95	
15	17.76	73.61	17.23	32.57	10.50	42.14	
20	14.18	62.83	13.93	26.54	8.85	26.42	
25	11.83	52.98	11.85	35.56	7.83	50.19	
30	6.14	26.85	10.10	27.32	7.03	25.96	
Total		462.16		235.91		218.62	305.56

Appendix 4: continued

10WPRS - ISP - (sprigs - 10 wks - 488.0 kg N ha^{-1})

	Nitrate from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	72.24	248.27	11.36	43.80	14.14	58.03	
10	32.86	92.70	9.16	32.17	7.75	36.66	
15	26.00	149.15	6.92	25.92	6.29	35.98	
20	13.68	41.66	5.60	22.63	4.94	29.27	
25	12.63	69.11	4.65	21.39	4.22	23.31	
30	10.31	52.42	4.19	21.54	3.72	22.24	
Total		653.31		167.45		205.49	342.08

10WPRS - LIN - (sprigs - 10 wks - 341.6 kg N ha^{-1})

	Nitrate from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	37.02	125.04	143.06	646.05	5.78	14.17	
10	22.88	49.37	53.79	416.12	4.01	11.62	
15	15.58	32.23	18.20	91.96	3.63	13.38	
20	9.38	23.60	10.49	66.54	3.20	13.97	
25	10.64	26.07	7.25	46.78	2.63	11.82	
30	7.46	17.20	5.85	36.46	2.40	11.00	
Total		273.51		1303.92		75.95	551.13

Appendix 4: continued

10WPRS - SOD - (sod - 10wks - 244 kg N ha^{-1})

	Nitrate from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	22.10	123.95	7.78	10.65	8.06	13.51	
10	12.81	69.59	6.15	18.59	5.10	5.58	
15	7.51	23.62	9.40	38.27	4.23	6.03	
20	7.50	25.36	3.66	14.70	3.53	4.74	
25	5.65	29.90	4.77	22.10	3.15	3.31	
30	6.11	32.47	4.50	22.87	2.90	3.72	
Total		304.89		127.18		36.89	156.32

Appendix 5: Rainfall simulated induced nitrate surface runoff concentrations over a thiry minute period from sprigged and sodded bermudagrass established 2, 4, 6, 8, and 10 WPRS under three nitrogen regimes in 2001.

Bare Ground - (bare soil - 10wks - 0 kg N ha^{-1})

	Nitrate from 1.5 m^2 plots								
	Repetition 1		Repetition 2		Repetition 3		Repetition 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	2.51	13.83	2.04	2.64	1.50	6.49	1.94	5.15	
10	1.93	11.57	1.12	2.87	1.22	7.97	1.19	7.58	
15	1.56	3.08	1.18	3.63	1.06	7.32	0.89	7.03	
20	0.97	10.63	1.21	3.67	0.59	4.31	0.60	3.58	
25	0.55	1.83	1.00	3.14	0.63	4.75	0.47	2.05	
30	0.49	3.24	3.68	15.19	0.58	3.59	0.78	3.23	
Total		44.17		31.15		34.42		28.63	34.59

2WPRS- ISP - (sprigs - 2 wks - 97.6 kg N ha^{-1})

	Nitrate from 1.5 m^2 plots								
	Repetition 1		Repetition 2		Repetition 3		Repetition 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	7.38	2.36	13.40	23.70	35.35	77.57	22.23	112.69	
10	6.61	7.59	11.75	53.30	22.22	119.10	10.61	54.91	
15	2.17	3.67	3.44	20.83	11.61	76.37	4.37	27.80	
20	2.91	12.47	6.68	36.65	8.41	59.93	1.36	10.60	
25	2.54	11.56	1.96	13.38	7.58	49.68	2.25	18.27	
30	1.52	7.83	2.83	17.53	4.99	35.58	1.30	9.12	
Total		45.50		165.39		418.23		233.39	215.62

Appendix 5: continued

2WPRS - LIN - (sod - 2wks - 24.4 kg N ha^{-1})

	Nitrate from 1.5 m^2 plots								
	Repetition 1		Repetition 2		Repetition 3		Repetition 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	6.82	22.98	7.48	6.70	22.76	57.81	8.29	9.52	
10	2.71	8.99	4.85	6.64	9.09	42.66	4.77	3.77	
15	1.13	5.81	3.59	7.39	6.81	35.74	4.00	5.47	
20	1.27	10.03	2.21	5.21	4.44	26.72	1.37	4.00	
25	1.09	13.74	2.37	6.34	2.79	16.02	1.42	3.58	
30	0.49	8.69	1.91	5.44	3.09	19.35	1.21	5.08	
Total		70.23		37.71		198.30		31.42	84.42

2WPRS - SOD - (sod - 2wks - 48.8 kg N ha^{-1})

	Nitrate from 1.5 m^2 plots								
	Repetition 1		Repetition 2		Repetition 3		Repetition 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	12.45	4.48	11.83	23.94	14.95	17.74	37.68	12.36	
10	7.35	3.63	20.06	53.22	18.14	31.47	39.48	38.19	
15	5.33	3.23	8.39	28.49	10.89	17.81	25.65	30.79	
20	6.41	4.48	5.55	21.48	12.71	21.76	22.10	27.83	
25	4.55	3.53	6.59	25.55	6.26	11.01	22.32	31.22	
30	4.67	5.08	7.77	25.34	4.89	7.86	9.40	14.64	
Total		24.43		178.02		107.65		155.04	116.28

Appendix 5: continued

4WPRS - ISP - (sprigs - 4 wks - 195.2 kg N ha^{-1})

	Nitrate from 1.5 m^2 plots								
	Repetition 1		Repetition 2		Repetition 3		Repetition 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	8.94	11.94	15.35	4.30	42.70	140.71	47.76	61.44	
10	13.98	28.29	9.36	6.35	14.46	86.13	30.77	149.62	
15	5.35	10.84	8.31	11.22	19.99	119.91	22.86	130.63	
20	4.47	11.59	3.93	6.49	12.84	79.81	10.68	67.38	
25	3.60	7.50	5.19	8.98	9.87	71.19	7.17	53.43	
30	3.53	8.80	2.21	3.72	6.05	41.09	9.92	70.32	
Total		78.96		41.06		538.83		532.84	297.92

4WPRS - LIN - (sprigs - 4 wks - 48.8 kg N ha^{-1})

	Nitrate from 1.5 m^2 plots								
	Repetition 1		Repetition 2		Repetition 3		Repetition 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	3.32	2.86	19.31	61.92	16.57	11.47	9.54	41.65	
10	4.35	10.86	2.81	11.84	14.78	38.68	6.59	32.04	
15	2.77	8.58	4.34	23.91	11.89	49.38	2.94	14.88	
20	3.05	11.27	4.03	21.47	7.45	36.35	3.23	16.18	
25	2.35	8.48	4.55	31.92	5.61	26.72	1.98	16.51	
30	1.54	6.86	2.63	18.64	3.62	23.78	1.75	11.78	
Total		48.91		169.70		186.37		133.04	134.51

4WPRS - SOD - (sod - 4 wks - 97.6 kg N ha^{-1})

	Nitrate from 1.5 m^2 plots								
	Repetition 1		Repetition 2		Repetition 3		Repetition 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	100.65	96.71	5.99	3.15	91.37	248.90	49.84	224.07	
10	49.23	481.97	10.35	12.48	32.36	104.01	28.78	221.71	
15	35.55	252.74	8.31	8.63	52.11	187.02	11.66	78.80	
20	15.52	107.99	0.57	0.38	52.57	197.95	17.78	133.82	
25	18.51	102.24	4.83	2.98	34.45	127.40	8.57	69.50	
30	13.18	103.53	3.53	1.93	26.40	106.38	6.98	46.38	
Total		1145.17		29.54		971.66		774.27	730.16

6WPRS - ISP - (sprigs - 6 wks - 292.8 kg N ha^{-1})

	Nitrate from 1.5 m^2 plots								
	Repetition 1		Repetition 2		Repetition 3		Repetition 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	36.26	96.24	8.21	22.56	46.89	241.84	40.32	40.77	
10	28.28	325.95	1.94	8.49	34.07	201.91	18.85	18.72	
15	15.50	175.73	1.85	9.39	16.13	104.94	15.96	49.59	
20	8.84	114.27	1.86	8.03	9.15	61.96	8.88	20.45	
25	7.07	93.02	2.03	11.76	8.27	55.88	8.81	16.85	
30	6.44	71.81	2.84	13.69	6.01	43.25	8.30	17.37	
Total		877.02		73.91		709.78		163.76	456.12

Appendix 5: continued

6WPRS - ISP - (sprigs - 6 wks - 292.8 kg N ha^{-1})

