Literature Review

Introduction

Nitrate contamination of ground and surface waters is of serious concern in the United States. Providing high quality ground and surface water resources is essential for human use and consumption and to help secure the stability of dynamic environmental systems. Nitrate is considered one of the most widespread ground water contaminants in the United States (Petrovic, 1990) and research, in many disciplines, has addressed this concern. There have been numerous nitrogen loss studies on established turfgrass systems, however, few have evaluated nitrogen loss during establishment (Petrovic, 1990).

An opportunity to evaluate a possible source of nitrate contamination exists during bermudagrass (*Cynodon dactylon*) sprig establishment. Most improved turf-type bermudagrass varieties are typically established vegetatively, by sod, plugs, or sprigs, rather than from seed because of low quantities of viable hybrid seed (Waddington et al., 1992). Typically, during vegetative sprig establishment high rates of soluble nitrogen are applied to encourage rapid establishment, therefore, the potential exists for nitrogen leaching and runoff. With the dominance of bermudagrass (*Cynodon dactylon)* in the southeastern and southern United States there is a need to determine appropriate nitrogen fertilization requirements during bermudagrass sprig establishment.

Warm Season Turfgrasses

Warm season turfgrasses include members of the eragrostoideae and panicoidae subfamilies (Turgeon, 1999). They are widely dispersed throughout the warm humid, warm sub-humid, and warm semi-arid climatic zones and marginally used in cooler transitional areas (Beard, 1973). Warm-season turfgrass species grow best at temperatures between 27° C and 35° C; however, shoot growth ceases and chlorophyll is degraded as temperatures decline (Beard, 1982). Grasses enter this dormancy period when soil temperatures drop below 10° C or when heavy frost occurs (Beard, 1982). With this onset of dormancy the turf becomes brown to tan in appearance.

Warm-season grasses have been evolving for millions of years and the oldest known fossil records of warm-season grasses are 17.7 million years old (Beard, 1998). These grasses evolved primarily in close proximity to the equator under warm, sunny climatic conditions (Beard, 1999). Carbon fixation in warm season turfgrasses occurs principally through the C-4 (Hatch and Slack) pathway (Turgeon, 1999). This C-4 photosynthetic pathway evolved from cool-season species much later in Earth's history and in a greater diversity of geographical locations (Beard, 1998). The evolution of the C-4 pathway greatly improved the energy efficiency and productivity of grasses in areas under high light intensity, which would be found in the geographical locales previously described.

C-4 photosynthesis enhances the ability of warm season grasses to fix carbon dioxide under conditions that cause most plants to lose organic material by photorespiration (Campbell, 1993). Warm season turfgrasses prelude the Calvin cycle with reactions that incorporate carbon dioxide into four-carbon compounds (Jones, 1985).

Through this process, C-4 grasses minimize photorespiration (which would be high in hot climates) and enhance sugar production because carbon dioxide is consumed rather than oxygen. If oxygen was consumed, ATP would not be generated and a decrease in photosynthetic activity would occur (Campbell, 1993). This adaptation is certainly desirable in the warmer regions of the world where these turfgrasses evolved.

Bermudagrass (*Cynodon* sp.) Origin and Adaptation

Bermudagrass is a member of the eragrostoid subfamily and a member of the Chloridaea tribe (Turgeon, 1999). *Cynodon sp.* is the major genera within this tribe with *Buchloe* and *Bouteloua* being the minor components (Turgeon, 1999). Of the approximately 10 species within the genus *Cynodon*, several are used as turfgrasses within the tropical and subtropical climates (Turgeon, 1999). Some of the bermudagrasses used for turfgrasses are interspecific hybrids. Within these genera, the primary turfgrass species include common bermudagrass (*Cynodon dactylon*), Bradley bermudagrass (*Cynodon bradleyi*), Magennis bermudagrass (*Cynodonxmagennisii*), and African Bermudagrass (*Cynodon transvaalensis*) (Turgeon, 1999).

According to Beard (1998), bermudagrass originated and subsequently evolved in Eastern Africa. Specifically, the grasses evolved in what is now the Kenyan and Ugandan regions under heavy grazing pressure from numerous herds of unique African hooved mammals (Beard, 1998). Due to grazing pressures and climatic effects, the grasses evolved relatively deep, extensive root systems, low evapotranspiration rates, extensive lateral growth capabilities, and superb drought resistance. Bermudagrass first arrived in North America in the mid 1700's and has since become the dominant warm season turfgrass in the United States (Christians, 1998).

Bermudagrass is defined by Duble (1989), as a highly variable, sod forming perennial that spreads by stolons, rhizomes, and seed. It also possesses an extensive, deep root system with vigorous rhizomes. Leaf width can range from the medium textured common bermudagrass to the very fine textured African bermudagrass (Beard, 1973). Also, bermudagrass has excellent wear tolerance, heat tolerance, drought tolerance, shoot density, establishment vigor, and salinity tolerance (Turgeon, 1999). Due to these inherent traits, bermudagrass is now a major turf species for lawns, parks, golf courses, athletic fields, and general utility turf in the Southern regions of the United States (Duble, 1989). The northern limit of bermudagrass adaptation is most influenced by a lack of cold tolerance and shorter growing seasons resulting in longer periods of winter dormancy. Therefore, its range is limited to the southern regions of the United States. Specifically, Duble (1996) states bermudagrass extends from New Jersey to Maryland, southward to Florida, and westward to Kansas and Texas. It can also proliferate in New Mexico, Arizona, and under irrigation in the major valleys of California (Duble, 1989).

Bermudagrass is best adapted to fine textured soils due to a higher cation exchange capacity and moisture holding capacity than coarse textured soils (Beard, 1973). Also, bermudagrass can tolerate a wide pH range (from 5.5 to 7.5) but performs best between pH 6.5 and 7.5 (Duble, 1989). Nitrogen fertility requirements of bermudagrass are high especially for quality turf; typical recommendations are 48.8 kg N ha^{-1} per growing month. However, the minimal nitrogen fertility that can be applied and still have an acceptable turf for golf course fairways is 24.4 kg ha^{-1} per growing month (Duble, 1996). Bermudagrass can persist at much lower nitrogen rates, but it will not be suitable as high quality turf without adequate nitrogen fertility and appropriate cultivar selection.

Bermudagrass has an extremely high light requirement due to inherent characteristics; therefore, growth is very poor in shaded conditions and slows considerably under shortened photoperiods. The species thrives when average daily temperatures are greater than 24° C while optimum bermudagrass photosynthetic activity occurs when daytime temperatures are between 35° C and 38° C (Duble, 1989). According to Duble (1989), soil temperatures are just as important as air temperatures for the growth and development of bermudagrass. Soil temperatures above 18° C are required for significant growth of roots, rhizomes, and stolons but optimum growth occurs when soil temperatures are at least 24° C. Annual precipitation rates for successful bermudagrass turf stands are between 63 cm yr^{-1} to 254 cm yr^{-1} (Duble, 1989). However, when annual precipitation is below 50.8 cm yr^{-1}, bermudagrass will survive under irrigation. Under very dry conditions, bermudagrass enters a semi-dormant state and has the capability to survive extreme droughts (Duble, 1989). Rhizomes of bermudagrass can lose 50 percent of their weight and still recover once a favorable growing environment returns (Duble, 1989).

As cooler temperature begin to arrive in the early fall, photoperiod decreases and bermudagrass enters a state of dormancy. Bermudagrass will continue to grow with nighttime temperatures as low as 1.1° C as long as daytime temperatures are near 21° C (Duble, 1989). However, when average daily temperatures drop below 10° C, growth stops and chlorophyll begins to degrade (Duble, 1996). Protein fractions within the plant change in composition and reserve carbohydrate storage increases, as starch, in the stolons, rhizomes, and roots for the winter months (Duble, 1989). After the arrival of the first killing frost, in the northern areas of it's adaptability, the grass turns a chlorotic brown straw color and enters a state of dormancy, however, roots and rhizomes of bermudagrass continue to grow several weeks after the leaves and stolons cease (Duble, 1989). The leaves and stems of bermudagrass remain dormant until average daily temperatures exceed 10° C for several days (Duble, 1996). If this brown appearance is not aesthetically pleasing, bermudagrass can be overseeded with an appropriate cool season species to provide color throughout the dormancy period. In the southern regions, as average temperatures drop and day length shortens, growth slows dramatically although a color change will not be visible.

The main environmental limit for bermudagrass, next to shade tolerance is susceptibility to cold temperature. A dormancy period is usually initiated with the onset of the first killing frost. Although, early autumn frosts can be followed by some leaf re-growth if periods of warm temperatures subsequently occur. Winterkill or injury can occur if extreme cold temperatures are present throughout the winter. Winterkill is primarily thought of as a gradual loss or thinning of bermudagrass turf and winter survival hinders the use of bermudagrass in the northern limits of adaptation (Chalmers and Schmidt, 1979). Winterkill occurs either as a direct result or indirect result of freezing temperatures (Fry, 1990) and can be caused by any number of factors. Factors affecting winterkill potential can include low temperature, winter moisture availability, length of dormancy, cultivar type, traffic, cultural practices, and turf age (Chalmers, 1978). Although bermudagrass is not a very cold tolerant species, newer cultivars have been developed over the years to increase the grasses ability to thrive in more northern climatic regions and may be the grass of choice in certain situations. Cultivars such as "Midiron", U-3, and "Vamont" have been developed and have been typically used in the more northern regions of bermudagrass adaptability.

Establishment

Some bermudagrass cultivars can be established from seed. However, those cultivars that are most suitable and preferred for fine turf situations are established by vegetative means. Some of these cultivars include Tifway, Tifgreen, Tifdwarf, Midiron, Tufcote, Vamont, Midlawn, Tifsport, and Quickstand. The choice of propagation method depends on cost, time, and availability of genetically pure planting materials (Turgeon, 1999). The principal environmental factors affecting establishment are temperature, moisture, light, wind, edaphology, and geography. All of these must be considered for successful establishment to occur (Watschke and Schmidt, 1992).

Seed

Until relatively recently, all bermudagrass cultivars for fine turf use were cloned and propagated vegetatively (Taliaferro, 1995). The primary bermudagrass for general seeding applications was 'Arizona Common', which is still popular in certain situations because of its low cost and quick establishment period (Puhalla et al., 1999). Over the past decade, efforts have increased to improve seeded bermudagrass cultivars. Today, a wide variety of improved bermudagrass seeded cultivars are being evaluated and marketed. Although, according to Puhalla et al. (1999), improved varieties carry a greater price per kilogram than the old standard variety ‘Arizona Common’. These cultivars offer substantially higher turf density and a finer leaf texture than ‘Arizona Common’ (Puhalla et al., 1999). Improved seed propagated bermudagrass varieties such as ‘Mirage’, ‘Jackpot’, and ‘Sundevil’ have arrived on the market through constant breeding efforts. However, even with all the advancements made to date with seeded propagation, the highest quality cultivars for fine turf situations are those established vegetatively by sod, sprigging, stolonizing, or plugging. Vegetative cultivars tend to offer superior density, finer leaf textures, fewer seed heads, and a tolerance for lower mowing (Puhalla et al., 1999).

Vegetative Establishment

Vegetatively established cultivars originated from interspecific hybridization of common bermudagrass (*Cynodon dactylon*) and African bermudagrass (*Cynodon transvaalensis*) (Puhalla et al., 1999). Crosses of these two species produce sterile plants; therefore, vegetative propagation is the only feasible way to establish these ‘improved” cultivars. Burton (1947) was the first to cross common bermudagrass and African bermudagrass, which resulted in ‘Coastal Bermudagrass’. ‘Coastal Bermudagrass’ is primarily used as a forage grass. Burton’s work led to the production of Tifgreen (328) and Tifway (419), both of which are dominant bermudagrasses in the southern United States (Fry, 1997). Today, numerous vegetatively established bermudagrasses exist and many fulfill certain niches. For example, certain cultivars extend bermudagrass northern limits of adaptation, such as cold-hardy types (Vamont and Midiron) and the extremely fine textured ultra dwarf bermudagrasses are used in golf course putting green situations. Some of the ultradwarf grasses can tolerate mowing to 0.31 cm or less and will provide a more desirable turf for putting greens in the deep south.

Sod

Rapid establishment of turfgrass is highly desirable to reduce the potential for soil loss by wind and water erosion and avert weed infestations, while allowing the site to be used as soon as possible (Reummele et al., 1993). Beard (1973) defines sodding as "a method of vegetative establishment where a mature, high quality turf is transplanted." Sodding produces the quickest stand of turf and all of the associated benefits (i.e. more immediate use, decrease erosion and runoff, etc.). However, sodding costs are greater than seed or sprig establishment especially when large areas are to be established. Also, an ample supply of sod for the desired cultivar may be unavailable; therefore, other vegetative material must be employed.

Sodding has greater versatility in the deep south because establishment is usually successful throughout the year, whereas, other vegetative materials can only be utilized during the spring and summer months to allow for the necessary establishment period (Rose et al., 1986). Sod can be installed when it is dormant, though, it is important to water the sod to allow roots to establish successfully (Rose et al., 1986). One benefit of dormant sodding is that less water is needed to establish the sod than in the summer months but a complete lack of water will lead to desiccation (Puhalla et al., 1999). To further prevent desiccation, sod edges should be tucked together tightly and the sod should be lightly topdressed (Turgeon, 1999). Due to the limited availability of cultivars, labor, and sod establishment cost, bermudagrass is typically established through other vegetative means, usually sprigging.