	Nitrate from 1.5 m^2 plots								
	Repetition 1		Repetition 2		Repetition 3		Repetition 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	2.01	0.29	6.30	8.15	16.77	66.33	21.56	56.10	
10	1.70	1.90	16.27	72.90	12.20	80.66	17.23	69.74	
15	2.29	2.82	13.96	88.35	14.89	93.06	9.77	45.85	
20	1.95	3.12	2.64	18.97	5.82	32.37	4.27	13.23	
25	1.55	2.55	1.76	11.90	2.77	21.84	4.61	27.99	
30	1.97	3.99	2.71	15.76	5.18	45.31	4.05	31.54	
Total		14.68		216.04		339.58		244.45	203.69

8WPRS - ISP - (sprigs - 8 wks - 390.4 kg N ha^{-1})

	Nitrate from 1.5 m^2 plots								
	Repetition 1		Repetition 2		Repetition 3		Repetition 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	12.59	13.77	86.73	88.59	74.87	179.16	35.28	27.03	
10	5.95	6.99	63.64	68.60	55.45	213.96	29.47	53.04	
15	3.27	6.79	17.50	18.41	22.14	83.78	16.15	54.22	
20	2.97	7.45	15.59	15.52	16.61	85.87	7.90	23.40	
25	3.58	9.16	4.83	5.78	10.70	46.76	8.42	27.38	
30	4.03	11.80	5.04	8.76	9.04	41.45	6.60	24.57	
Total		55.96		205.66		650.99		209.65	280.56

8WPRS - LIN - (sprigs - 8 wks - 244.0 kg N ha^{-1})

	Nitrate from 1.5 m^2 plots								
	Repetition 1		Repetition 2		Repetition 3		Repetition 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	27.32	18.85	7.40	7.54	8.66	16.04	32.74	97.82	
10	27.42	17.46	9.41	16.44	13.77	59.09	28.51	125.22	
15	16.06	7.65	10.55	42.43	14.01	57.05	19.60	125.73	
20	12.99	13.56	4.19	10.00	8.39	27.72	12.76	85.39	
25	8.84	7.60	7.40	30.28	6.87	22.10	8.96	63.83	
30	4.72	4.62	3.59	12.26	6.90	21.37	4.90	40.88	
Total		69.74		118.96		203.36		538.87	232.74

Appendix 5: continued

10WPRS - ISP - (sprigs - 10 wks - 488.0 kg N ha^{-1})

	Nitrate from 1.5 m^2 plots								
	Repetition 1		Repetition 2		Repetition 3		Repetition 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	41.62	3.99	4.16	12.99	31.38	118.76	11.20	11.36	
10	20.22	5.41	8.44	41.99	23.44	120.28	7.21	14.35	
15	16.88	4.48	5.84	34.82	12.09	64.07	23.54	54.97	
20	13.45	2.53	5.69	38.45	14.85	87.15	4.42	12.34	
25	12.09	7.14	2.94	21.05	7.67	50.71	4.43	14.58	
30	6.87	3.18	1.82	13.88	7.18	38.55	3.72	12.36	
Total		26.74		163.18		479.52		119.96	197.35

Appendix 5: continued

10WPRS - LIN - (sprigs - 10 wks - 341.6 kg N ha^{-1})

	Nitrate from 1.5 m^2 plots								
	Repetition 1		Repetition 2		Repetition 3		Repetition 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	11.85	30.79	4.04	10.03	10.98	4.15	26.72	10.42	
10	10.39	50.58	14.57	56.97	16.86	12.98	32.64	74.49	
15	6.89	30.75	4.57	23.85	9.27	7.79	22.46	68.54	
20	6.29	36.43	5.42	31.47	10.35	9.45	23.82	76.80	
25	4.95	31.50	4.75	29.23	4.20	3.87	14.22	46.39	
30	2.16	13.88	3.70	21.07	5.92	4.62	8.44	30.73	
Total		193.93		172.62		42.86		307.36	179.19

Appendix 6: Rainfall simulation induced ammonia surface runoff concentrations over a thirty minute period from sprigged and sodded bermudagrass established 4, 6, 8, and 10 WPRS under three nitrogen regimes in 2000

Bare Ground - (bare soil - 10wks - 0 kg N ha^{-1})

	Ammonia from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	1.79	13.13	2.37	4.71	1.22	5.46	
10	1.20	9.79	0.54	2.49	0.77	5.79	
15	0.72	5.56	0.43	2.72	0.63	4.09	
20	0.55	4.19	0.58	3.49	0.53	3.89	
25	0.50	4.37	0.62	4.46	0.54	3.40	
30	0.40	2.31	0.47	2.88	0.52	3.51	
Total		39.34		20.74		26.15	**28.75**

4WPRS- ISP - (sprigs - 4 wks - 195.2 kg N ha^{-1})

	Ammonia from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	21.88	30.50	15.96	22.68	4.48	16.38	
10	17.73	69.43	11.90	36.46	6.08	19.87	
15	12.10	77.63	7.30	33.24	7.26	45.93	
20	9.48	51.53	5.62	30.04	7.89	23.88	
25	7.64	59.26	2.28	19.65	6.88	48.88	
30	5.86	27.54	3.74	31.52	4.92	35.01	
Total		315.90		173.60		189.95	**226.48**

Appendix 6: continued

4WPRS - LIN - (sprigs - 4 wks - 48.8 kg N ha^{-1})

	Ammonia from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	2.41	4.22	36.43	107.72	14.19	23.98	
10	1.89	4.63	17.85	107.80	9.06	25.94	
15	1.66	6.97	10.47	49.98	5.99	32.73	
20	1.59	7.56	7.65	37.97	4.98	35.43	
25	1.62	8.63	5.82	33.05	3.99	31.34	
30	1.41	7.55	4.73	25.50	3.61	27.86	
Total		39.56		362.01		177.28	**192.95**

4WPRS - SOD - (sod - 4 wks - 97.6 kg N ha^{-1})

	Ammonia from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	-0.07	-0.11	8.24	22.77	11.61	24.35	
10	3.70	4.27	8.96	32.31	12.31	49.52	
15	3.58	4.29	5.43	17.31	11.26	44.70	
20	3.17	5.87	7.26	30.71	9.67	42.58	
25	2.80	5.43	6.52	25.31	8.76	39.45	
30	2.37	3.91	4.63	16.29	7.94	39.49	
Total		23.67		144.71		240.09	**136.16**

6WPRS - ISP - (sprigs - 6 wks - 292.8 kg N ha^{-1})

	Ammonia from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	53.64	181.52	37.53	139.96	21.62	97.92	
10	35.38	169.96	26.81	126.12	15.47	93.97	
15	18.03	76.60	18.78	91.12	11.09	49.39	
20	11.82	62.80	14.04	49.31	10.89	68.29	
25	8.73	46.57	10.53	45.97	8.69	48.00	
30	6.06	30.24	9.15	24.70	6.84	42.97	
Total		567.69		477.18		400.54	**481.80**

6WPRS - ISP - (sprigs - 6 wks - 292.8 kg N ha^{-1})

	Ammonia from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	47.32	257.90	48.89	131.64	8.61	17.41	
10	30.97	87.97	30.47	46.07	7.47	34.99	
15	18.82	81.26	16.04	67.70	5.57	31.35	
20	14.29	41.66	10.98	55.56	4.58	24.25	
25	10.96	44.43	8.71	45.50	3.93	25.92	
30	9.96	42.60	7.38	34.51	3.38	20.71	
Total		555.83		380.99		154.64	**363.82**

Appendix 6: continued

8WPRS - ISP - (sprigs - 8 wks - 390.4 kg N ha^{-1})

	Ammonia from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	13.18	20.18	42.05	96.90	4.50	12.28	
10	11.93	35.54	20.01	75.10	5.25	25.62	
15	9.37	30.76	13.34	55.00	4.85	30.52	
20	7.12	29.47	9.03	36.23	4.32	30.68	
25	6.04	28.72	7.09	50.59	3.54	19.76	
30	5.13	21.72	4.81	23.51	3.32	22.97	
Total		166.38		337.33		141.82	**215.18**

8WPRS - LIN - (sprigs - 8 wks - 244.0 kg N ha^{-1})

	Ammonia from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	34.48	110.67	22.18	37.98	13.25	24.86	
10	23.85	86.06	16.75	42.88	10.98	35.10	
15	16.27	67.45	12.27	23.20	9.21	36.97	
20	12.36	54.79	10.04	19.12	7.51	22.41	
25	10.12	45.33	8.90	26.70	6.76	43.32	
30	5.62	24.58	7.66	20.72	6.07	22.42	
Total		388.88		170.59		185.09	**248.18**