Plugging

Plugging, defined by Turgeon (1999), "is the planting of turf sections varying in size from small cores extracted during core cultivation to large plugs extracted with a cup cutter or similar device." Plugging of bermudagrass usually occurs during the optimum growing season and is far less prone from desiccation and drought stress than sprigging and stolonizing (Gary, 1967). Also, no special equipment is required to establish plugs. Plugging, however, is extremely labor intensive and used primarily for small renovations rather than large expanses of turf (Puhalla et al., 1999). When plugging, a typical establishment period is two months with applications of 24.4 kg N ha^{-1} wk^{-1} during the grow-in period (Puhalla et al., 1999). A study by Reummele et al. (1993) found that bermudagrass sprigs and plugs tend to establish during the same time period. Therefore, with the labor intensity of plugging, especially in large areas, sprigging and stolonizing are the most desirable method of bermudagrass establishment. Although, Mandi and Wyckoff (1953) found that sprigs typically establish more rapidly than plugs and Busey and Myers (1979) reported, plugging takes longer to establish because growth levels off as the plugs of turf become larger or more dense. This can be explained by self-inhibition through crowding (Busey and Myers, 1979). Therefore, it appears that smaller, more frequent divisions of vegetative propagules will lead to a more rapid establishment.

Sprigging

The most common method of establishment is to plant rhizome or stolon segments of bermudagrass, commonly know as sprigs in the industry (Mueller et al., 1992). A "sprig" is defined by Puhalla et al. (1999), as "a vegetative stem (a rhizome or stolon) that has multiple nodes that will initiate growth when properly planted." Sprigs are harvested by shredding harvested sod (Reumelle et al., 1993) or more commonly for large applications, by implementing a sprig harvester. Due to the extensive harvesting process and lack of adhering soil on the sprigs, they can desiccate rapidly and should be planted as soon as possible (Beaty, 1966). Also, sprigs should not be transported long distances because respiration of packaged propagules will cause temperatures to increase and can led to high mortality rates. Sprigs are often planted in furrows, by implementing a disc-like machine pulled behind a tractor to set the sprigs in the ground (Puhalla et al., 1999). However, they can also be broadcast on the soil surface, lightly topdressed and then rolled to provide adequate soil contact (Chalmers, 1998).

Typical establishment rates for sprigs range from 538 to 1614 bu ha^{-1}, however, rates in excess of 2690 bu ha^{-1} can be used if an even more rapid establishment is desired (Duble, 1989). A bushel is typically thought of in the industry as a shredded square yard (0.83 m^2) of sod. Sprig establishment is best performed when soil temperatures are at least 18.3° C. Depending on geographic location, planting times typically range from April 15 to August 15 (Puhalla et al., 1999). For rapid bermudagrass sprig establishment and rooting, soil temperatures of 21° C to 27° C are ideal (Beard, 1989). However, planting later into the summer can often increase the risk of winterkill (Reumelle et al., 1993). After the sprigs have been planted it is essential to keep the sprigs moist for the first few weeks to avoid excess sprig desiccation and mortality. When sprigging, a typical establishment period is 2 months with applications of 24.4 kg N ha^{-1} wk^{-1} during the grow-in period (Puhalla et al., 1999). However, industry standard practice (ISP) applies as much as 48.8 kg N ha^{-1} wk^{-1} to speed the grow-in period. Mowing should begin three to four weeks after planting to promote lateral development (Beard, 1989).

Another method of establishment, which is very similar to sprigging, is stolonizing. Using a vertical mower or flail mower creates stolons; therefore, rhizomes are not harvested and used in this process (Beard, 1982). Turgeon (1999) defines stolonizing as ‘broadcast sprigging, where the vegetative planting material is uniformly deposited on a moist, but not wet soil surface”. Establishment rates for stolonizing are similar to that recommended for sprigging. After distribution, stolons are either lightly topdressed or shallowly disced into the soil. Since desiccation of stolons is even higher than sprigs, Turgeon (1999) recommends stolonizing in .91 m to 1.2 m strips followed immediately by topdressing and light irrigation.

Weed control is essential during vegetative establishment as well as newly seeded areas. The only product on the market today that is recommended in the state of Virginia to provide excellent preemergent annual grass control during vegetative sprig establishment is oxadiazon (Ronstar) (Bigham, 1999). It provides excellent crabgrass (*Digitaria spp.*) and goosegrass (*Elusine indica*) control along with some broadleaf control (Puhalla et al.; 1999, Uva et al., 1997). It is classified as a pre-emergence herbicide that controls weeds by killing the young germinating seedlings as they come into contact with the herbicide so it actually possesses slight post-emergence activity (Anonymous, 1999). Oxadiazon is classified chemically in the group pyridazinones

(Ware, 1994). According to Ware (1994), upon uptake the herbicide inhibits the formation of chlorophyll, therefore, the weed leaves appear bleached shortly after germination. The compounds within the group of pyridazinones are known as the 'bleaching" herbicides, which have varied effects on the plant. They inhibit the Hill reaction and consequently photosynthesis; inhibit pigment formation (chlorophyll, carotene), and an uncoupling of photophosphorylation and electron transport in the photosynthetic process (Ware, 1994). As with many herbicides there is no single, easily identifiable mode of action. Oxadiazon has a LD50 of greater than 8000 mg kg^{-1}, therefore, is relatively non-toxic to humans but a caution label is required.

Nitrogen

Nitrogen is the elemental nutrient required in the greatest quantities by turfgrasses (Turgeon, 1999). It is an essential element for turfgrass establishment and maintenance and a managed turfgrass plant contains anywhere from 3 to 5 percent nitrogen on a dry weight basis (Turner and Hummel, 1992). Most soils do not contain enough plant available nitrogen to satisfy the nutritional needs of turfgrass systems. Therefore, nitrogen fertilization occurs frequently, especially when fine turf is desired. Grasses can also obtain nitrogen from decomposing organic matter (mineralization) and to a much lesser extent from the air. Generally, neither source provides enough nitrogen to adequately sustain turfgrass quality (Duble, 1996). Nitrogen is an essential component of proteins, amino acids, nucleic acids, enzymes, vitamins, and the chlorophyll molecule (Turgeon, 1999). Therefore, proper nitrogen nutrition is necessary for healthy turf systems while excess nitrogen applications can result in excessive shoot growth, reduced root and lateral shoot growth, reduced carbohydrate reserves, higher disease incidence, and reduced tolerance to heat, drought, traffic, cold, and other environmental stresses (Turgeon, 1999). Turf symptoms such as chlorosis, sluggish growth, low density, and severe incidence of certain diseases (rust, dollar spot, red thread), may indicate nitrogen deficiency that can often readily be corrected with supplemental nitrogen applications (Turner and Hummel, 1992).

Nitrogen Sources Used in Turfgrass Systems

Numerous fertilizer sources are applicable for turfgrass use. Compared to other fields of agriculture, there is a much larger group of available nitrogen sources for turf use. This is mainly due to economics, since many of the nitrogen sources used in turf would be prohibitively expensive for production-based agriculture (Christians, 1998). Turfgrass fertilizers are primarily classified into two separate categories: readily available and slowly available.

Readily available sources include the inorganic salts such as ammonium nitrate, ammonium sulfate, calcium nitrate, and potassium nitrate (Christians, 1998). These inorganic salts can be used effectively in turf situations; however, they have a very high burn potential and must be used with caution. Also, they tend to be hygroscopic, often making them difficult to apply (Christians, 1998). Because of these characteristics, synthetic readily available organic nitrogen sources are often employed in the turfgrass industry. Urea and calcium cyanide fall into this category. Unfortunately, calcium cyanide also has high burn potential and is rarely used as a turfgrass fertilizer (Christians, 1998).

Today, urea is the most dominant readily available nitrogen source in the turfgrass industry and contains 46 percent nitrogen, making it the most concentrated nitrogen source. To synthesize urea, ammonia and carbon dioxide react under pressure to form ammonium carbamate, which subsequently decomposes into ammonia and one molecule of urea (Follett et al., 1981). Ammonia is then recycled, combined with more carbon dioxide and urea is drawn off as a liquid (Follett et al., 1981).

Urea has many benefits, because of it's high nitrogen content it is inexpensive to ship, it's high water solubility (780 g L^{-1}) makes it desirable for tank mixing and fertigation, and it has a much lower burn potential than other readily available sources like ammonium nitrate (Turgeon, 1999). Ammonium nitrate has a salt index of 3.2 per unit of nitrogen whereas urea has a salt index of 1.7 per unit of nitrogen (Turgeon, 1999). However, there are numerous situations where urea's inherent water solubility and moderate burn potential do create concerns. In addition, its rapid plant availability poses volatilization, leaching, and runoff threats. Because of this, scientists have developed numerous ways to control the release of urea over time.

Slow release organic nitrogen sources are produced either by chemical reaction or encapsulation. Isobutyraldehyde Diurea (IBDU) and Ureaformaldehyde (UF) have slow release characteristics built in their chemical structure (Puhalla, 1999). Both are desirable due to their low burn potential and gradual nitrogen release over a long period of time (Christians, 1998). UF was first identified in 1948 and was formed by the chemical reaction of urea with formaldehyde. Depending on the length of the methyl chains, UF can have as much as 60 percent of the nitrogen in the cold-water insoluble form (CWIN) or as little as 25 percent in the CWIN form (Christians, 1998). Since UF depends on microbial activity for degradation, little release will occur when soil temperatures are below 10° C. IBDU is formed by the reaction of isobutyraldehyde and urea. When formulated in this fashion, it is 1000 times less soluble in water than urea itself and is not hygroscopic (Christians, 1998). IBDU breaks down through hydrolysis; therefore, it dissolves into the soil slowly and release is not a function of microbial activity.

Encapsulated nitrogen sources consist of soluble urea pellets encircled by less soluble coverings like sulfur or plastic (Christians, 1998). Originally developed by the Tennessee Valley Authority, sulfur coated urea (SCU) is the most popular and inexpensive way of encapsulating urea (Follett et al., 1981). The release mechanism of SCU depends upon water movement (hydrolysis) through micropores and cracks in the sulfur coating. Once water penetrates the granule, nitrogen release is rapid. In order to prevent all particles from releasing at the same time, typically sulfur coating thickness will vary to provide a slow release of nitrogen overtime. However, release from SCU can be unpredictable, because of cracks in the coating, if care is not taken during shipping, storage, or application.

The last group of slowly available nitrogen sources is the natural organics. Natural organics are gaining in popularity and are perceived as being more "environmentally friendly" by the public. Milorganite is the most popular organic fertilizer used in the turfgrass industry today. It is created in Milwaukee, WI by drying, heating, and granulating biosolids (Christians, 1998). Organic nitrogen sources are desirable because of their extremely low burn potential and slow uniform release, provided that soil temperatures are suitable for microbial activity. Milorganite also provides phosphorus, iron, and many micronutrients and leaching losses are negligible.

Research has reported lower disease and insect activity and less thatch accumulation when Milorganite was applied rather than soluble nitrogen sources (Duble, 1989). However, because it only contains 6 percent nitrogen by weight the product is extremely costly to ship and is often only used on putting greens or for other very fine turf situations. As a general rule relative to urea, SCU costs 2 times as much, UF and IBDU are 3 to 4 times greater, and organic sources (Milorganite) cost about 5 to 6 times greater (Duble, 1989).

Fate of Nitrogen Applied to Turfgrass Systems

Once nitrogen has been applied to the turfgrass plant-soil system it may be found in one of the nitrogen pools of nitrate, ammonium, soil organic nitrogen or in the turfgrass plant (Turgeon, 1999). Nitrogen undergoes many transformations in the plant-soil system. Ammoniacal and nitrate nitrogen forms add directly to the available nitrogen pool, while other forms are primarily transformed to NH_4 and NO_3 before plant uptake (Petrovic, 1990). Upon mineralization to the NH_4 cation species, nitrogen is further transformed to NO_3 through nitrification. Nitrification is a two-step process that is a function of soil microbial activity and is sensitive to a number of environmental conditions. Specifically, *Nitrosomonas,* an obligate autotrophic bacterium, obtain their energy from the oxidation of nitrogen thus converting the NH_4 species to NO_2 (Tisdale et al., 1993). Other bacteria can make this conversion; however, *Nitrosomonas* are the dominant species. Once in the NO_2 form, nitrite oxidation occurs by another autotrophic bacteria, *Nitrobacter*, which converts nitrite to nitrate (Tisdale et al., 1993). Nitrite oxidation usually occurs more rapidly than ammonium conversion; therefore, nitrite (which is toxic to plant roots) does not accumulate in the soil (Tisdale et al., 1993). Nitrification does not occur below freezing and is slow to occur in cool soils, compacted soils, very dry or wet soils, or high acid soils (Paul and Clark, 1996). Environmental conditions also affect mineralization of organic matter into the available nitrogen pool. For example, in compacted situations nitrification is often inhibited and ammonium tends to accumulate, causing volatilization losses to be excessive (Duble, 1989).