Appendix 6: continued

10WPRS - ISP - (sprigs - 10 wks - 488.0 kg N ha^{-1})

	Ammonia from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	51.90	178.39	10.85	41.85	12.54	51.48	
10	29.92	84.41	8.89	31.21	7.54	35.63	
15	24.47	140.40	6.77	25.34	5.95	34.01	
20	13.64	41.55	5.30	21.43	4.70	27.81	
25	11.95	65.39	4.50	20.72	3.83	21.14	
30	9.89	50.25	3.95	20.33	3.35	20.03	
Total		560.38		160.88		190.11	**303.79**

10WPRS - LIN - (sprigs - 10 wks - 341.6 kg N ha^{-1})

	Ammonia from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	30.59	103.34	72.26	326.33	5.71	14.00	
10	21.26	45.87	44.55	344.63	3.83	11.12	
15	14.75	30.52	18.12	91.55	3.54	13.07	
20	9.36	23.54	10.57	67.04	3.16	13.81	
25	10.12	24.80	7.35	47.40	2.67	12.01	
30	7.30	16.83	5.79	36.07	2.22	10.19	
Total		244.91		913.02		74.20	**410.71**

Appendix 6: continued

10WPRS - SOD - (sod - 10wks - 244 kg N ha^{-1})

	Ammonia from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	14.95	83.86	6.13	8.39	7.56	12.66	
10	8.27	44.94	5.16	15.60	5.53	6.05	
15	5.94	18.69	8.15	33.20	4.92	7.02	
20	6.05	20.43	3.40	13.68	4.20	5.62	
25	4.95	26.17	4.17	19.32	3.79	3.99	
30	5.23	27.80	3.96	20.13	3.56	4.57	
Total		221.89		110.32		39.90	**124.04**

Appendix 7: Rainfall simulated induced ammonia surface runoff concentrations over a thiry minute period from sprigged and sodded bermudagrass established 2, 4, 6, 8, and 10 WPRS under three nitrogen regimes in 2001.

Bare Ground - (bare soil - 10wks - 0 kg N ha^{-1})

	Ammonia from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.82	4.52	0.64	0.83	0.16	0.69	0.82	2.18	
10	0.55	3.30	0.41	1.05	0.25	1.63	0.42	2.68	
15	0.50	0.99	0.46	1.42	0.16	1.10	0.39	3.08	
20	0.34	3.73	0.43	1.30	0.17	1.24	0.38	2.27	
25	0.27	0.90	0.37	1.16	0.15	1.13	0.10	0.44	
30	0.21	1.39	3.84	15.85	0.05	0.31	0.21	0.87	
Total		14.81		21.62		6.11		11.51	13.51

2WPRS- ISP - (sprigs - 2 wks - 97.6 kg N ha^{-1})

	Ammonia from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	7.79	2.50	10.12	17.90	25.74	56.48	66.05	334.83	
10	7.87	9.04	10.32	46.81	18.50	99.16	40.90	211.66	
15	3.50	5.92	4.31	26.10	10.05	66.10	17.48	111.21	
20	4.03	17.27	6.86	37.64	7.55	53.80	6.75	52.61	
25	3.52	16.03	3.20	21.85	6.60	43.26	9.51	77.21	
30	2.58	13.29	3.84	23.78	5.03	35.86	6.61	46.36	
		64.05		174.08		354.67		833.88	356.67
Total									

Appendix 7: continued

2WPRS - LIN - (sprigs - 2wks - 24.4 kg N ha^{-1})

	Ammonia from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	7.10	23.92	6.07	5.44	18.79	47.72	6.71	7.71	
10	3.80	12.61	4.72	6.46	9.25	43.41	4.60	3.64	
15	1.79	9.21	3.72	7.66	7.11	37.32	4.41	6.03	
20	1.82	14.38	2.42	5.70	5.24	31.54	2.32	6.77	
25	1.85	23.31	2.75	7.35	3.88	22.28	2.41	6.07	
30	0.96	17.02	2.22	6.32	4.26	26.67	2.45	10.30	
Total		100.44		38.93		208.94		40.50	97.20

2WPRS - SOD - (sod - 2wks - 48.8 kg N ha^{-1})

	Ammonia from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	10.67	3.84	7.91	16.01	7.52	8.93	25.61	8.40	
10	6.33	3.13	11.82	31.36	9.27	16.08	26.53	25.66	
15	4.66	2.82	6.45	21.91	6.53	10.68	18.05	21.67	
20	5.15	3.60	4.75	18.38	7.00	11.98	15.84	19.94	
25	3.68	2.86	5.43	21.05	4.52	7.95	15.80	22.10	
30	3.43	3.73	6.08	19.83	3.48	5.60	8.20	12.77	
Total		19.98		128.53		61.22		110.55	80.07

Appendix 7: continued

4WPRS - ISP - (sprigs - 4 wks - 195.2 kg N ha^{-1})

	Ammonia from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	8.48	11.32	14.01	3.93	26.89	88.61	29.31	37.71	
10	11.76	23.80	8.56	5.81	10.47	62.36	24.80	120.59	
15	5.51	11.16	7.04	9.50	13.02	78.10	19.38	110.75	
20	4.43	11.49	3.78	6.24	8.94	55.57	10.39	65.55	
25	3.21	6.69	3.95	6.83	6.59	47.53	7.29	54.32	
30	3.44	8.57	1.99	3.35	4.76	32.33	8.15	57.78	
Total		73.04		35.66		364.50		446.70	229.98

4WPRS - LIN - (sprigs - 4 wks - 48.8 kg N ha^{-1})

	Ammonia from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	2.65	2.28	16.41	52.62	13.75	9.52	8.22	35.88	
10	3.94	9.84	3.95	16.64	11.51	30.12	6.24	30.34	
15	2.76	8.55	4.55	25.07	8.40	34.88	3.39	17.16	
20	2.60	9.61	3.96	21.10	5.42	26.44	3.43	17.18	
25	2.12	7.65	3.90	27.36	4.41	21.01	2.22	18.51	
30	1.35	6.01	2.57	18.22	3.37	22.13	1.80	12.12	
Total		43.94		161.00		144.11		131.19	120.06

Appendix 7: continued

4WPRS - SOD - (sod - 4 wks - 97.6 kg N ha^{-1})

	Ammonia from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	68.82	66.13	4.43	2.33	66.19	180.31	32.48	146.02	
10	35.86	351.07	7.67	9.25	25.45	81.80	19.73	151.99	
15	27.87	198.14	6.26	6.50	38.97	139.86	9.37	63.32	
20	14.08	97.97	0.23	0.15	38.38	144.52	12.75	95.96	
25	16.03	88.54	4.16	2.56	26.21	96.92	7.53	61.07	
30	13.18	103.53	3.27	1.79	20.16	81.24	6.14	40.80	
Total		905.38		22.58		724.65		559.16	552.94

6WPRS - ISP - (sprigs - 6 wks - 292.8 kg N ha^{-1})

	Ammonia from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	28.71	76.20	5.90	16.22	39.22	202.28	29.93	30.27	
10	22.24	256.33	2.28	9.98	28.60	169.49	16.62	16.50	
15	13.52	153.28	2.04	10.35	15.29	99.47	13.84	43.01	
20	8.25	106.64	2.03	8.76	9.25	62.64	8.62	19.85	
25	6.78	89.21	2.22	12.86	8.32	56.21	8.11	15.51	
30	6.02	67.12	2.65	12.77	6.41	46.13	7.06	14.78	
Total		748.79		70.94		636.23		139.92	398.97

Appendix 7: continued

6WPRS - LIN - (sprigs - 6 wks - 146.4 kg N ha^{-1})

	Ammonia from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	1.14	0.17	6.74	8.72	11.43	45.21	14.20	36.95	
10	1.21	1.35	15.00	67.21	9.30	61.49	12.35	49.99	
15	1.38	1.70	13.15	83.23	10.10	63.13	8.19	38.43	
20	1.19	1.90	3.73	26.80	4.70	26.14	4.01	12.43	
25	1.02	1.68	2.38	16.10	2.94	23.18	4.16	25.25	
30	1.14	2.31	3.17	18.44	3.75	32.80	3.31	25.78	
Total		9.11		220.49		251.95		188.83	167.60

8WPRS - ISP - (sprigs - 8 wks - 390.4 kg N ha^{-1})