Whereas, nitrification can be extremely rapid in conditions ideal for microbial populations and available nitrogen is readily transformed into the nitrate form (Paul and Clark, 1996). Subsequently, the nitrate species, which is anionic in nature, is readily leached through most soil systems if precipitation or irrigation is excessive (Paul and Clark, 1996). Coarse textured soils are much more prone to leaching than fine textured soils because of their low water holding capacity and rapid infiltration rates. Leaching of nitrate nitrogen is a major environmental and health concern and will be discussed in more detail below. If large quantities of plant available nitrogen exist in the nitrate-N form and soil oxygen levels are low, alkaline conditions are present, high soil moisture or high temperatures exist nitrate can readily be lost through denitrification as long as a carbon source is present. As defined by Duble (1989), denitrification is the conversion of nitrate nitrogen to gaseous elemental nitrogen, which is lost to the atmosphere either as the N_2 or N_20 species.

Therefore, the balance of nitrogen in the turfgrass plant-soil system is essential to minimize nitrogen losses through the system while at the same time providing suitable growth and development of turfgrasses. Nitrogen can be made unavailable to the plant through immobilization during organic matter decomposition; and also lost through from the plant-soil system through leaching, principally as nitrate; clipping removal; and gaseous loss from volatilization of ammonia and denitrification to N_2 and N_20 (Turgeon, 1999). Increases in nitrogen pools occur from fertilization, deposition of nitrogen from the atmosphere, and mineralization (through microbial activity) of dead and decaying organic matter (Paul and Clark, 1996).

Perhaps the greatest environmental concern regarding nitrogen fertilization is potential nitrate nitrogen loss via leaching and runoff. Nitrate is inherently mobile in the soil and nitrate is considered the most widespread groundwater contaminate (Petrovic, 1990). Potential sources of nitrate pollution include effluent from cesspools and septic tanks, animal and human wastes, urban runoff, and losses of nitrogen from agricultural land uses (Pye et al., 1983, Keeney, 1986). Major concerns of nitrate contamination of ground and surface waters arise because nitrogen poses major human health and environmental risks.

Health concerns over nitrate contamination result when nitrate in drinking water supplies are elevated. Groundwater provides 50 percent of our drinking water and as much as 95 percent in rural areas, therefore, protecting groundwater from pollution is essential if we are to have safe drinking water in all areas (Petrovic, 1990). When there are high levels of nitrate in drinking water supplies, in combination with conditions favorable for nitrate reduction to nitrite, toxic effects are produced (Keeney, 1982). Nitrate is reduced to nitrite in the gastrointestinal tract and subsequently moves into the bloodstream and reacts with hemoglobin to produce methemoglobin (USEPA, 1976). This causes the transport of oxygen to be altered and can cause methemoglobinema or “blue-baby syndrome” in infants. Primarily, methemoglobinema only occurs in infants under three months old and can result in serious or fatal poisonings (USEPA, 1976). Because of this concern, the EPA has set 10 mg NO_3-N L^{-1} as the maximum concentration limit (MCL) for drinking water. According to Groover et al. (1997) this MCL was based on clinical studies but remains somewhat controversial. Petrovic (1989) states the lowest level recorded to cause health problems was 20 mg L^{-1}; however, very few cases of methemoglobinema have been documented recently. Other documented potential health effects from excess nitrate in drinking water include birth defects, cancer, and nervous system impairment (Petrovic, 1989).

Nitrate contamination of ground and surface waters also pose major environmental threats. Because nitrogen and phosphorus are limiting in aquatic systems, these nutrients increase the biological productivity of aquatic ecosystems (Balogh and Walker, 1992). This can be desirable in low productivity water bodies, but can cause major problems through excess plant and organism growth (Keeney, 1986). According to Keeney (1986), excess loading of nutrients into aquatic systems, and subsequent explosion of plant and algal growth is known as cultural eutrophication. As plant and algal growth increases, the organic matter produced eventually dies and decays decreasing valuable oxygen supplies necessary for aquatic organisms. Increased biological oxygen demand reduces the quality of fish habitat and can cause changes in fish populations to those that can thrive in low oxygen systems (Groover et al, 1997). However, oxygen can be completely depleted due to the decaying organic matter and lead to significant fish kills. Also, excess nitrogen and phosphorus cause algal blooms, which increases turbidity and reduces sunlight in the aquatic system. Algal blooms in water bodies also decrease the recreational appeal to the user. Not only do these algal blooms further contribute to oxygen depletion as they die and decay but they block out valuable sunlight that submerged aquatic vegetation (SAV) depend on. The problem is further compounded because the SAV dies and decays causing further oxygen depletion while fish habitat is simultaneously destroyed. Because of the health and environmental risks associated with nitrate contamination, sources need identification and remediation.

Leaching

Over the years, leaching from turfgrass fertilizers has been proposed to be a major source of nitrate contamination of ground and surface waters especially in suburban areas where turfgrasses are planted over a significant land area (Flipse et al., 1984). Numerous nitrogen loss studies have been done on established turf systems (Petrovic, 1990; Petrovic, 1993). Several methods have been utilized in studying leachate from fertilizer nitrogen (Petrovic, 1990). These include collection of drainage water, soil sampling, sampling of soil water above the saturated zone, trapping nitrate on ion exchange resins, and sampling shallow groundwater (Petrovic, 1990). Nitrate-N leaching from these numerous studies has been highly variable. Some research has suggested that as high as 80 percent of the fertilizer nitrogen is leached while others suggest very little (Petrovic, 1990). The primary factors affecting nitrogen leaching are soil type, irrigation regimes, nitrogen source, nitrogen rate, and season of application (Petrovic, 1990).

Brown et al. (1977) applied ammonium sulfate in a single application of 98 kg N ha^{-1} to bermudagrass putting greens on a sand-soil (80-20) mix. Leaching losses accounted for 16 percent of that applied and nitrate concentrations rose to greater than 60 mg L^{-1} for ten days and then dropped below the EPA MCL. In contrast, Snyder et al.

(1984) applied ammonium sulfate bi-monthly at 98 kg N ha^{-1} to bermudagrass on a sandy soil which was irrigated daily. Nitrate-N leaching losses accounted for 56 percent of the applied nitrogen and ranged from 6.2 to 18.9 mg L^{-1}. Brown et al. (1982) noted a 22 percent loss of ammonium nitrate as nitrate-N when nitrogen was applied at 163 kg ha^{-1} on bermudagrass with a USGA specification soil. However, in the same study only 9 percent of nitrogen applied was lost on a sandy loam soil. Leaching losses were excessive; however, nitrogen was applied at three times the normal rate. Furthermore, Snyder et al. (1981) fertilized bermudagrass sand greens with 78 kg ha^{-1} of urea bi-monthly and leaching losses were negligible and accounted for 1 percent of applied nitrogen.

Liquid and granular urea applications were compared on a sandy loam soil that had been sodded with tall fescue (*Festuca arundinacea)*/Kentucky bluegrass (*Poa pratensis)* sod (Gross et al., 1990). Urea was applied at a rate of 220 kg N ha^{-1} yr^{-1}. Nitrate collected at the 75 cm depth varied between 0 and 3.2 mg L^{-1}. Mancino and Troll (1990) applied a single application (48.8 kg N ha^{-1}) with equal nitrogen rate and identical irrigation. Calcium nitrate and ammonium nitrate produced elevated nitrogen levels (41 and 71 mg L^{-1}, respectively), however urea, ammonium sulfate, and urea formaldehyde, produced leaching levels that were less than 1 mg L^{-1}; equal to or less than the controls. Snyder et al (1981) compared leaching losses of readily available nitrogen sources (Urea and Calcium Nitrate) vs. slow release nitrogen sources (isobutylenediurea, methylene urea, urea formaldehyde, and sulfur coated urea), on a sandy soil with frequent irrigation and abundant rainfall in Florida. Nitrogen was applied bi-monthly, throughout the study at 40 and 80 kg ha^{-1} to established bermudagrass. Nitrate-N concentrations were highest using calcium nitrate (2.4 mg L^{-1}); however, levels were not elevated above EPA's MCL. Leaching losses from urea were even lower, attributed to volatilization of surface applied nitrogen. At the high rate of IBDU, in which nitrogen is released through hydrolysis, nitrate-N concentrations were 1.4 mg L^{-1}. All other nitrogen sources produced lower rates of nitrate-N. Slow release fertilizers at the 80 kg N ha^{-1} rate produced acceptable turfgrass quality with little leaching.

Much of the research that has been completed on nitrogen losses through turfgrass fertilization has been conducted using various sources in worst-case scenarios (Groover et al., 1997). In general, as the rate of nitrogen increases the percent applied that leaches decreases; however, the amount of nitrate-N leaching on an area basis increases (Petrovic, 1990). Leaching of fertilizer-applied nitrogen to turfgrass is highly influenced by soil texture, nitrogen source, rate and timing, and amount of irrigation/rainfall (Petrovic, 1990). Applying nitrogen at excessive rates on a sandy soil that is highly irrigated can cause significant leaching (Brown et al., 1977). However, nitrate-N leaching from turfgrass can be significantly reduced or eliminated by limiting irrigation to only satisfy the needs of the plant, using slow-release sources, and proper application timing (Petrovic, 1990). In general, leaching of turfgrass fertilizers has been well studied; however, research must continue with numerous nitrogen sources to be able to predict the potential of leaching dependant upon soil type, irrigation rate, time of year, geographic locale etc. There have been numerous nitrogen loss studies on established turf systems; however, few studies have addressed quantifying nitrate-N loss during turfgrass establishment.

Runoff

Once nitrogen has been applied to turfgrass it can also contaminate surface and ground water via runoff. Runoff occurs when precipitation or irrigation exceeds the infiltrative capacity of the soil (Hino et al., 1987). Turfgrass has been reported to slow runoff velocity, increase uptake of rainfall and irrigation waters, and improve soil infiltration rates. Turfgrass provides such a dense stand of plant material that runoff is difficult due to the tortuous path of water through the turfgrass stand. In a study by Morten et al. (1988) in Rhode Island, on an established turfgrass site, only two natural events led to runoff of any water over the two-year study period. One precipitation event occurred when the ground was frozen and the other on soils that received 12 cm of precipitation in one week and already possessed a high antecedent soil moisture content. The concentration of nitrate-N in the runoff was 1.1 mg L^{-1} and 4.2 mg L^{-1} respectively; well below EPA's MCL. Wauchope et al. (1990), evaluated runoff from established turfgrass versus a bare plot using simulated rainfall. It was found that the amount of precipitation required to initiate runoff from the grassed plots was twice that of the bare plots suggesting that bare slopes would produce much more runoff than grassed areas. A study by Watschke et al. (1989), on established turfgrass growing on a silt loam soil with 9 to 14 percent slopes, only noted one natural precipitation event that led to runoff over the two-year study period. Watschke et al. (1989) concluded that the results indicate that dense, high quality turfgrass stands, regardless of establishment method led to an insignificant amount of runoff. He suggests that turfgrass may be a valuable tool as a water quality treatment medium because of turf's inherent abilities to allow water to infiltrate rapidly and metabolize solutes (Watschke, 1989). Runoff of established turfgrass sites has proved insignificant unless site conditions are favorable for runoff such as: unhealthy turf density, compaction, or high antecedent soil moisture. According to Harrison (1993), consistently small runoff volumes and low frequency of natural runoff events are a common theme within all studies to date. However, studies on turf systems as they are becoming established are lacking and should be addressed to minimize nutrient loss via runoff. During establishment turf density is low and the potential for nutrient loss from fertilizer applications could be excessive.

Fertigation

Fertigation, as defined by Turgeon (1999), is the application of fertilizer using the irrigation system. Fertigation is desirable because it provides a very even dispersal of nitrogen over an area and if implemented properly can decrease leaching losses (Busey and Parker, 1992). Fertigation is gaining in popularity in the turfgrass industry, especially in golf course situations (Perrault, 1998). There are numerous advantages to fertigation. Fertigation can be used on a daily basis to slowly feed the turf overtime (Synder et al., 1989). This tends to decrease the intermittent response associated using periodic granular applications and proves to be much more economical than slow release sources while still producing a desirable turfgrass response. Snyder et al. (1989) found that nitrogen fertigation stabilized turfgrass nitrogen nutrition overtime while providing a uniform nitrogen response. Also, fertigation is ideal for allowing very low nutrient rates to be applied evenly over the soil surface; a process commonly referred to in turfgrass management circles as “spoonfeeding”. Fertigation is also desirable in establishment situations because you can slowly feed the newly germinated or sprigged area without having to traverse the site.

Using fertigation decreases labor, decreases storage space, can reduce leaching, and the turfgrass plant can more efficiently utilize applied nitrogen (Snyder et al., 1989). Snyder et al. (1980) evaluated leaching from bermudagrass on a sandy soil in southern Florida. Comparisons were made between daily fertigation vs. tri-weekly fertilization using 5 g N m^{-1} $month^{-1}$ of ammonium nitrate. Nitrogen leaching was 50 percent higher in the conventionally fertilized plots than those fertigated when irrigation or rainfall occurred shortly after plot fertilization. However, leaching losses from fertigation existed as well especially when excessive irrigation or rainfall occurred. In another study by Snyder et al. (1984), bermudagrass was fertilized through fertigation using 5 g N m^{-1} $month^{-1}$. However, fertilizer was applied either daily or using moisture sensor controlled tensionmeters. It was found that by using fertigation and moisture sensor controlled irrigation that nitrate-N leaching could be reduced. Fertigation, if implemented correctly, can decrease fertilizer costs, labor costs, and leaching while providing adequate nutrition for turfgrass growth and development.