	Ammonia from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	10.16	11.11	67.15	68.59	56.82	135.97	20.50	15.71	
10	5.54	6.51	51.87	55.91	43.46	167.70	18.56	33.41	
15	3.40	7.06	17.01	17.90	19.17	72.54	12.31	41.33	
20	2.71	6.80	15.27	15.20	14.63	75.63	6.95	20.58	
25	2.98	7.62	5.92	7.08	9.50	41.51	7.02	22.83	
30	2.56	7.50	5.46	9.49	7.98	36.59	5.80	21.59	
Total		46.60		174.17		529.95		155.45	226.54

Appendix 7: continued

8WPRS - LIN - (sprigs - 8 wks - 244.0 kg N ha^{-1})

	Ammonia from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	22.55	15.56	5.94	6.05	17.67	32.72	24.07	71.92	
10	23.50	14.97	8.35	14.59	11.93	51.19	20.51	90.08	
15	15.05	7.17	9.35	37.61	10.92	44.47	14.08	90.32	
20	11.57	12.08	4.46	10.65	6.83	22.56	9.64	64.51	
25	8.12	6.98	7.11	29.09	5.41	17.40	7.08	50.43	
30	4.56	4.46	3.83	13.08	5.22	16.17	4.67	38.96	
Total		61.21		111.07		184.52		406.23	190.76

10WPRS - ISP - (sprigs - 10 wks - 488.0 kg N ha^{-1})

	Ammonia from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	32.66	3.13	4.15	12.96	24.18	91.51	28.02	28.41	
10	17.16	4.59	6.91	34.38	18.00	92.37	17.88	35.59	
15	15.03	3.99	5.01	29.87	10.11	53.57	17.74	41.43	
20	12.27	2.31	4.45	30.07	10.88	63.85	10.02	27.97	
25	10.85	6.41	2.69	19.26	5.98	39.54	9.07	29.86	
30	7.18	3.32	1.92	14.64	5.36	28.78	7.61	25.28	
Total		23.76		141.18		369.62		188.54	180.78

Appendix 7: continued

10WPRS - LIN - (sprigs - 10 wks - 341.6 kg N ha^{-1})

	Ammonia from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	8.52	22.14	3.88	9.63	6.80	2.57	18.09	7.05	
10	7.61	37.05	10.64	41.60	9.44	7.27	22.16	50.57	
15	5.59	24.94	4.22	22.02	6.38	5.36	15.85	48.37	
20	4.50	26.06	4.87	28.28	6.60	6.03	15.69	50.59	
25	3.50	22.27	4.54	27.94	2.45	2.26	10.43	34.02	
30	1.90	12.21	3.43	19.53	4.24	3.31	7.31	26.61	
Total		144.67		149.01		26.79		217.22	134.42

Appendix 8: Rainfall simulation induced dissolved reactive P (DRP) surface runoff concentrations over a thirty minute period from sprigged and sodded bermudamgrasss established 4, 6, 8, and 10 WPRS under three nitromgen remgimes in 2000

Bare mground - (bare soil - 10wks - 0 kg N ha-1)

	Dissolved reactive P from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averamged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	0.26	1.91	0.30	0.59	0.33	1.49	
10	0.29	2.38	0.30	1.38	0.38	2.84	
15	0.29	2.27	0.31	1.95	0.36	2.35	
20	0.30	2.31	0.34	2.03	0.39	2.87	
25	0.32	2.75	0.35	2.50	0.39	2.48	
30	0.33	1.92	0.35	2.14	0.40	2.70	
Total		13.53		10.59		14.72	12.95

4WPRS- ISP - (sprigs - 4 wks - 195.2 kg N ha-1)

	Dissolved reactive P from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averamged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	4.39	5.43	0.82	3.18	0.84	3.43	
10	8.77	4.00	0.77	2.72	0.72	3.40	
15	13.16	7.03	0.71	2.67	0.72	4.14	
20	17.54	3.04	0.68	2.75	0.68	4.00	
25	21.93	5.28	0.64	2.96	0.65	3.60	
30	26.32	4.94	0.63	3.25	0.63	3.79	
Total		29.72		17.52		22.35	23.20

Appendix 8: continued

4WPRS - LIN - (sprigs - 4 wks - 48.8 kg N ha-1)

	Dissolved reactive P from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averamged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	0.30	1.01	0.48	2.18	0.77	1.88	
10	0.39	0.84	0.46	3.55	0.55	1.60	
15	0.42	0.88	0.43	2.18	0.54	1.99	
20	0.44	1.11	0.42	2.64	0.53	2.33	
25	0.43	1.06	0.36	2.33	0.48	2.15	
30	0.44	1.02	0.41	2.54	0.49	2.25	
Total		5.93		15.43		12.19	11.18

4WPRS - SOD - (sod - 4 wks - 97.6 kg N ha-1)

	Dissolved reactive P from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averamged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	0.71	3.97	0.77	1.06	0.37	0.61	
10	0.72	3.91	1.01	3.05	0.45	0.49	
15	0.66	2.07	0.77	3.13	0.58	0.83	
20	0.69	2.33	0.89	3.59	0.54	0.72	
25	0.71	3.76	0.89	4.15	0.52	0.54	
30	0.68	3.64	0.86	4.39	0.53	0.68	
Total		19.68		19.37		3.87	14.31

Appendix 8: continued

6WPRS - ISP - (sprigs - 6 wks - 292.8 kg N ha-1)

	Dissolved reactive P from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averamged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	0.24	0.37	0.42	0.96	0.33	0.91	
10	0.31	0.93	0.43	1.60	0.45	2.17	
15	0.34	1.13	0.40	1.65	0.46	2.91	
20	0.36	1.47	0.40	1.61	0.45	3.16	
25	0.36	1.72	0.41	2.90	0.44	2.46	
30	0.36	1.53	0.39	1.90	0.46	3.19	
Total		7.16		10.61		14.80	10.85

6WPRS - LIN - (sprigs - 6 wks - 146.4 kg N ha-1)

	Dissolved reactive P from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averamged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	0.28	0.90	0.53	0.90	0.39	0.73	
10	0.32	1.15	0.62	1.58	0.47	1.50	
15	0.36	1.47	0.63	1.19	0.50	2.02	
20	0.35	1.56	0.66	1.26	0.52	1.55	
25	0.36	1.59	0.65	1.96	0.52	3.35	
30	0.32	1.42	0.64	1.73	0.51	1.89	
Total		8.09		8.62		11.03	9.25

8WPRS - ISP - (sprigs - 8 wks - 390.4 kg N ha-1)

	Dissolved reactive P from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averamged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	4.39	0.79	0.40	1.50	0.59	2.68	
10	8.77	1.18	0.42	1.96	0.59	3.57	
15	13.16	1.16	0.43	2.09	0.55	2.47	
20	17.54	1.49	0.43	1.49	0.54	3.36	
25	21.93	1.51	0.43	1.86	0.51	2.83	
30	26.32	1.41	0.43	1.15	0.51	3.21	
Total		7.54		10.05		18.12	11.91

8WPRS - LIN - (sprigs - 8 wks - 244.0 kg N ha-1)

	Dissolved reactive P from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averamged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	0.23	1.24	0.39	1.06	0.54	1.10	
10	0.27	0.77	0.44	0.67	0.56	2.63	
15	0.32	1.38	0.47	1.99	0.54	3.04	
20	0.32	0.94	0.48	2.45	0.53	2.79	
25	0.31	1.26	0.49	2.57	0.54	3.56	
30	0.32	1.37	0.48	2.26	0.52	3.17	
Total		6.96		10.99		16.28	11.41

Appendix 8: continued

10WPRS - ISP - (sprigs - 10 wks - 488.0 kg N ha-1)

	Dissolved reactive P from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averamged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	0.20	0.28	0.45	0.63	0.17	0.60	
10	0.21	0.81	0.47	1.44	0.22	0.72	
15	0.25	1.58	0.53	2.42	0.22	1.39	
20	0.27	1.48	0.53	2.81	0.28	0.85	
25	0.29	2.25	0.58	5.01	0.28	2.01	
30	0.29	1.38	0.50	4.25	0.31	2.22	
Total		7.77		16.56		7.79	10.71

10WPRS - LIN - (sprigs - 10 wks - 341.6 kg N ha-1)

	Dissolved reactive P from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averamged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	0.20	0.36	0.25	0.73	0.42	0.71	
10	0.24	0.59	0.32	1.91	0.42	1.19	
15	0.28	1.19	0.32	1.54	0.41	2.26	
20	0.31	1.46	0.33	1.63	0.43	3.07	
25	0.32	1.71	0.33	1.86	0.43	3.39	
30	0.32	1.71	0.31	1.69	0.43	3.30	
Total		7.02		9.35		13.93	10.10

Appendix 8: continued

10WPRS - SOD - (sod - 10wks - 244 kg N ha-1)

	Dissolved reactive P from 1.5 m^2 plots						
	Rep 1		Rep 2		Rep 3		Averamged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	mg
5	0.28	0.42	0.68	1.87	0.51	1.06	
10	0.58	0.67	0.78	2.80	0.65	2.60	
15	0.54	0.65	0.94	2.99	0.71	2.83	
20	0.56	1.04	0.75	3.17	0.75	3.30	
25	0.57	1.11	0.72	2.78	0.73	3.28	
30	0.54	0.90	0.73	2.58	0.75	3.71	
Total		4.78		16.18		16.78	12.58

Appendix 9: Rainfall simulated induced dissolved reactive P (DRP) surface runoff concentrations over a thiry minute period from sprigged and sodded bermudagrass established 2, 4, 6, 8, and 10 WPRS under three nitrogen regimes in 2001.