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Chapter 1

Effects of Reduced Early Post-Sprigging Nitrogen Application on Bermudagrass Sprig Establishment

Introduction

Bermudagrass (*Cynodon dactylon*) is the dominant turfgrass used for fine turf situations in the southern United States. It is the primary turfgrass species used on home lawns, athletic fields and golf course tees, fairways, and roughs in the southern United States. Most improved turf-type bermudagrass cultivars are typically established vegetatively, by sod, plugs, or sprigs, rather than from seed because of low quantities of viable hybrid seed (Duble, 1989). The most common method of vegetative establishment is to plant bermudagrass rhizome or stolon segments, commonly referred to as sprigs. Puhalla et al. (1999) define a "sprig" as "a vegetative stem (a rhizome or stolon) that has multiple nodes that will initiate growth when properly planted." Sprigs are often planted in furrows by a disc-like machine for large applications or they can be broadcast on the soil surface, lightly topdressed and then rolled to provide adequate soil contact (Chalmers, 1998). Typically, establishment rates of bermudagrass range from 538 bu ha^{-1} to 1614 bu ha^{-1}; however, rates in excess of 1614 bu ha^{-1} can be used if a more rapid establishment is desired (Duble, 1989).

Sprig establishment is best suited when soil temperatures are at least 18.3° C and ideal growth and development of bermudagrass occurs when soil temperatures are between 21° C to 27° C (Beard, 1982). Therefore, unless a rapid grow-in is not desired, bermudagrass sprigs should not be planted until soil temperatures are adequate for rapid growth and development. However, sprigs should not be planted too late in the season since late plantings can often increase the risk of winterkill in the cooler regions of bermudagrass adaptation (Reumelle et al., 1993). Once sprigging has occurred, the rhizome and stolon segments must be kept moist the first few weeks until adequate rooting develops. If not, sprigs will desiccate rapidly and sprig mortality will be great, which will hinder establishment success (Beaty, 1966). A typical establishment period is approximately 2 months with applications of 24.4 kg N ha^{-1} wk^{-1} during the grow-in period (Puhalla et al., 1999). However, turf managers typically apply 48.8 kg N ha^{-1} wk^{-1} from a water-soluble nitrogen source to promote rapid sprig development and growth (Chalmers, 1998).

Nitrate contamination of ground and surface waters is a major concern in the United States and nitrate is considered the most widespread groundwater contaminate (Petrovic, 1990). Research continues within many disciplines to identify, quantify, and mediate sources of nitrate-N into our water resources. Numerous nitrogen loss studies have occurred on established turf systems; however, nitrogen loss from establishing turfgrass systems also needs to be addressed (Petrovic, 1990). An opportunity to evaluate a possible source of nitrate contamination exists during bermudagrass sprig establishment. Large quantities of soluble nitrogen are applied to promote a rapid establishment. However, during the first few weeks of establishment root systems are beginning to develop (using reserve carbohydrates) and there are very few plants per unit area. The potential for nitrogen loss via runoff and leaching is great. By examining nitrogen fertilization requirements during bermudagrass sprig establishment, the potential exists to minimize nitrogen leaching without compromising sprig growth and development.

Objectives

The objective of this study was to:

1) To evaluate early post-sprigging nitrogen requirements during bermudagrass sprig establishment and subsequent establishment success.

Materials and Methods (1998 and 1999)

Field studies were conducted at the Turfgrass Research Center in Blacksburg, Virginia on two separate adjacent sites in the summer of 1998 and 1999. A Groseclose silt loam (fine, mixed, mesic Typic Hapludult) on an east-facing slope ranging from 2 to 7 percent was used for this study. Each approximately 745 m^2 site was sprayed with Glyphosate (Roundup Pro) at 1.4 kg a.i. ha^{-1} in two directions approximately 2 months prior to sprigging. After glyphosate had taken effect, each area was tilled and allowed to lay fallow until sprigging. Initial soil test results (analyzed by the Virginia Tech soil testing laboratory) for the 1998 site reported pH = 6.2, P = 45 ppm (H+), K = 104 ppm (H-), Ca = 598 ppm (M), Mg = 101 ppm (H+). Initial soil test results (analyzed by the Virginia Tech soil testing laboratory) for the 1999 site reported pH = 6.5, P = 100 ppm (VH), K = 46 ppm (M-), Ca = 750 ppm (H-), Mg = 120 ppm (VH).

In both years, Tifway 419 Bermudagrass sprigs were obtained from Piedmont Turf in Maiden, NC and were packaged into 16 equal sized burlap bags for transportation to the Turfgrass Research Center. During sprigging, the following day, each 745 m^2 area was divided into sixteen equal parts and each bag was then broadcast on the soil surface. After four bags of sprigs were broadcast across a row, the sprigs were lightly tilled under to provide adequate soil contact and then rolled using a Brillion Seeder. After rolling, each row of four sections was immediately watered to minimize sprig desiccation. This procedure was repeated three more times until all sixteen sections of the study area were uniformly sprigged, tilled, rolled, and watered-in. Sprigging took place on July 8, 1998 and July 22, 1999 at a rate of 43.5 bu ac^{-1} (1076 bu ha^{-1}). In 1999, a first sprigging took place on July 1, 1999, however, temperatures were excessively high, weed germination was excessive, and irrigation did not occur frequently enough. Sprig mortality and competition were very high, therefore, it was decided to resprig. In both years, just after sprigging each 745 m^2 site, Oxadiazon (Ronstar) was applied using a Scott's Professional Drop Spreader calibrated to apply 1.68 kg a.i. ha^{-1} to control summer annual grasses and other annual weeds.

Plots were established one week after sprigging by dividing each area into 4 replications of 27 different nitrogen treatments (Table 1.1). Each treatment was 1.8 m^2 with a .3 m wide buffer strip surrounding each plot. Also, a .9 m wide buffer strip separated each replication. The buffer strips were employed to reduce potential nitrogen runoff into adjacent plots and/or replications. Plots were arranged in each replication using a randomized complete block design.

Nitrogen application rates ranged from 4.9 kg N ha^{-1} wk^{-1} to 48.8 kg N ha^{-1} wk^{-1} using Urea (46-0-0) and continued for eight weeks (Table 1.1). The Industry Standard Practice (ISP) was considered to be 48.8 kg N ha^{-1} wk^{-1}. Urea was dissolved in water and spray applied (using a Wheelie Sprayer calibrated to deliver 407 L ha^{-1}) bi-weekly and

Table 1.1 Nitrogen Treatments (kg ha^{-1}) for 1998 and 1999 Bermudagrass Sprig Establishment Field Studies in Blacksburg, Virginia.

Treatment	Weeks 1 to 2	Weeks 3 to 4	Weeks 5 to 6	Weeks 7 to 8	Total Nitrogen Applied
1	0	0	0	0	0
2	4.9	4.9	4.9	4.9	39.0
3	4.9	4.9	9.8	9.8	58.6
4	4.9	4.9	19.5	19.5	97.6
5	4.9	4.9	39.0	39.0	175.7
6	4.9	4.9	48.8	48.8	214.7
7	4.9	9.8	9.8	9.8	68.3
8	4.9	9.8	19.5	19.5	107.4
9	4.9	9.8	39.0	39.0	185.4
10	4.9	9.8	48.8	48.8	224.5
11	4.9	19.5	19.5	19.5	126.9
12	4.9	19.5	39.0	39.0	205.0
13	4.9	19.5	48.8	48.8	244.0
14	4.9	39.0	39.0	39.0	244.0
15	4.9	39.0	48.8	48.8	283.0
16	9.8	9.8	9.8	9.8	78.1
17	9.8	9.8	19.5	19.5	117.1
18	9.8	9.8	39.0	39.0	195.2
19	9.8	9.8	48.8	48.8	234.2
20	9.8	19.5	19.5	19.5	136.6
21	9.8	19.5	39.0	39.0	214.7
22	9.8	19.5	48.8	48.8	253.8
23	9.8	39.0	39.0	39.0	253.8
24	9.8	39.0	48.8	48.8	292.8
25	9.8	48.8	48.8	48.8	312.3
26	48.8	48.8	48.8	48.8	390.4
27*	0	0	48.8	48.8	195.2

* In 1998, treatment 27 was also a control.

then lightly watered in to simulate fertigation. Each area was irrigated twice daily during the first few weeks to reduce sprig desiccation and mortality. Irrigation was applied as needed after bermudagrass sprigs established. To help promote lateral sprig growth and development each area was mowed with a reel mower (Toro, Reelmaster 2300-D) at 2.0 cm two to three times per week once mowing was deemed necessary. Bi-weekly nitrogen applications continued for an eight-week period (Table 1.1).

Data Recorded

In 1998 and 1999, observations recorded throughout the bermudagrass establishment period consisted of percent bermudagrass cover after four weeks of nitrogen treatment and percent bermudagrass cover, turf density, and turf color eight and ten weeks after nitrogen applications began. Also, final biomass was determined from each plot. Percent bermudagrass cover was recorded on a scale from 0 to 100 (0 = no bermudagrass and 100 = total bermudagrass cover). Density was recorded on a scale of 1 to 9 (1 = no turf and 9=dense, uniform turf). Density was recorded at weeks eight and ten when the bermudagrass was established enough to visually see differences in varying turfgrass density. A rating of 5 was indicative of acceptable turfgrass density for a golf course fairway. Turf color was recorded on a scale of 1 to 9 (1 = brown turf and 9 = dark green turf). A rating of 5 was indicative of acceptable turfgrass color for a golf course fairway. Turf color was only recorded at weeks eight and ten because at week four color differences were not apparent. In both years biomass was determined eleven weeks after sprigging and consisted of randomly removing two 15.24 cm plugs from each plot and removing top growth. Top growth was then oven dried and weighed. All data was subjected to analysis of variance (ANOVA) procedure using the SAS system (SAS, 1985). Treatment means were compared using Tukey's studentized range test at the 0.05 level of probability.

1998 Results and Discussion

Mean daily temperatures during the months of July, 1998 through October, 1998 were slightly warmer than the thirty year mean daily normal temperatures (Table 1.2). In all months of the grow-in it is important to note that temperatures are still below that necessary for ideal bermudagrass growth and development (24°C) to occur (Duble, 1989).

Nitrogen Treatment Effect on Percent Cover

Four weeks after nitrogen treatments began, significant differences were not found with respect to percent bermudagrass cover (Table 1.3). All treatments, including the control, achieved percent cover ratings similar to the ISP (Table 1.3). In 1998, it is apparent that the ISP of 48.8 kg N ha^{-1} wk^{-1} was certainly not necessary to achieve similar percent cover after four weeks of sprig development. At this stage of development, sprigs have immature roots systems and there is little plant material per unit area, therefore, the ISP nitrogen rate may be excessive and unnecessary under the soil conditions of this study. In 1998, during early post-sprigging establishment, it was possible to apply little if any nitrogen while still achieving percent cover similar to the ISP.

Table 1.2 Thirty Year Mean Daily Temperature (^{0}C) Normals and and Mean Daily Temperatures (^{0}C) for 1998 in Blacksburg, Virginia.

Month	1998	
	Mean Normal	Mean Daily
July	21.7	22.2
August	20.9	21.8
September	17.3	17.6
October	11.1	11.2

Table 1.3 Effect of Nitrogen Regime on Percent Cover During the 1998 Bermudagrass Sprig Establishment Field Study in Blacksburg, VA.

Treatment	Nitrogen applied			Percent Cover		
	Weeks 1-4	Weeks 5-8	Total	Week 4	Week 8	Week 10
	---------------kg ha^{-1}-----------------					
1	0.0	0.0	0.0	48.8 NS[2]	73.8 bcd[1]	77.5 c
2	19.5	19.5	39.0	47.5	71.3 cd	77.5 c
3	19.5	39.0	58.6	53.8	85.8 abcd	92.5 abc
4	19.5	78.1	97.6	55.0	85.0 abcd	90.0 abc
5	19.5	156.2	175.7	53.8	93.8 abc	95.0 abc
6	19.5	195.2	214.7	48.8	97.0 ab	99.5 ab
7	29.3	39.0	68.3	48.8	80.8 abcd	90.0 abc
8	29.3	78.1	107.4	47.5	92.0 abc	93.8 abc
9	29.3	156.2	185.4	52.5	98.8 ab	98.8 ab
10	29.3	195.2	224.5	55.0	97.5 ab	100.0 a
11	48.8	78.1	126.9	61.3	95.8 ab	100.0 a
12	48.8	156.2	205.0	52.5	96.3 ab	97.5 ab
13	48.8	195.2	244.0	57.5	97.5 ab	97.0 ab
14	87.8	156.2	244.0	56.3	97.5 ab	98.3 ab
15	87.8	195.2	283.0	56.3	99.5 ab	99.5 ab
16	39.0	39.0	78.1	51.3	86.3 abcd	91.3 abc
17	39.0	78.1	117.1	52.5	87.5 abcd	98.3 ab
18	39.0	156.2	195.2	48.8	96.3 ab	98.8 ab
19	39.0	195.2	234.2	55.0	98.3 ab	99.5 ab
20	58.6	78.1	136.6	60.0	97.8 ab	100.0 a
21	58.6	156.2	214.7	62.5	100.0 a	100.0 a
22	58.6	195.2	253.8	61.3	99.5 ab	100.0 a
23	97.6	156.2	253.8	60.0	98.8 ab	100.0 a
24	97.6	195.2	292.8	62.5	100.0 a	100.0 a
25	117.1	195.2	312.3	62.5	100.0 a	100.0 a
26	195.2	195.2	390.4	68.8	100.0 a	100.0 a
27	0.0	0.0	0.0	53.8	78.8 bcd	81.3 bc

[1] Means in the same column followed by the same letter are not significantly different according to Tukey' s Studentized Range test at the 0.05 level of probability.