Bare Ground - (bare soil - 10wks - 0 kg N ha^{-1})

	DRP from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.29	1.59	0.38	0.49	0.30	1.30	0.53	1.42	
10	0.34	2.01	0.33	0.83	0.35	2.25	0.54	3.43	
15	0.32	0.63	0.38	1.17	0.40	2.76	0.48	3.82	
20	0.35	3.79	0.42	1.28	0.35	2.52	0.51	3.06	
25	0.24	0.79	0.44	1.39	0.41	3.12	0.75	3.28	
30	0.16	1.07	0.53	2.18	0.29	1.78	0.50	2.05	
Total		9.88		7.35		13.73		17.05	12.00

2WPRS- ISP - (sprigs - 2 wks - 97.6 kg N ha^{-1})

	DRP from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.39	0.13	0.32	0.56	0.28	0.62	0.29	1.45	
10	0.42	0.49	0.32	1.43	0.25	1.33	0.28	1.47	
15	0.24	0.40	0.29	1.73	0.22	1.42	0.22	1.40	
20	0.45	1.94	0.40	2.20	0.25	1.80	0.35	2.73	
25	0.49	2.23	0.36	2.45	0.32	2.06	0.39	3.14	
30	0.40	2.08	0.24	1.51	0.33	2.32	0.44	3.09	
Total		7.26		9.88		9.55		13.28	9.99

Appendix 9: continured

2WPRS - LIN - (sod - 2wks - 24.4 kg N ha^{-1})

	DRP from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.29	0.98	0.35	0.31	0.24	0.61	0.31	0.36	
10	0.26	0.87	0.28	0.38	0.27	1.28	0.49	0.39	
15	0.32	1.64	0.30	0.61	0.27	1.39	0.46	0.62	
20	0.26	2.04	0.42	0.99	0.29	1.73	0.38	1.11	
25	0.35	4.44	0.50	1.35	0.28	1.58	0.63	1.59	
30	0.17	3.00	0.39	1.11	0.21	1.29	0.41	1.72	
Total		12.95		4.75		7.88		5.79	7.84

2WPRS - SOD - (sod - 2wks - 48.8 kg N ha^{-1})

	DRP from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.77	0.28	0.59	1.19	0.98	1.16	0.43	0.14	
10	0.61	0.30	0.83	2.21	0.72	1.24	0.48	0.46	
15	0.45	0.27	0.50	1.69	0.82	1.34	0.63	0.76	
20	0.67	0.47	0.51	1.96	0.93	1.59	0.69	0.87	
25	0.56	0.43	0.84	3.27	0.78	1.37	0.75	1.05	
30	0.58	0.64	0.75	2.46	0.63	1.01	0.37	0.57	
Total		2.38		12.78		7.71		3.85	6.68

Appendix 9: continured

4WPRS - ISP - (sprigs - 4 wks - 195.2 kg N ha^{-1})

	DRP from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.24	0.33	0.30	0.08	0.54	1.79	0.39	0.50	
10	0.42	0.86	0.48	0.33	0.31	1.83	0.28	1.36	
15	0.21	0.42	0.41	0.56	0.38	2.30	0.40	2.29	
20	0.27	0.69	0.30	0.49	0.28	1.72	0.28	1.75	
25	0.34	0.70	0.46	0.79	0.45	3.22	0.32	2.38	
30	0.37	0.92	0.46	0.77	0.36	2.43	0.42	2.98	
Total		3.91		3.02		13.29		11.26	7.87

4WPRS - LIN - (sprigs - 4 wks - 48.8 kg N ha^{-1})

	DRP from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.23	0.19	0.78	2.51	0.43	0.30	0.42	1.85	
10	0.42	1.05	0.22	0.93	0.41	1.08	0.51	2.47	
15	0.30	0.92	0.50	2.77	0.34	1.40	0.30	1.51	
20	0.40	1.49	0.63	3.34	0.36	1.76	0.39	1.94	
25	0.47	1.70	0.64	4.48	0.54	2.57	0.47	3.92	
30	0.35	1.54	0.41	2.88	0.66	4.30	0.42	2.82	
Total		6.89		16.91		11.39		14.51	12.43

4WPRS - SOD - (sod - 4 wks - 97.6 kg N ha^{-1})

	DRP from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.62	0.60	0.45	0.24	0.98	2.67	0.92	4.14	
10	0.51	5.00	0.62	0.74	0.31	0.98	0.78	6.02	
15	0.49	3.48	0.65	0.67	0.65	2.31	0.83	5.64	
20	0.40	2.76	0.28	0.19	0.76	2.85	0.70	5.25	
25	0.58	3.21	0.55	0.34	0.83	3.08	0.63	5.14	
30	0.59	4.61	0.63	0.35	0.89	3.57	0.63	4.19	
Total		19.67		2.53		15.47		30.38	17.01

6WPRS - ISP - (sprigs - 6 wks - 292.8 kg N ha^{-1})

	DRP from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.47	1.24	0.32	0.89	0.31	1.61	0.19	0.20	
10	0.40	4.59	0.42	1.85	0.34	2.00	0.21	0.21	
15	0.38	4.33	0.31	1.58	0.40	2.62	0.32	1.00	
20	0.37	4.72	0.51	2.20	0.59	4.00	0.34	0.79	
25	0.50	6.51	0.39	2.23	0.26	1.78	0.45	0.85	
30	0.50	5.60	0.30	1.46	0.30	2.14	0.51	1.06	
Total		26.98		10.20		14.15		4.11	13.86

Appendix 9: continured

6WPRS - LIN - (sprigs - 6 wks - 146.4 kg N ha^{-1})

	DRP from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.34	0.05	0.42	0.54	0.35	1.37	0.19	0.50	
10	0.37	0.41	0.35	1.58	0.33	2.21	0.30	1.23	
15	0.48	0.58	0.48	3.06	0.35	2.19	0.38	1.80	
20	0.53	0.85	0.16	1.11	0.28	1.53	0.29	0.89	
25	0.39	0.63	0.48	3.22	0.33	2.61	0.32	1.92	
30	0.46	0.92	0.35	2.01	0.36	3.11	0.39	3.06	
Total		3.45		11.52		13.02		9.39	9.35

8WPRS - ISP - (sprigs - 8 wks - 390.4 kg N ha^{-1})

	DRP from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.45	0.49	0.45	0.46	0.59	1.40	0.22	0.17	
10	0.37	0.43	0.52	0.56	0.43	1.65	0.32	0.58	
15	0.31	0.63	0.40	0.42	0.72	2.74	0.31	1.05	
20	0.44	1.10	0.41	0.41	0.39	2.00	0.30	0.89	
25	0.51	1.29	0.28	0.34	0.45	1.95	0.47	1.54	
30	0.55	1.60	0.32	0.56	0.43	1.95	0.43	1.61	
Total		5.55		2.74		11.69		5.83	6.45

8WPRS - LIN - (sprigs - 8 wks - 244.0 kg N ha^{-1})

	DRP from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.57	0.39	0.64	0.65	0.50	0.92	0.34	1.02	
10	0.58	0.37	0.48	0.83	0.41	1.77	0.34	1.51	
15	0.52	0.25	0.61	2.44	0.26	1.04	0.40	2.57	
20	0.50	0.52	0.35	0.83	0.23	0.75	0.36	2.42	
25	0.41	0.35	0.61	2.50	0.24	0.77	0.30	2.13	
30	0.28	0.28	0.53	1.81	0.37	1.15	0.24	1.98	
Total		2.15		9.07		6.39		11.63	7.31

10WPRS - ISP - (sprigs - 10 wks - 488.0 kg N ha^{-1})