[2] NS= Not significant according to Tukey' s Studentized Range test at the 0.05 level of probability.

After eight weeks, when nitrogen treatments ended, significant differences in percent cover were apparent (Table 1.3). However, only the control and the treatment receiving the least amount of nitrogen had significantly lower percent cover than the ISP treatment (Table 1.3). More importantly, is that all treatments which received low nitrogen early, even as little as 19.5 kg N ha^{-1} total during the first four weeks, followed by high rates of nitrogen during the last four weeks of treatments (39.0 kg N ha^{-1} wk^{-1} or 48.8 kg N ha^{-1} wk^{-1}) tended to achieve the greatest overall percent cover (Table 1.3). Therefore, high nitrogen rates were not necessary during the first four weeks but were more appropriate during the last four weeks when root systems are more established and bermudagrass density is greater, thus, increasing nitrogen uptake.

Even though nitrogen applications ended at week eight, plots were visually rated at week ten to evaluate further bermudagrass growth and development. Percent cover at week ten was very similar to that at week eight (Table 1.3). Certainly, in 1998, the ISP of 48.8 kg N ha^{-1} wk^{-1} was not necessary to achieve adequate percent cover after ten weeks on this silt loam site. Once again, the general trend of applying low rates of nitrogen during the first four weeks of grow-in, followed by greater nitrogen rates during the last four weeks of grow-in, when the potential for nitrogen uptake is greater, appears to be very successful for sprig establishment on this silt loam soil. In 1998, this nitrogen regime tended to produce the greatest and most consistent percent cover ratings.

Nitrogen Treatment Effects on Turfgrass Color

With respect to turfgrass color, visual differences occurred after eight weeks of nitrogen treatments (Table 1.4). All treatments receiving 107.4 kg N ha^{-1} total or greater

Table 1.4 Effect of Nitrogen Regime on Turfgrass Color During the 1998 Bermudagrass Sprig Establishment Field Study in Blacksburg, VA.

Treatment	Nitrogen Applied			Turfgrass Color[2]	
	Weeks 1-4	Weeks 5-8	Total	Week 8	Week 10
	-----------------kg ha^{-1}	-----------------			
1	0.0	0.0	0.0	4.3 f[1]	4.5 d
2	19.5	19.5	39.0	4.8 def	4.5 d
3	19.5	39.0	58.6	5.5 abcdef	5.5 bcd
4	19.5	78.1	97.6	5.3 bcdef	6.0 abc
5	19.5	156.2	175.7	6.3 abcd	6.5 ab
6	19.5	195.2	214.7	6.8 ab	7.0 a
7	29.3	39.0	68.3	5.0 cdef	5.0 cd
8	29.3	78.1	107.4	5.8 abcdef	6.3 abc
9	29.3	156.2	185.4	6.5 abc	7.0 a
10	29.3	195.2	224.5	6.8 ab	7.0 a
11	48.8	78.1	126.9	6.0 abcde	6.8 ab
12	48.8	156.2	205.0	5.8 abcdef	6.5 ab
13	48.8	195.2	244.0	6.3 abcd	7.0 a
14	87.8	156.2	244.0	6.3 abcd	6.8 ab
15	87.8	195.2	283.0	6.5 abc	7.0 a
16	39.0	39.0	78.1	5.0 cdef	6.0 abc
17	39.0	78.1	117.1	5.8 abcdef	6.0 abc
18	39.0	156.2	195.2	6.3 abcd	6.8 ab
19	39.0	195.2	234.2	6.8 ab	6.8 ab
20	58.6	78.1	136.6	6.5 abc	6.8 ab
21	58.6	156.2	214.7	7.0 a	7.0 a
22	58.6	195.2	253.8	6.5 abc	7.0 a
23	97.6	156.2	253.8	6.8 ab	7.0 a
24	97.6	195.2	292.8	7.0 a	7.0 a
25	117.1	195.2	312.3	6.5 abc	7.3 a
26	195.2	195.2	390.4	7.0 a	7.3 a
27	0.0	0.0	0.0	4.5 ef	5.0 dc

[1] Means in the same column followed by the same letter are not significantly different according to Tukey' s Studentized Range test at the 0.05 level of probability.

[2] Turf Color data was recorded on a 1 to 9 scale (1=brown turf, 5=acceptable, 9=dark green turf)

had color indices similar to the ISP treatment (Table 1.4). The general trend of low nitrogen during the first four weeks, followed by either 39 kg N ha^{-1} wk^{-1} or 48.8 kg N ha^{-1} wk^{-1} during the last four weeks generally achieved the most desirable color indices (Table 1.4). It is important to note that virtually all plots receiving any supplemental nitrogen had color values suitable for golf course fairways (Table 1.4). Also, all treatments that possessed suitable percent cover after the eight week nitrogen treatment period had color values of 5.0 or greater (Table 1.4). A turfgrass color rating of 5.0 may be statistically lower than the ISP color rating but is an acceptable rating for turfgrass color.

Color values were virtually identical from week eight to week ten. At week ten most plots that received 185.4 kg N ha^{-1} total or greater had color ratings similar to the ISP treatment (48.8 kg N ha^{-1} wk^{-1}) (Table 1.4). As in the eight week ratings, it is important to note that all but one plot receiving supplemental nitrogen had color values suitable for golf course fairways, and this treatment received the lowest amount of total applied nitrogen (Table 1.4). Also, all treatments that possessed suitable percent cover at the ten week establishment date had color values of 5.5 or greater (Table 1.4). A turfgrass color rating of 5.5 may be statistically lower than the ISP color rating but is more than an acceptable rating for turfgrass color. However, lower color ratings would indicate nitrogen being less available which could inhibit establishment but in this case it appears to not hinder development. It is important to note that many treatments receiving less nitrogen than the ISP treatment had similar color ratings which may indicate acceptable establishment if all other traits are non-limiting. Once again, the general trend of low nitrogen during the first four weeks, followed by either 39 kg N ha^{-1} wk^{-1} or 48.8

kg N ha^{-1} wk^{-1} during the last four weeks achieved very desirable color indices. All of these treatments had ratings of 6.5 or greater, which is a very desirable turfgrass color (Table 1.4).

Nitrogen Treatment Effects on Turfgrass Density

Density of the turfgrass stand is important in determining when a turfgrass stand is to be used following grow-in. As would be expected, very low total applied nitrogen tended to produce the lowest density ratings (Table 1.5). Treatments receiving higher rates of total applied nitrogen still exhibited density indices similar to the ISP treatment. All treatments receiving 292.8 kg N ha^{-1} total or greater exhibited turfgrass density similar to the ISP treatment (Table 1.5). Density values suitable for golf course fairways were achieved in all treatments receiving 107.4 kg N ha^{-1} total, a 72 percent reduction in total applied nitrogen (Table 1.5). The general trend of low nitrogen during the first four weeks, followed by either 39 kg N ha^{-1} wk^{-1} or 48.8 kg N ha^{-1} wk^{-1} during the last four weeks achieved very desirable density indices. All but one of these treatments had density ratings of 6.3 or greater (Table 1.5).

Many statistical differences were evident in the ten week density ratings and turfgrass density indices were more variable than turfgrass color or percent cover ratings. For example, some treatments only receiving 175.7 kg N ha^{-1} total had similar results compared to the ISP treatment, whereas, other treatments that received 292.9 kg N ha^{-1} total possessed lower density ratings (Table 1.5). However, all treatments receiving greater than 78.1 kg N ha^{-1} total possessed density values acceptable for golf course fairways (Table 1.5). Also, all but one treatment, which received 78.1 kg N ha^{-1} total, that

Table 1.5 Effect of Nitrogen Regime on Turfgrass Density During the 1998 Bermudagrass Sprig Establishment Field Study in Blacksburg, VA.

Treatment	Nitrogen Applied			Turfgrass Density[2]	
	Weeks 1-4	Weeks 5-8	Total	Week 8	Week 10
	-----------------kg ha^{-1}----------------				
1	0.0	0.0	0.0	4.3 j[1]	4.3 d
2	19.5	19.5	39.0	4.3 j	4.3 d
3	19.5	39.0	58.6	4.8 ij	5.5 abcd
4	19.5	78.1	97.6	4.8 ij	5.5 abcd
5	19.5	156.2	175.7	6.8 bcde	6.5 abcd
6	19.5	195.2	214.7	6.3 defg	6.8 abc
7	29.3	39.0	68.3	5.5 ghi	4.8 cd
8	29.3	78.1	107.4	6.5 cdef	5.5 abcd
9	29.3	156.2	185.4	7.0 abcd	7.0 abc
10	29.3	195.2	224.5	7.0 abcd	6.3 bcd
11	48.8	78.1	126.9	5.8 fgh	6.5 abcd
12	48.8	156.2	205.0	5.0 hij	5.8 abcd
13	48.8	195.2	244.0	7.0 abcd	6.8 abc
14	87.8	156.2	244.0	6.8 bcde	6.0 abcd
15	87.8	195.2	283.0	6.5 cdef	7.0 abc
16	39.0	39.0	78.1	5.5 hij	4.8 cd
17	39.0	78.1	117.1	5.5 hij	5.0 bcd
18	39.0	156.2	195.2	6.0 efg	6.3 abcd
19	39.0	195.2	234.2	7.5 ab	6.3 abcd
20	58.6	78.1	136.6	6.3 defg	6.5 bcd
21	58.6	156.2	214.7	6.3 defg	6.8 abc
22	58.6	195.2	253.8	6.8 bcde	6.5 abcd
23	97.6	156.2	253.8	6.5 cdef	7.0 abc
24	97.6	195.2	292.8	6.5 cdef	7.5 a
25	117.1	195.2	312.3	7.3 abc	7.3 ab
26	195.2	195.2	390.4	7.8 a	7.8 a
27	0.0	0.0	0.0	4.3 j	4.3 d

[1] Means in the same column followed by the same letter are not significantly different according to Tukey' s Studentized Range test at the 0.05 level of probability.

[2] Turf Density was recorded on a 1 to 9 scale (1=no turf, 5=acceptable, 9=dense, uniform turf)

had percent cover values similar to the ISP after the ten week grow-in had acceptable density values. The general trend of low nitrogen during the first four weeks, followed by either 39 kg N ha^{-1} wk^{-1} or 48.8 kg N ha^{-1} wk^{-1} during the last four weeks achieved very desirable density indices at the ten week rating. All of these treatments had ratings of 5.8 or greater, which is more than acceptable turfgrass density (Table 1.5). Furthermore, if additional turfgrass density is desired, supplemental nitrogen applications after the sprig establishment period could thicken the turfgrass stand without adding excess nitrogen during establishment.

Nitrogen Treatment Effects on Biomass

On October 9, 1998, biomass was sampled to quantify the effects of varying nitrogen applications on bermudagrass top growth production. In general, total biomass (top growth) increased as nitrogen application rate increased (Figure 1.1). However, all treatments except the control and the treatment receiving the least amount of total applied nitrogen exhibited biomass similar to the ISP treatment (Table 1.6). As a general trend treatments which received low nitrogen during the first four weeks, followed by 39 kg N ha^{-1} wk^{-1} or 48.8 kg N ha^{-1} wk^{-1} during the last four weeks, tended to produce the greatest biomass (Table 1.6). By observing the variability of visual density indices at week ten, biomass (a measure of turfgrass density) also exhibited that same variability. Post establishment supplemental nitrogen applications may enhance turfgrass density without increasing nitrogen required for sprig establishment.

Figure 1.1 Effect of Nitrogen Regime on Biomass Production for the 1998 Bermudagrass Sprig Establishment Field Study in Blacksburg, VA.