	DRP from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.53	0.05	0.20	0.61	0.57	2.17	0.60	0.61	
10	0.53	0.14	0.35	1.74	0.55	2.81	0.42	0.84	
15	0.51	0.14	0.34	2.04	0.51	2.70	0.35	0.82	
20	0.61	0.11	0.44	2.99	0.50	2.94	0.69	1.91	
25	0.48	0.28	0.27	1.90	0.52	3.41	0.52	1.70	
30	0.52	0.24	0.20	1.50	0.53	2.82	0.36	1.18	
Total		0.97		10.80		16.84		7.07	8.92

Appendix 9: continured

10WPRS - LIN - (sprigs - 10 wks - 341.6 kg N ha^{-1})

	DRP from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.63	1.64	0.38	0.93	0.49	0.19	0.26	0.10	
10	0.65	3.18	0.42	1.64	0.59	0.45	0.25	0.57	
15	0.56	2.52	0.22	1.14	0.55	0.46	0.33	1.00	
20	0.60	3.47	0.27	1.59	0.60	0.55	0.46	1.49	
25	0.46	2.95	0.36	2.22	0.82	0.75	0.28	0.93	
30	0.37	2.36	0.44	2.48	0.63	0.49	0.20	0.74	
Total		16.13		10.00		2.89		4.82	8.46

Appendix 10: Rainfall simulated induced inorganic and organic dissolved P (ICAP) surface runoff concentrations over a thirty minute period from sprigged and sodded bermudagrass established 2, 4, 6, 8, and 10 WPRS under three nitrogen regimes in 2001

Bare Ground - (bare soil - 10wks - 0 kg N ha^{-1})

	Inorganic and organic dissolved P from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.43	2.39	0.45	0.59	1.50	6.49	1.94	5.15	
10	0.43	2.58	0.44	1.13	1.22	7.97	1.19	7.58	
15	0.38	0.75	0.46	1.42	1.06	7.32	0.89	7.03	
20	0.60	6.53	0.46	1.40	0.59	4.31	0.60	3.58	
25	0.60	2.00	0.85	2.68	0.63	4.75	0.47	2.05	
30	0.54	3.56	1.01	4.18	0.58	3.59	0.78	3.23	
Total		17.81		11.40		34.42		28.63	23.07

2WPRS- ISP - (sprigs - 2 wks - 97.6 kg N ha^{-1})

	Inorganic and organic dissolved P from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.67	0.21	0.64	1.14	35.35	77.57	22.23	112.69	
10	0.57	0.65	0.68	3.07	22.22	119.10	10.61	54.91	
15	0.47	0.79	1.07	6.50	11.61	76.37	4.37	27.80	
20	0.56	2.40	0.49	2.71	8.41	59.93	1.36	10.60	
25	0.49	2.22	0.72	4.91	7.58	49.68	2.25	18.27	
30	0.58	2.97	0.77	4.76	4.99	35.58	1.30	9.12	
Total		9.25		23.08		418.23		233.39	170.99

2WPRS - LIN - (sod - 2wks - 24.4 kg N ha^{-1})

Inorganic and organic dissolved P from 1.5 m^2 plots

	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.46	1.56	0.48	0.43	22.76	57.81	8.29	9.52	
10	0.42	1.38	0.50	0.68	9.09	42.66	4.77	3.77	
15	0.48	2.49	0.45	0.93	6.81	35.74	4.00	5.47	
20	0.46	3.61	0.59	1.38	4.44	26.72	1.37	4.00	
25	0.42	5.35	0.46	1.24	2.79	16.02	1.42	3.58	
30	0.52	9.13	0.53	1.52	3.09	19.35	1.21	5.08	
Total		23.51		6.18		198.30		31.42	64.85

2WPRS - SOD - (sod - 2wks - 48.8 kg N ha^{-1})

Inorganic and organic dissolved P from 1.5 m^2 plots

	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.86	0.31	0.82	1.66	14.95	17.74	37.68	12.36	
10	0.65	0.32	0.98	2.59	18.14	31.47	39.48	38.19	
15	1.67	1.01	0.97	3.30	10.89	17.81	25.65	30.79	
20	0.93	0.65	1.10	4.26	12.71	21.76	22.10	27.83	
25	0.79	0.62	0.88	3.42	6.26	11.01	22.32	31.22	
30	1.06	1.15	0.67	2.17	4.89	7.86	9.40	14.64	
Total		4.06		17.41		107.65		155.04	71.04

Appendix 10: continued

4WPRS - ISP - (sprigs - 4 wks - 195.2 kg N ha^{-1})

	Inorganic and organic dissolved P from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.53	0.70	0.32	0.09	42.70	140.71	47.76	61.44	
10	0.67	1.36	0.27	0.18	14.46	86.13	30.77	149.62	
15	0.90	1.83	0.32	0.43	19.99	119.91	22.86	130.63	
20	0.60	1.55	0.49	0.81	12.84	79.81	10.68	67.38	
25	0.44	0.92	0.45	0.78	9.87	71.19	7.17	53.43	
30	0.89	2.21	0.46	0.78	6.05	41.09	9.92	70.32	
Total		8.57		3.08		538.83		532.84	270.83

4WPRS - LIN - (sprigs - 4 wks - 48.8 kg N ha^{-1})

	Inorganic and organic dissolved P from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.72	0.62	0.76	2.45	16.57	11.47	9.54	41.65	
10	0.79	1.96	0.63	2.63	14.78	38.68	6.59	32.04	
15	0.83	2.56	0.75	4.15	11.89	49.38	2.94	14.88	
20	0.60	2.23	0.83	4.40	7.45	36.35	3.23	16.18	
25	0.79	2.86	0.84	5.89	5.61	26.72	1.98	16.51	
30	0.85	3.80	0.68	4.78	3.62	23.78	1.75	11.78	
Total		14.02		24.31		186.37		133.04	89.44

Appendix 10: continued

4WPRS - SOD - (sod - 4 wks - 97.6 kg N ha^{-1})

	Inorganic and organic dissolved P from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	1.32	1.27	0.61	0.32	91.37	248.90	49.84	224.07	
10	1.10	10.80	0.63	0.76	32.36	104.01	28.78	221.71	
15	0.81	5.77	0.65	0.67	52.11	187.02	11.66	78.80	
20	0.85	5.94	0.39	0.26	52.57	197.95	17.78	133.82	
25	0.76	4.18	0.56	0.35	34.45	127.40	8.57	69.50	
30	0.88	6.94	0.73	0.40	26.40	106.38	6.98	46.38	
Total		34.88		2.75		971.66		774.27	445.89

6WPRS - ISP - (sprigs - 6 wks - 292.8 kg N ha^{-1})

	Inorganic and organic dissolved P from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.87	2.30	0.20	0.56	46.89	241.84	40.32	40.77	
10	0.66	7.64	0.44	1.94	34.07	201.91	18.85	18.72	
15	0.67	7.55	0.55	2.81	16.13	104.94	15.96	49.59	
20	0.56	7.28	0.54	2.32	9.15	61.96	8.88	20.45	
25	0.62	8.16	0.55	3.19	8.27	55.88	8.81	16.85	
30	0.63	6.99	0.38	1.81	6.01	43.25	8.30	17.37	
Total		39.91		12.62		709.78		163.76	231.52

Appendix 10: continued

6WPRS - LIN - (sprigs - 6 wks - 146.4 kg N ha^{-1})

	Inorganic and organic dissolved P from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.86	0.13	0.60	0.78	16.77	66.33	21.56	56.10	
10	0.57	0.64	0.56	2.53	12.20	80.66	17.23	69.74	
15	0.71	0.87	0.74	4.66	14.89	93.06	9.77	45.85	
20	0.46	0.74	0.80	5.71	5.82	32.37	4.27	13.23	
25	0.65	1.07	0.77	5.22	2.77	21.84	4.61	27.99	
30	0.48	0.97	0.71	4.12	5.18	45.31	4.05	31.54	
Total		4.42		23.02		339.58		244.45	152.87

8WPRS - ISP - (sprigs - 8 wks - 390.4 kg N ha^{-1})

	Inorganic and organic dissolved P from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	1.35	1.47	0.48	0.49	74.87	179.16	35.28	27.03	
10	1.51	1.78	0.56	0.61	55.45	213.96	29.47	53.04	
15	1.32	2.74	0.66	0.69	22.14	83.78	16.15	54.22	
20	0.53	1.34	0.44	0.43	16.61	85.87	7.90	23.40	
25	0.45	1.16	0.33	0.40	10.70	46.76	8.42	27.38	
30	0.51	1.49	0.63	1.10	9.04	41.45	6.60	24.57	
Total		9.98		3.72		650.99		209.65	218.58

Appendix 10: continued

8WPRS - LIN - (sprigs - 8 wks - 244.0 kg N ha^{-1})