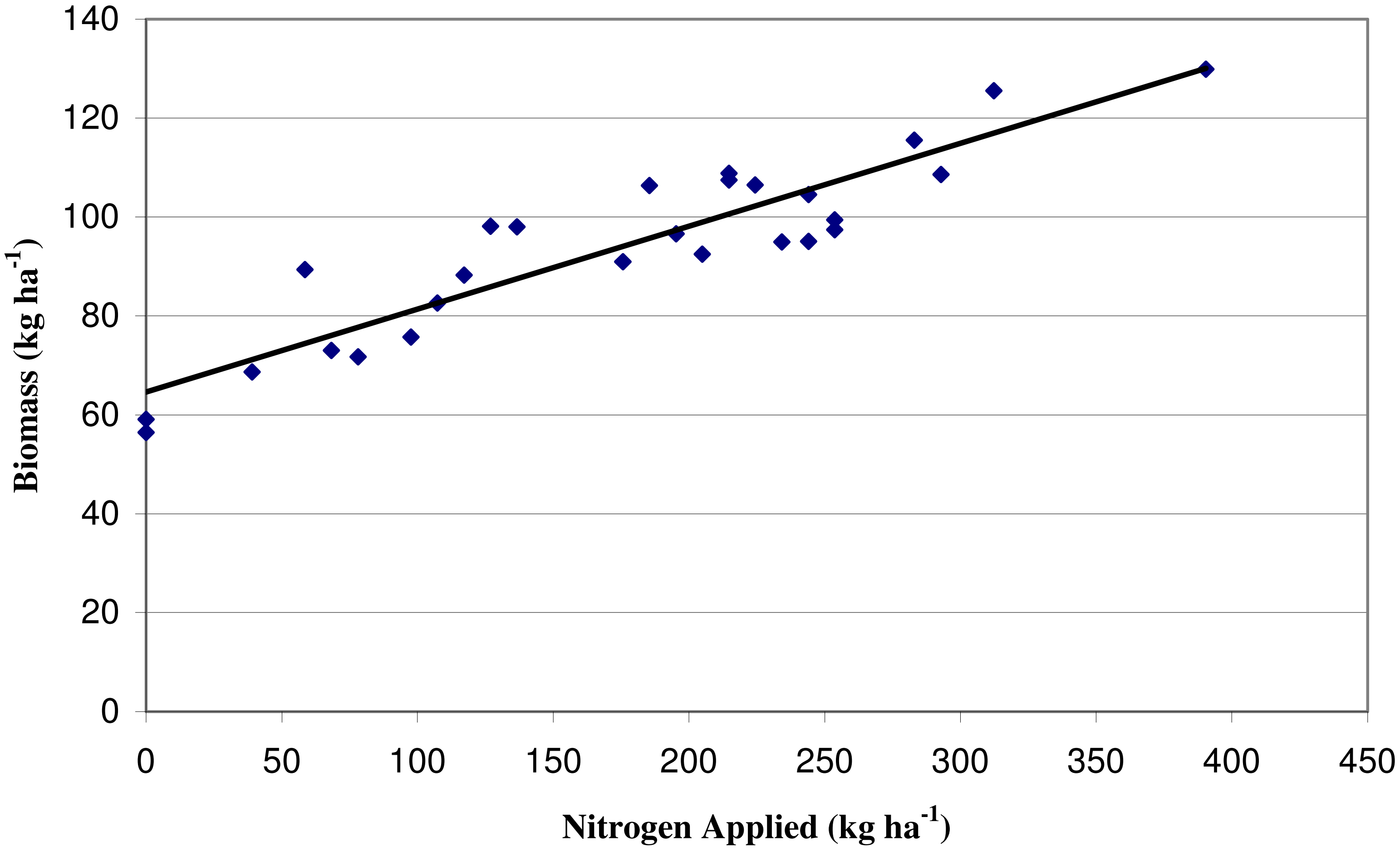

Table 1.6 Effect of Nitrogen Regime on Week 11 Biomass for the 1998 Bermudagrass Sprig Establishment Field Study in Blacksburg, VA.

Treatment	Nitrogen Applied Weeks 1-4	 Weeks 5-8	 Total	Biomass Week 11
	----------------kg ha^{-1}	-------------	-------------	------------kg ha^{-1}--------
1	0.0	0.0	0.0	59.1 d[1]
2	19.5	19.5	39.0	68.7 cd
3	19.5	39.0	58.6	89.4 abcd
4	19.5	78.1	97.6	75.8 abcd
5	19.5	156.2	175.7	90.9 abcd
6	19.5	195.2	214.7	107.5 abcd
7	29.3	39.0	68.3	73.0 bcd
8	29.3	78.1	107.4	82.6 abcd
9	29.3	156.2	185.4	106.3 abcd
10	29.3	195.2	224.5	106.5 abcd
11	48.8	78.1	126.9	98.1 abcd
12	48.8	156.2	205.0	92.4 abcd
13	48.8	195.2	244.0	95.1 abcd
14	87.8	156.2	244.0	104.5 abcd
15	87.8	195.2	283.0	115.5 abc
16	39.0	39.0	78.1	71.7 bcd
17	39.0	78.1	117.1	88.3 abcd
18	39.0	156.2	195.2	96.6 abcd
19	39.0	195.2	234.2	94.9 abcd
20	58.6	78.1	136.6	98.0 abcd
21	58.6	156.2	214.7	108.8 abcd
22	58.6	195.2	253.8	99.4 abcd
23	97.6	156.2	253.8	97.4 abcd
24	97.6	195.2	292.8	108.6 abcd
25	117.1	195.2	312.3	125.5 a
26	195.2	195.2	390.4	129.8 ab
27	0.0	0.0	0.0	56.4 d

[1] Means in the same column followed by the same letter are not significantly different according to Tukey' s Studentized Range test at the 0.05 level of probability.

1999 Results and Discussion

Mean daily temperatures during the months of July, 1999 through October, 1999 were slightly warmer compared to the thirty year mean daily normal temperatures (Table 1.7). However, in all months of the grow-in it is important to note that temperatures are still below that necessary for ideal bermudagrass growth and development (24°C) to occur (Duble, 1989).

Nitrogen Treatment Effects on Percent Cover

Four weeks after nitrogen treatments began, significant differences did not occur with respect to percent cover (Table 1.8). As in 1998, at this stage of development sprigs have immature root systems and turfgrass density is very low. Therefore, application of the ISP nitrogen rates may be in excess of what the bermudagrass sprigs can use in the early post establishment period.

After eight weeks, when nitrogen treatments ended, only the control had percent cover ratings lower than the ISP (Table 1.8). All treatments receiving nitrogen were statistically similar to the ISP treatment with respect to percent cover (Table 1.8). Therefore, ten times less total applied nitrogen achieved percent cover ratings similar to the ISP. Also, treatment 27, which did not receive nitrogen for the first four weeks and the ISP nitrogen rate for the last four weeks, exhibited 99.5 percent cover (Table 1.8). This indicates that in the early post-sprigging period applying zero nitrogen did not impact overall bermudagrass establishment success. In 1999, as in 1998, the ISP weekly nitrogen rate was not necessary to achieve desirable percent cover after eight weeks of grow-in.

Table 1.7 Thirty Year Mean Daily Temperature (^{0}C) Normals and and Mean Daily Temperatures (^{0}C) for 1999 in Blacksburg, Virginia.

Month	1999	
	Mean Normal	Mean Daily
July	21.7	23.5
August	20.9	21.2
September	17.3	20.2
October	11.1	12.4

Table 1.8 Effect of Nitrogen Regime on Percent Cover During the 1999 Bermudagrass Sprig Establishment Field Study in Blacksburg, VA.

Treatment	Nitrogen Applied			Percent Cover		
	Weeks 1-4	Weeks 5-8	Total	Week 4	Week 8	Week 10
	----------------$kg\ ha^{-1}$---------------					
1	0.0	0.0	0.0	41.3 NS[2]	83.8 b[1]	92.5 b
2	19.5	19.5	39.0	45.0	92.0 ab	97.0 ab
3	19.5	39.0	58.6	42.5	93.8 ab	96.3 ab
4	19.5	78.1	97.6	46.3	95.8 ab	98.8 ab
5	19.5	156.2	175.7	46.3	92.5 ab	97.5 ab
6	19.5	195.2	214.7	53.8	100.0 a	100.0 a
7	29.3	39.0	68.3	55.0	98.3 a	97.5 ab
8	29.3	78.1	107.4	53.8	97.5 ab	98.8 ab
9	29.3	156.2	185.4	43.8	97.8 ab	100.0 a
10	29.3	195.2	224.5	46.3	98.8 a	100.0 a
11	48.8	78.1	126.9	47.5	98.3 a	98.8 ab
12	48.8	156.2	205.0	46.3	93.3 ab	98.8 ab
13	48.8	195.2	244.0	48.8	95.0 ab	98.8 ab
14	87.8	156.2	244.0	57.5	99.0 a	100.0 a
15	87.8	195.2	283.0	51.3	100.0 a	100.0 a
16	39.0	39.0	78.1	55.0	98.8 a	98.8 ab
17	39.0	78.1	117.1	50.0	93.8 ab	98.8 ab
18	39.0	156.2	195.2	55.0	98.3 a	100.0 a
19	39.0	195.2	234.2	47.5	93.8 ab	98.8 ab
20	58.6	78.1	136.6	58.8	100.0 a	100.0 a
21	58.6	156.2	214.7	50.0	97.0 ab	98.8 ab
22	58.6	195.2	253.8	50.0	100.0 a	100.0 a
23	97.6	156.2	253.8	57.5	97.8 ab	100.0 a
24	97.6	195.2	292.8	56.3	98.8 a	99.5 a
25	117.1	195.2	312.3	52.5	97.0 ab	100.0 a
26	195.2	195.2	390.4	66.3	100.0 a	100.0 a
27	0.0	195.2	195.2	52.5	99.5 a	100.0 a

[1] Means in the same column followed by the same letter are not significantly different according to Tukey' s Studentized Range test at the 0.05 level of probability.

[2] NS= Not significant according to Tukey' s Studentized Range test at the 0.05 level of probabilit

Even though nitrogen applications ended at week eight, plots were visually rated at week ten to evaluate further growth and development of bermudagrass sprigs. Percent cover after ten weeks was very similar to that after week eight. All treatments receiving any nitrogen were similar to the ISP treatment (Table 1.8). However, due to further development many more treatments had 100 percent cover. Therefore, in 1999, ten times less total nitrogen could be applied and still achieve percent cover similar to the ISP. Also, treatments which received low nitrogen early, even as little as 19.5 kg N ha^{-1} total during the first four weeks, followed by high rates of nitrogen during the last four weeks (39.0 kg N ha^{-1} wk^{-1} or 48.8 kg N ha^{-1} wk^{-1}) tended to provide the greatest and most consistent final percent cover ratings (Table 1.8).

Nitrogen Treatment Effects on Turfgrass Color

In 1999, there were visual differences in turfgrass color associated with nitrogen regimes (Table 1.9). However, all treatments except the control and the treatment receiving the least amount of nitrogen were similar to the ISP treatment (Table 1.9). It is important to note that treatment 27, which received no nitrogen the first four weeks followed by 48.8 kg N ha^{-1} wk^{-1} for the last four weeks (ISP rate) of the study had color ratings similar to the ISP treatment (Table 1.9). All treatments except for one (39 kg N ha^{-1} total) that possessed suitable percent cover after eight weeks of nitrogen treatment had color values greater than 5.0, which is statistically lower than ISP turfgrass color but still acceptable for golf course fairways (Table 1.9). Also, the general trend of low nitrogen during the first four weeks, followed by either 39 kg N ha^{-1} wk^{-1}or 48.8 kg N ha^{-1} wk^{-1} during the last four weeks achieved color values of 5.3 or greater (Table 1.9).

Table 1.9 Effect of Nitrogen Regime on Turfgrass Color During the 1999 Bermudagrass Sprig Establishment Field Study in Blacksburg, VA.

Treatment	Nitrogen Applied			Turfgrass Color[2]	
	Weeks 1-4	Weeks 5-8	Total	Week 8	Week 10
	----------------kg ha^{-1}---------------				
1	0.0	0.0	0.0	4.3 c[1]	5.0 b
2	19.5	19.5	39.0	4.8 bc	5.5 ab
3	19.5	39.0	58.6	5.3 abc	5.3 ab
4	19.5	78.1	97.6	5.3 abc	5.8 ab
5	19.5	156.2	175.7	5.3 abc	5.8 ab
6	19.5	195.2	214.7	6.3 ab	6.8 a
7	29.3	39.0	68.3	5.3 abc	5.5 ab
8	29.3	78.1	107.4	5.8 abc	5.5 ab
9	29.3	156.2	185.4	5.3 abc	6.3 ab
10	29.3	195.2	224.5	5.8 abc	6.0 ab
11	48.8	78.1	126.9	5.8 abc	5.8 ab
12	48.8	156.2	205.0	5.3 abc	5.8 ab
13	48.8	195.2	244.0	5.3 abc	6.0 ab
14	87.8	156.2	244.0	6.8 a	6.0 ab
15	87.8	195.2	283.0	6.0 ab	6.8 a
16	39.0	39.0	78.1	6.0 ab	5.5 ab
17	39.0	78.1	117.1	5.0 abc	5.8 ab
18	39.0	156.2	195.2	6.3 ab	6.3 ab
19	39.0	195.2	234.2	5.3 abc	6.0 ab
20	58.6	78.1	136.6	5.8 abc	5.8 ab
21	58.6	156.2	214.7	5.8 abc	6.3 ab
22	58.6	195.2	253.8	6.0 ab	6.8 a
23	97.6	156.2	253.8	5.8 abc	6.5 ab
24	97.6	195.2	292.8	5.8 abc	6.5 ab
25	117.1	195.2	312.3	5.8 abc	6.3 ab
26	195.2	195.2	390.4	6.3 ab	6.3 ab
27	0.0	195.2	195.2	6.0 ab	6.0 ab

[1] Means in the same column followed by the same letter are not significantly different according to Tukey' s Studentized Range test at the 0.05 level of probability.

[2] Turf Color data was recorded on a 1 to 9 scale (1=brown turf, 5=acceptable, 9=dark green turf)

Color ratings did not change much from week eight to week ten. At week ten, all plots receiving any nitrogen had color ratings similar to the ISP treatment (Table 1.9). Also, the general trend of low nitrogen during the first four weeks, followed by either 39 kg N ha^{-1} wk^{-1}or 48.8 kg N ha^{-1} wk^{-1} during the last four weeks always achieved color values 5.8 or greater (Table 1.9). Once again, treatment 27, which did not received nitrogen the first four weeks and ISP nitrogen rates during the last four weeks of nitrogen treatment exhibited turfgrass color similar to the ISP treatment (Table 1.9). Therefore, the general trend of low nitrogen or no nitrogen the first four weeks followed by ISP nitrogen did not influence turfgrass color response. In 1999, nitrogen treatment the first four weeks was not necessary if the ISP nitrogen rate was applied the last four weeks. Early post-sprigging root systems are immature and there are very few plants per unit area, therefore, nitrogen uptake appears to be very low.

Nitrogen Treatment Effects on Turfgrass Density

During sprig establishment total percent cover is important, however, density of the turfgrass stand must also be considered. Virtually all plots receiving nitrogen exhibited turfgrass density similar to the ISP treatment (Table 1.10). It is important to note that treatment 27, which received no nitrogen the first four weeks followed by 48.8 kg N ha^{-1} wk^{-1} for the next four weeks had density ratings similar to the ISP treatment (Table 1.10). Little if any nitrogen the first four weeks followed by 39 kg N ha^{-1} wk^{-1}or 48.8 kg N ha^{-1} wk^{-1} during the last four weeks achieved density values of 5.5 or greater (Table 1.10). It is important to note that in 1999, all treatments that had percent cover

Table 1.10 Effect of Nitrogen Regime on Turfgrass Density During the 1999 Bermudagrass Sprig Establishment Field Study in Blacksburg, VA.

Treatment	Nitrogen Applied			Turfgrass Density[2]	
	Weeks 1-4	Weeks 5-8	Total	Week 8	Week 10
	-----------------kg ha^{-1}----------------				
1	0.0	0.0	0.0	5.0 b[1]	4.3 c
2	19.5	19.5	39.0	5.0 b	5.0 bc
3	19.5	39.0	58.6	5.5 ab	5.0 bc
4	19.5	78.1	97.6	5.8 ab	5.8 abc
5	19.5	156.2	175.7	5.5 ab	5.8 abc
6	19.5	195.2	214.7	6.3 ab	6.5 ab
7	29.3	39.0	68.3	5.5 ab	5.5 abc
8	29.3	78.1	107.4	5.8 ab	5.3 abc
9	29.3	156.2	185.4	5.8 ab	5.8 abc
10	29.3	195.2	224.5	5.8 ab	6.0 ab
11	48.8	78.1	126.9	5.8 ab	5.8 abc
12	48.8	156.2	205.0	5.5 ab	6.0 ab
13	48.8	195.2	244.0	5.5 ab	6.0 ab
14	87.8	156.2	244.0	6.5 a	6.5 ab
15	87.8	195.2	283.0	6.3 ab	6.8 a
16	39.0	39.0	78.1	6.0 ab	5.3 abc
17	39.0	78.1	117.1	5.3 ab	5.5 abc
18	39.0	156.2	195.2	6.3 ab	6.5 ab
19	39.0	195.2	234.2	5.8 ab	5.3 abc
20	58.6	78.1	136.6	5.8 ab	5.8 abc
21	58.6	156.2	214.7	5.8 ab	5.8 abc
22	58.6	195.2	253.8	6.0 ab	6.5 ab
23	97.6	156.2	253.8	5.8 ab	6.5 ab
24	97.6	195.2	292.8	5.8 ab	6.3 ab
25	117.1	195.2	312.3	6.3 ab	6.0 ab
26	195.2	195.2	390.4	6.5 a	6.3 ab
27	0.0	195.2	195.2	6.0 ab	6.0 ab

[1] Means in the same column followed by the same letter are not significantly different according to Tukey's Studentized Range test at the 0.05 level of probability.

[2] Turf Density was recorded on a 1 to 9 scale (1=no turf, 5=acceptable, 9=dense, uniform turf)

ratings similar to the ISP also had acceptable density ratings (>5.0) for golf course fairways (Table 1.10).

Statistical differences existed with respect to turfgrass density at the ten week date (Table 1.10). However, all treatments receiving nitrogen were still similar to the ISP treatment. Also, treatment 27, which did not receive nitrogen the first four weeks and 48.8 kg N ha^{-1} wk^{-1} for the last four weeks of nitrogen treatment exhibited turfgrass density similar to the ISP treatment. In 1999, all treatments that had percent cover ratings similar to the ISP also had density ratings acceptable for golf course fairways at the ten week rating (Table 1.10).

Nitrogen Treatment Effects on Biomass

On October 14, 1999, biomass sampling attempted to better quantify the effects of varying nitrogen regimes on bermudagrass top growth production after the establishment period. In general as nitrogen application rate increased, total biomass (top growth) production increased (Figure 1.2). Also, biomass production in 1999 was much lower than 1998 and may be attributed to mowing just prior to sampling in 1999 and a later planting date decreasing sprig development due to a shortened photoperiod. In general, nitrogen treatment effect on total biomass production, in 1999 as in 1998, was inconsistent and highly variable (Table 1.11). Some treatments with low total applied nitrogen had high biomass values and other treatments receiving greater total applied nitrogen had lower biomass (Figure 1.2). This could possibly be attributed to sprig variability from plot to plot. However, all treatments receiving greater than 39.0 kg N ha^{-1} total had biomass similar to the ISP (Table 1.11). As a general trend, little if any

Figure 1.2 Effect of Nitrogen Regime on Biomass Production for the 1999 Bermudagrass Sprig Establishment Field Study in Blacksburg, VA.

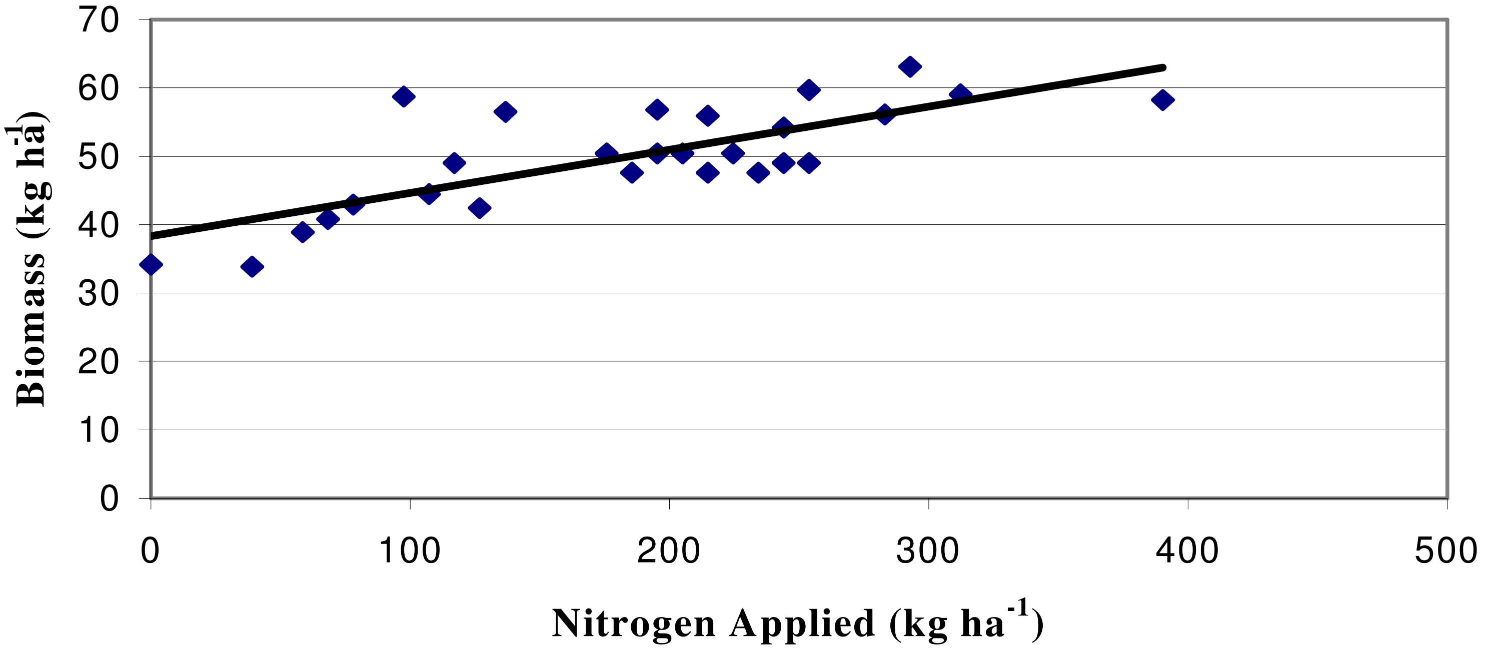

Table 1.11 Effect of Nitrogen Regime on Week 11 Biomass for the 1999 Bermudagrass Sprig Establishment Field Study in Blacksburg, VA.

Treatment	Nitrogen Applied			Biomass
	Weeks 1-4	Weeks 5-8	Total	Week 11
	----------------kg ha^{-1}-------------------------			-kg ha^{-1}------
1	0.0	0.0	0.0	34.2 cd[1]
2	19.5	19.5	39.0	33.9 d
3	19.5	39.0	58.6	38.9 bcd
4	19.5	78.1	97.6	58.7 ab
5	19.5	156.2	175.7	50.4 abcd
6	19.5	195.2	214.7	56.0 abc
7	29.3	39.0	68.3	40.8 bcd
8	29.3	78.1	107.4	44.5 abcd
9	29.3	156.2	185.4	47.6 abcd
10	29.3	195.2	224.5	50.4 abcd
11	48.8	78.1	126.9	42.4 abcd
12	48.8	156.2	205.0	50.4 abcd
13	48.8	195.2	244.0	49.0 abcd
14	87.8	156.2	244.0	54.2 abcd
15	87.8	195.2	283.0	56.1 abc
16	39.0	39.0	78.1	42.9 abcd
17	39.0	78.1	117.1	49.0 abcd
18	39.0	156.2	195.2	56.8 ab
19	39.0	195.2	234.2	47.6 abcd
20	58.6	78.1	136.6	56.5 ab
21	58.6	156.2	214.7	47.6 abcd
22	58.6	195.2	253.8	49.0 abcd
23	97.6	156.2	253.8	59.7 ab
24	97.6	195.2	292.8	63.1 a
25	117.1	195.2	312.3	59.1 ab
26	195.2	195.2	390.4	58.2 ab
27	0.0	195.2	195.2	50.4 abcd

[1] Means in the same column followed by the same letter are not significantly different according to Tukey' s Studentized Range test at the 0.05 level of probability

nitrogen the first four weeks followed by 39 kg N ha^{-1} wk^{-1}or 48.8 kg N ha^{-1} wk^{-1} during the last four weeks of nitrogen treatment tended to produce the greatest biomass (Table 1.11). Although, as in 1998, supplemental nitrogen applications post establishment would, if necessary, enhance turfgrass density without increasing nitrogen required for sprig establishment.

Conclusions

Is the Industry Standard Practice (ISP) nitrogen rate necessary, especially shortly after sprigging when root systems are immature and density of the turfgrass stand is low? This study has provided data to suggest that little if any nitrogen during the first four weeks post-sprigging will achieve percent cover similar to that of the ISP after four weeks of establishment. In both years, applying nitrogen made no difference in overall sprig development. Even the control had similar development to the ISP treatment. At this stage of sprig establishment root systems are immature and plant density is low, therefore, it seems unlikely that the developing bermudagrass stand can utilize the ISP nitrogen rate. Excess nitrogen at this time could be subject to runoff/leaching losses. Very simply, even though soluble nitrogen is inexpensive, the ISP rate appears unnecessary and could pose environmental risk

At both the eight and ten week establishment ratings it was found that much lower rates of nitrogen could be applied while still achieving suitable turfgrass cover in 1998 and 1999. Specifically, 10 times less total applied nitrogen than the ISP treatment provided similar turfgrass cover. Also, there was certainly some density variability in both years and the ISP treatment tended to produce the best density ratings but virtually all treatments that had similar turfgrass cover had density ratings acceptable for golf course fairways. This same trend holds true for overall color ratings. Also, if density needed to be increased a supplemental nitrogen application could be made post-establishment to thicken the stand.

Overall, it is apparent that the ISP nitrogen rate for an eight week period does not significantly increase percent cover, color, or density over treatments receiving far less nitrogen on a silt loam soil. In both 1998 and 1999, many treatments receiving far less nitrogen than the ISP possessed similar cover and more than acceptable color and density at the eight and ten week rating.

Biomass, in 1999, was interesting because the ISP nitrogen rate did not achieve the greatest biomass and the data was more compressed and much lower than in 1998. It would be expected that the ISP would have the greatest biomass but perhaps sprig variability played a role or the random sampling removed thin areas of turf. Mowing just prior to sampling in 1999 explains why biomass was so much lower than in 1998. In 1998, biomass was sampled 4 days after the last mowing, whereas in 1999 mowing occurred just before biomass sampling.