	Inorganic and organic dissolved P from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.72	0.50	0.42	0.43	8.66	16.04	32.74	97.82	
10	0.84	0.54	0.72	1.26	13.77	59.09	28.51	125.22	
15	0.85	0.40	0.63	2.52	14.01	57.05	19.60	125.73	
20	0.56	0.58	0.97	2.31	8.39	27.72	12.76	85.39	
25	0.57	0.49	0.36	1.46	6.87	22.10	8.96	63.83	
30	0.61	0.60	0.41	1.42	6.90	21.37	4.90	40.88	
Total		3.11		9.40		203.36		538.87	188.68

10WPRS - ISP - (sprigs - 10 wks - 488.0 kg N ha^{-1})

	Inorganic and organic dissolved P from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.83	0.08	0.67	2.10	31.38	118.76	11.20	11.36	
10	0.73	0.19	0.57	2.83	23.44	120.28	7.21	14.35	
15	0.75	0.20	0.77	4.57	12.09	64.07	23.54	54.97	
20	0.59	0.11	0.65	4.37	14.85	87.15	4.42	12.34	
25	0.57	0.34	0.49	3.54	7.67	50.71	4.43	14.58	
30	0.51	0.24	0.53	4.01	7.18	38.55	3.72	12.36	
Total		1.16		21.41		479.52		119.96	155.51

Appendix 10: continued

10WPRS - LIN - (sprigs - 10 wks - 341.6 kg N ha^{-1})

	Inorganic and organic dissolved P from 1.5 m^2 plots								
	Rep 1		Rep 2		Rep 3		Rep 4		Averaged Total
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg	mg
5	0.49	1.27	0.57	1.42	10.98	4.15	26.72	10.42	
10	0.82	3.98	0.41	1.61	16.86	12.98	32.64	74.49	
15	0.62	2.77	0.67	3.49	9.27	7.79	22.46	68.54	
20	0.60	3.46	0.59	3.42	10.35	9.45	23.82	76.80	
25	0.64	4.08	0.45	2.77	4.20	3.87	14.22	46.39	
30	0.79	5.05	0.44	2.50	5.92	4.62	8.44	30.73	
Total		20.61		15.21		42.86		307.36	96.51

Appendix 11: Rainfall simulated induced total P (TKP) surface runoff concentrations over a thiry minute period from sprigged and sodded established 2, 4, 6, 8, and 10 WPRS under three nitrogen regimes in 2001.

Bare Ground - (bare soil - 10wks - 0 kg N ha^{-1})

	Total P from 1.5 m^2 plots							
	Rep 1		Rep 2		Rep 3		Rep 4	
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg
5	0.6288	3.46	0.8406	1.09	0.339989	1.47	0.269468	0.72
10	1.0095	6.05	0.6293	1.61	-0.000328	0.00	0.377238	2.40
15	0.9815	1.94	1.0495	3.23	0.000429	0.00		0.00
20	0.6291	6.90	0.9372	2.84	0.326429	2.38	0.455046	2.72
25	1.1450	3.80	0.6297	1.98		0.00	0.30527	1.33
30	1.0561	6.98	0.6299	2.60		0.00	-0.00003	0.00
Total		29.13		13.35		3.85		7.17

2WPRS- ISP - (sprigs - 2 wks - 97.6 kg N ha^{-1})

	Total P from 1.5 m^2 plots							
	Rep 1		Rep 2		Rep 3		Rep 4	
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg
5	0.9231	0.30		0.00	0.3528	0.77	0.20019	1.01
10	0.9234	1.06		0.00	0.3608	1.93	-0.00018	0.00
15	0.6309	1.07	1.0421	6.31	-0.0027	-0.02	0.244922	1.56
20	0.9715	4.16	0.6290	3.45	0.3416	2.43	0.252642	1.97
25	0.6290	2.86		0.00		0.00		0.00
30	1.0274	5.29	1.0979	6.80	0.3112	2.22		0.00
Total		14.75		16.56		7.34		4.54

Appendix 11: continued

2WPRS - LIN - (sod - 2wks - 24.4 kg N ha^{-1})

	Total P from 1.5 m^2 plots							
	Rep 1		Rep 2		Rep 3		Rep 4	
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg
5	1.0916	3.68	0.6286	0.56	0.544962	1.38	0.62158	0.71
10	1.1565	3.84	0.7759	1.06	0.561899	2.64		0.00
15	1.1325	5.83	1.0451	2.15	0.570427	2.99		0.00
20	1.1440	9.04	0.6283	1.48	0.597293	3.59	0.538215	1.57
25	0.6287	7.92	0.9082	2.43	0.615957	3.54	0.001341	0.00
30	1.1702	20.74	1.0395	2.96	0.590449	3.70	0.474757	2.00
Total		51.04		10.65		17.84		4.28

2WPRS - SOD - (sod - 2wks - 48.8 kg N ha^{-1})

	Total P from 1.5 m^2 plots							
	Rep 1		Rep 2		Rep 3		Rep 4	
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg
5	0.6292	0.23	1.3890	2.81	1.5249	1.81		0.00
10	1.1515	0.57	1.4204	3.77	1.5537	2.70	0.696614	0.67
15	1.1329	0.69	1.5473	5.25	0.6291	1.03	0.000182	0.00
20	0.6352	0.44	0.6290	2.43	1.4911	2.55	0.668451	0.84
25	0.6316	0.49	0.6307	2.44		0.00	0.002099	0.00
30	1.0566	1.15	0.6304	2.06	1.3667	2.20	0.133167	0.21
Total		3.57		18.77		10.28		1.73

Appendix 11: continued

4WPRS - ISP - (sprigs - 4 wks - 195.2 kg N ha^{-1})

	Total P from 1.5 m^2 plots							
	Rep 1		Rep 2		Rep 3		Rep 4	
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg
5	1.0343	1.38	0.6308	0.18	0.4965	1.64	0.172317	0.22
10	0.9821	1.99	0.7840	0.53	0.5171	3.08	0.378478	1.84
15	1.0130	2.05	0.9862	1.33	0.3530	2.12	0.287996	1.65
20	0.6294	1.63	0.6326	1.04	0.8519	5.30	0.31801	2.01
25	1.1799	2.46	1.0347	1.79	0.744584	5.37	0.349599	2.61
30	0.9159	2.28	1.1086	1.87	0.797198	5.41		0.00
Total		11.80		6.74		22.91		8.32

4WPRS - LIN - (sprigs - 4 wks - 48.8 kg N ha^{-1})

	Total P from 1.5 m^2 plots							
	Rep 1		Rep 2		Rep 3		Rep 4	
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg
5	0.6286	0.54	0.6291	2.02	0.8184	0.57		0.00
10	0.9022	2.25	1.2155	5.12	0.6281	1.64	-0.000799	0.00
15	0.9326	2.89		0.00	0.6334	2.63	-0.000674	0.00
20	0.9949	3.68	1.0916	5.82	0.9054	4.42	-0.000338	0.00
25	0.6316	2.28		0.00	0.6288	3.00	0.386519	3.22
30	1.0489	4.67	1.1698	8.29	0.8508	5.59	-0.000642	0.00
Total		16.31		21.24		17.84		3.21

4WPRS - SOD - (sod - 4 wks - 97.6 kg N ha^{-1})

	Total P from 1.5 m^2 plots							
	Rep 1		Rep 2		Rep 3		Rep 4	
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg
5	0.6294	0.60	0.6305	0.33	1.363739	3.72	0.001677	0.01
10	0.9283	9.09	0.6287	0.76	1.183818	3.80	0.794576	6.12
15	1.1935	8.49	1.1979	1.24	0.369123	1.32	0.819115	5.54
20	1.0438	7.26	1.0828	0.72	1.179923	4.44		0.00
25		0.00	1.3127	0.81	1.009459	3.73	0.697223	5.65
30	1.0974	8.62	1.2026	0.66	0.9979	4.02		0.00
Total		34.06		4.52		21.04		17.32

6WPRS - ISP - (sprigs - 6 wks - 292.8 kg N ha^{-1})

	Total P from 1.5 m^2 plots							
	Rep 1		Rep 2		Rep 3		Rep 4	
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg
5	0.6284	1.67		0.00	0.671045	3.46		
10	0.9334	10.76		0.00	0.369513	2.19		
15	0.9942	11.27	1.0977	5.57	0.368487	2.40		
20	1.0300	13.31	0.8973	3.87	0.368904	2.50		
25	1.0095	13.28	0.6281	3.64	0.367696	2.48		
30	0.6296	7.02	0.9470	4.56	0.62784	4.52		
Total		57.31		17.65		17.55		

Appendix 11: continued

6WPRS - LIN - (sprigs - 6 wks - 146.4 kg N ha^{-1})

	Total P from 1.5 m^2 plots							
	Rep 1		Rep 2		Rep 3		Rep 4	
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg
5	0.9546	0.14	1.0659	1.38	0.623803	2.47	-0.000255	0.00
10	1.0253	1.15	1.0709	4.80	0.654314	4.33	0.22843	0.92
15	0.8967	1.10	1.0125	6.41	0.371929	2.32	0.329188	1.54
20	0.6302	1.01	1.1474	8.24	0.728204	4.05	0.37428	1.16
25	0.6289	1.04		0.00	0.722608	5.70	0.270084	1.64
30	0.9613	1.95	1.0740	6.25	0.581427	5.09		0.00
Total		6.38		27.08		23.95		5.27

8WPRS - ISP - (sprigs - 8 wks - 390.4 kg N ha^{-1})

	Total P from 1.5 m^2 plots							
	Rep 1		Rep 2		Rep 3		Rep 4	
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg
5	1.1092	1.21	0.6284	0.64	0.783111	1.87	0.003134	0.00
10	0.6287	0.74	0.8860	0.96	0.754003	2.91	0.339278	0.61
15	1.1279	2.34	1.0380	1.09	0.63966	2.42	0.002674	0.01
20	1.2229	3.07	0.6300	0.63	0.369727	1.91	0.334564	0.99
25	1.1254	2.88	1.0608	1.27	0.427159	1.87	-0.000294	0.00
30	0.6303	1.85	1.0192	1.77	0.349054	1.60	0.709758	2.64
Total		12.09		6.36		12.58		4.25

Appendix 11: continued

8WPRS - LIN - (sprigs - 8 wks - 244.0 kg N ha^{-1})

	Total P from 1.5 m^2 plots							
	Rep 1		Rep 2		Rep 3		Rep 4	
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg
5	1.1358	0.78	1.0769	1.10	0.6294	1.17	0.001864	0.01
10	1.1429	0.73	0.6294	1.10		0.00	0.347742	1.53
15	1.0986	0.52	1.1304	4.55	0.9757	3.97	0.475478	3.05
20	1.0691	1.12	1.1835	2.83	0.6297	2.08	-0.000051	0.00
25	1.1677	1.00	1.0862	4.44	0.9935	3.20	0.349279	2.49
30	1.1352	1.11	1.1753	4.01		0.00	0.427736	3.57
Total		5.27		18.03		10.42		10.64

10WPRS - ISP - (sprigs - 10 wks - 488.0 kg N ha^{-1})

	Total P from 1.5 m^2 plots							
	Rep 1		Rep 2		Rep 3		Rep 4	
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg
5		0.00	1.1599	3.62	1.0357	3.92	0.407545	0.41
10	0.6284	0.17	1.1183	5.56	1.0292	5.28	0.501839	1.00
15		0.00	1.0236	6.10	0.6294	3.34	0.213577	0.50
20	1.0898	0.21	0.9784	6.61	1.0605	6.22	0.000507	0.00
25	0.9776	0.58	0.6285	4.50	1.0606	7.01	0.401188	1.32
30	1.0024	0.46	1.0306	7.86		0.00	0.460865	1.53
Total		1.41		34.26		25.77		4.76

Appendix 11: continued

10WPRS - LIN - (sprigs - 10 wks - 341.6 kg N ha^{-1})

	Total P from 1.5 m^2 plots							
	Rep 1		Rep 2		Rep 3		Rep 4	
Minutes	ppm	mg	ppm	mg	ppm	mg	ppm	mg
5	1.1805	3.07	1.0906	2.71	1.1330	0.43	-0.000118	0.00
10	1.1990	5.84	0.6292	2.46	1.0902	0.84	-0.000907	0.00
15	1.1992	5.35	1.1710	6.11	1.1129	0.94	0.388378	1.19
20	1.2767	7.39	0.6286	3.65	1.1080	1.01	0.414069	1.34
25	1.3156	8.37	0.6287	3.87	1.2184	1.12		0.00
30	1.2732	8.18	1.1206	6.38	1.0776	0.84		0.00
Total		38.20		25.18		5.18		2.52

Appendix 12: Soil moisture prior to rainfall simulation on sprigged and sodded bermudagrass established 4, 6, 8, and 10 WPRS under three nitromgen remgimes in 2000

Treatment	Soil Moisture for 1.5m^2 plots			
	Rep 1	Rep 2	Rep 3	Average
	%	%	%	
Bare Ground - (bare soil - 10wks - 0 kg N ha^{-1})	12.8	7.2	7.0	9.000
4WPRS- ISP - (sprimgs - 4 wks - 195.2 kmg N ha^{-1})	10.6	3.5	7.6	7.233
4WPRS - LIN - (sprimgs - 4 wks - 48.8 kmg N ha^{-1})	11.5	11.1	15.0	12.533
4WPRS - SOD - (sod - 4 wks - 97.6 kmg N ha^{-1})	8.6	5.7	7.1	7.133
6WPRS - ISP - (sprimgs - 6 wks - 292.8 kmg N ha^{-1})	17.6	6.4	8.0	10.667
6WPRS - ISP - (sprimgs - 6 wks - 292.8 kmg N ha^{-1})	6.4	13.8	13.5	11.233
8WPRS - ISP - (sprimgs - 8 wks - 390.4 kmg N ha^{-1})	18.4	18.1	7.5	14.667
8WPRS - LIN - (sprimgs - 8 wks - 244.0 kmg N ha^{-1})	12.8	10.4	12.3	11.833
10WPRS - ISP - (sprimgs - 10 wks - 488.0 kmg N ha^{-1})	13.7	9.7	7.5	10.300
10WPRS - LIN - (sprimgs - 10 wks - 341.6 kmg N ha^{-1})	10.9	11.0	8.3	10.067
10WPRS - SOD - (sod - 10wks - 244 kmg N ha^{-1})	16.9	4.0	13.0	11.300

Appendix 13: Soil moisture prior to rainfall simulation on sprigged and sodded bermudagrass established 2, 4, 6, 8, and 10 WPRS under three nitromgen remgimes in 2001

Treatment	Soil Moisture for 1.5m^2 plots				
	Rep 1	Rep 2	Rep 3	Rep 4	Average
	%	%	%		
Bare Ground - (bare soil - 0wks - 0 kg N ha^{-1})	10.9	18.5	4.8	4.2	9.570
2WPRS- ISP - (sprigs - 2 wks - 97.6 kg N ha^{-1})	18.4	15.2	18.8	18.6	17.763
2WPRS - LIN - (sprigs - 2wks - 24.4 kg N ha^{-1})	14.2	17.4	19.5	18.5	17.385
2WPRS - SOD - (sod - 2wks - 48.8 kg N ha^{-1})	21.8	23.4	21.6	22.3	22.275
4WPRS- ISP - (sprigs - 4 wks - 195.2 kg N ha^{-1})	18.2	20.0	24.3	20.4	20.748
4WPRS - LIN - (sprigs - 4 wks - 48.8 kg N ha^{-1})	23.2	20.6	16.8	17.7	19.583
4WPRS - SOD - (sod - 4 wks - 97.6 kmg N ha^{-1})	35.7	26.4	28.8	25.3	29.050
6WPRS - ISP - (sprigs - 6 wks - 292.8 kg N ha^{-1})	20.7	25.8	24.2	25.1	23.955
6WPRS - LIN - (sprigs - 6 wks - 146.4 kg N ha^{-1})	25.8	18.8	23.5	23.1	22.793
8WPRS - ISP - (sprigs - 8 wks - 390.4 kg N ha^{-1})	20.2	22.7	24.3	21.1	22.075
8WPRS - LIN - (sprigs - 8 wks - 244.0 kg N ha^{-1})	24.3	18.7	25.6	17.7	21.560
10WPRS - ISP - (sprigs - 10 wks - 488.0 kg N ha^{-1})	19.5	15.6	19.3	20.1	18.623
10WPRS - LIN - (sprigs - 10 wks - 341.6 kg N ha^{-1})	19.5	15.6	19.3	20.1	18.623

Vita

Jeffrey S. Beasley was born July 19, 1974 in Greenville, North Carolina to the parents of Bob and Lisbeth Beasley. He graduated from J. H. Rose High School in June of 1992. The Fall of 1992 he enrolled in the University of North Carolina at Greensboro where he attained a B.S. in accounting. After a short period at work, Jeffrey, returned to school at North Carolina State University to complete a bachelor of science in crop science. While attending NCSU, Jeffrey married Kendall Ann George on May 15, 1999 in Perry, Georgia. Graduating in December 1998, he entered graduate school at Virginia Polytechnic Institute and State University to pursue a Masters degree in Agronomy in January of 1999.