Interestingly enough, overall the 1999 site tended to produce slightly higher percent cover ratings after the establishment period was completed than in 1998. One would have expected the 1998 site to produce better overall percent cover due to an earlier planting date. However, 1999 had a much warmer September than 1998, with mean monthly temperatures of 20.2° C and 17.6° C respectively. This would lead to a much more rapid establishment during the final stages of bermudagrass development. Also, the 1999 site was sprigged twice because mortality was excessive shortly after the first sprigging. Even though a broad-spectrum herbicide was applied to eradicate plant material, some bermudagrass may have survived and led to a higher overall sprigging rate when the second sprigging commenced. Although, when the area was re-sprigged it appeared that sprigs from the previous sprigging were not viable.

Identifying a suitable nitrogen regime during bermudagrass sprig establishment was the goal of this research. As a safe recommendation, the general trend of low nitrogen rates (4.9 kg N ha^{-1} wk^{-1}) during the first four weeks post-sprigging followed by the ISP nitrogen rates during the last four weeks may indeed be adequate during bermudagrass sprig establishment on a silt loam soil. This would be a 45 percent reduction in total applied nitrogen used during the sprig establishment period. This trend tended to produce the most consistent results compared to the ISP treatment. Although, if a rapid grow-in is not necessary or as a best management practice much less nitrogen could most likely be applied. Another option would be to apply a slow-release nitrogen source right at sprigging to provide supplemental nitrogen during the first four weeks of sprig development when root systems are immature and plant density is low. This should provide adequate nitrogen fertility during this time. Following that, the ISP nitrogen rate could be applied, through fertigation, during the last four weeks when sprig density is greater and more extensive root systems exist, thereby requiring more nitrogen fertility. This treatment was not implemented in this study but this researcher believes that this nitrogen regime could minimize nitrogen loss without compromising the eight to ten week grow-in period. However, further research should evaluate this hypothesis.

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Chapter 2

Effects of Reduced Early Post-Sprigging Nitrogen Application on Nitrate Leaching During Bermudagrass Sprig Establishment

Introduction

Evaluating potential sources of nitrate contamination into ground and surface waters is essential today and into the future. Groundwater provides 50 percent of our nation's drinking water and as much as 95 percent of drinking water in rural areas (Petrovic, 1990). Nitrate is considered the most widespread groundwater contaminant and many people depend on groundwater as their primary drinking water source (Petrovic, 1990). Therefore, groundwater protection from nitrate contamination is extremely important.

Loss of nitrate-N to ground and surface waters can cause major health and environmental threats. Infants drinking water high in nitrate can lead to methemoglobinema or 'blue-baby syndrome". Blue-baby syndrome is caused by consuming high levels of nitrate, which is reduced to nitrite in the gastrointestinal tract and subsequently moves into the bloodstream to react with hemoglobin to produce methemoglobin (USEPA, 1976). This causes the transport of oxygen to be altered and can lead to serious or even fatal poisonings. Other potential health effects from excess nitrate in drinking water include birth defects, cancer, and nervous system impairment

(Petrovic, 1989). Due to these concerns, the EPA has set nitrate-N drinking water standards of 10 mg L^{-1} (USEPA, 1976).

Also, high levels of nitrate-N in surface waters can lead to cultural eutrophication (Keeney, 1986). Because nitrogen and phosphorous are limiting in aquatic systems, excess loading of these nutrients into aquatic systems can cause an explosion of growth. The organic material produced, primarily algae, will cause an increase in turbidity, blocking out the sun that submerged aquatic vegetation (SAV) depend on. Fish, in turn, which depend on SAV for essential habitat are affected. Also, when the algae and the SAV die and decay large quantities of oxygen are consumed in their microbial decomposition. This can lead to massive fish kills and/or drastically change the ecology and diversity of aquatic systems.

Numerous nitrogen loss studies have been completed on established turfgrass systems, however, much less attention has been paid to nitrogen loss during turfgrass establishment (Petrovic, 1990). Specifically, a potential source of nitrate-N contamination exists during bermudagrass (*Cynodon dactylon*) sprig establishment. Most improved turf-type bermudagrass varieties are typically established vegetatively, by sod, plugs, or sprigs, rather than from seed because of low quantities of viable hybrid seed (Duble, 1989). Typically, during vegetative establishment, high rates of soluble nitrogen are applied weekly in an effort to speed establishment growth. For example, applications of 48.8 kg N ha^{-1} wk^{-1} of soluble nitrogen for an eight to ten week period is quite common and considered to be the Industry Standard Practice (ISP) (Chalmers, 1998). Therefore, there exists an increased potential for nitrogen leaching and runoff especially during early-post-sprigging when there are very few plants per unit area and root systems are establishing. With the dominance of bermudagrass (*Cynodon dactylon)* in the southeastern and southern United States, there is a need to quantify and, if necessary, minimize nitrogen loss during sprig establishment.

Objectives

The objectives of this study were to:

1) To quantify potential nitrate-N leaching loss during bermudagrass sprig establishment.
2) To determine how varying nitrogen rates correlate with bermudagrass sprig establishment growth and overall turf quality.

Materials and Methods

Identical lysimeter studies were conducted at the Turfgrass Research Center in Blacksburg, Virginia in 1998 and 1999. Lysimeters were constructed out of 18.9 L plastic buckets, placed in the ground and leveled to allow for successful sample evacuation. Each lysimeter had a diameter of approximately 28 cm and a surface area of 615.5 cm^2. Each lysimeter was comprised of 7.62 cm of a medium sand to act as the collection reservoir, over which 33 cm of a sand/soil/peat (70-10-20 percent by volume) topdressing mix for the root zone. Initial soil test results (analyzed by the Virginia Tech soil testing laboratory) for the medium sand collection reservoir reported pH = 5.4, P = 2 ppm (L-), K = 5 ppm (L-), Ca = 75 ppm (L-), Mg = 10 ppm (L-). Initial soil test results (analyzed by the Virginia Tech soil testing laboratory) for the root zone mix reported pH = 5.5, P = 25 ppm (H-), K = 25 ppm (L), Ca = 300 ppm (L+), Mg = 90 (H-). The root zone mix possessed an initial infiltration rate of 49 cm hr^{-1}, aeration porosity of 20.8 percent, and moisture retention at 30 cm of 9.9 percent (E and S soils, 1998). A 0.95 cm diameter polyethylene tube covered with mesh silk-screen extended to the bottom of each lysimeter to allow for sample extraction.

Lysimeters were planted with Tifway 419 bermudagrass on July 16, 1998 and July 22, 1999. Two rows of sprigs, spaced 5 cm apart, were planted in each lysimeter. Sprigs were approximately 4 cm long and consisted of approximately the same number of nodes (4) per sprig. Nitrogen treatments were started one week after sprigging. Six weekly nitrogen treatment regimes existed ranging from 4.8 kg N ha^{-1} to 48.8 kg N ha^{-1} (Table 2.1). The 48.8 kg N ha^{-1} wk^{-1} treatment was considered to be the Industry Standard Practice (ISP). Each nitrogen treatment was replicated four times in a randomized complete block design for a total of 24 lysimeters.

Nitrogen applications were made bi-weekly using ammonium nitrate (34-0-0) and lightly watered in to simulate fertigation. Applications were made using a wheel driven sprayer (calibrated to deliver 407 l ha^{-1}) in 1998 and with a 60 cm^3 syringe calibrated to deliver the appropriate nitrogen rate dissolved in 20 cm^3 of water in 1999. Also in 1999, the low label rate (2.3 L ha^{-1}) of Scott's Fluid Minors package was also applied once per week to ensure that other nutrients were not limiting. The Scott's Fluid Minors package contains P (4%), K (4%), Mg (2%), S (3%), B (0.02%), Fe (5%), Mn (0.5%), and Zn (0.05%). Lysimeters were irrigated with approximately 3.8 cm of water per week and samples were evacuated using a 1.5 amp Air Cadet vacuum pump every seven days (+/- 2 days). Lysimeters were completely evacuated each time samples were

Table 2.1 Weekly Nitrogen Treatments for the 1998 and 1999 Bermudagrass Sprig Establishment Lysimeter Studies in Blacksburg, VA.

Nitrogen Treatments	Total Applied Nitrogen
---kg ha^{-1} wk^{-1}---	---kg ha^{-1}---
0.0	0.0
4.9	39.0
9.8	78.1
19.5	156.2
39.0	312.3
48.8	390.4

taken. A 250 ml sub-sample from each lysimeter was taken to the lab for nitrate analysis using a Lachat Quik-Chem Auto-Analyzer.

Data Recorded

Visual observations recorded throughout the bermudagrass establishment period consisted of percent bermudagrass cover after four weeks of nitrogen treatment and percent bermudagrass cover, turf density, and turf color after eight and ten weeks of sprig development. Percent bermudagrass cover was recorded on a scale from 0 to 100 (O = no bermudagrass and 100 = total bermudagrass cover). Density was recorded on a scale of 1 to 9 (1 = no turf and 9=dense, uniform turf). Density only occurred at weeks eight and ten when the bermudagrass was established enough to visually see differences in turfgrass density. A rating of 5 would be indicative of acceptable turfgrass density for a golf course fairway. Turf color was recorded on a scale of 1 to 9 (1 = brown turf and 9 = dark green turf). A rating of 5 would be indicative of acceptable turfgrass color for a golf course fairway. Turf color was only recorded at weeks eight and ten. At week four, color differences were not apparent. Lysimeters were evacuated approximately weekly to quantify nitrate-N loss during bermudagrass sprig establishment just prior to weekly nitrogen treatment. All data was analyzed using Tukey's studentized range test at the 0.05 level of confidence (SAS, 1985).

1998 Results

Mean daily temperatures during the months of July, 1998 through October, 1998 were slightly warmer compared to the thirty year mean daily normal temperatures (Table

2.2). However, in all months of the grow-in it is important to note that temperatures are still below that necessary for ideal bermudagrass growth and development (24°C) to occur (Duble, 1989).

Nitrogen Treatment Effects on Nitrate Leaching

In 1998, a misapplication on nitrogen occurred during the first week of nitrogen treatments to the control, the 4.9 and the 9.8 kg N ha $^{-1}$ wk^{-1} treatments, therefore, these treatments were removed from the study to avoid skewing nitrate-N data. During the first two sampling dates there were no differences in the quantity of nitrate-N leached between treatments (Table 2.3). However, by observing Table 2.4, after the first week a relatively large percent of applied nitrogen leached as nitrate-N, therefore, leaching potential appears great shortly after sprigging when uptake of nitrogen by sprigs is low due to minimal root development and plants per unit area. Just prior to the third week sampling, there was a large precipitation event (6.3 cm), which is evident by observing the first peak in Figure 2.1. Therefore, at the three week sampling date, very high levels of nitrate-N leached (Table 2.3). The 39 and the 48.8 kg N ha $^{-1}$ wk^{-1} treatments leached a significantly greater amount of nitrate than the 19.8 kg N ha $^{-1}$ wk^{-1} treatment (Table 2.3). Also, this precipitation event caused the percent of applied nitrogen leached total, at three weeks, to be excessive. The ISP treatment leached 40 percent of the total applied nitrogen as nitrate-N due to this one rain event and even the 19.8 kg N ha $^{-1}$ wk^{-1} treatment leached 57 percent of total applied nitrogen (Table 2.4). Therefore, during early post-sprigging when nitrogen uptake is low, the potential for significant quantities of nitrogen lost as nitrate can occur, especially on a high sand content soil.

Table 2.2 Thirty Year Mean Daily Temperature (^{0}C) Normals and and Mean Daily Temperatures (^{0}C) for 1998 in Blacksburg, Virginia.

Month		1998
	Mean Normal	Mean Daily
July	21.7	22.2
August	20.9	21.8
September	17.3	17.6
October	11.1	11.2

Table 2.3 Weekly Applied Nitrogen Influence on Nitrate Leaching During the 1998 Bermudagrass Sprig Establishment Lysimeter Study in Blacksburg, VA.

Weekly Applied Nitrogen	Total Applied Nitrogen	Leachate Collection (weeks)[3] 1 Week	2 Weeks	3 Weeks	4 Weeks	5 Weeks	6 Weeks
-------------kg ha^{-1}	---------------	---------NO$_3$-N Leached (kg ha^{-1})					
19.5	156.2	2.55 NS[2]	0.46 NS	33.89 b[1]	12.25 NS	1.77 b	4.41 b
39.0	312.3	3.22	0.77	55.29 a	16.79	4.06 a	22.36 a
48.8	390.4	3.39	0.74	58.05 a	17.74	5.08 a	22.93 a

Weekly Applied Nitrogen	Total Applied Nitrogen	Leachate Collection (weeks)[3] 7 Weeks	8 Weeks	4-Nov[4]	18-Nov	2-Dec
-------------kg ha^{-1}	---------------	---------NO$_3$-N Leached (kg ha^{-1})				
19.5	156.2	2.33 b	0.46 b	0.09 NS	0.05 NS	0.03 NS
39.0	312.3	12.49 a	4.89 ab	0.57	0.03	0.03
48.8	390.4	14.34 a	6.29 a	3.81	2.98	0.26

[1] Means in the same column followed by the same letter are not significantly different according to Tukey' s Studentized Range test at the 0.05 level of probability.

[2] NS= Not Significant according to Tukey' s Studentized Range test at the 0.05 level of probability.

[3] Nitrogen Treatment began on July 24, 1998 and ended on September 11, 1998.

[4] Three samplings occurred well after nitrogen treatments ended to quantify NO$_3$-N lost post-establishment.

Table 2.4 Weekly Applied Nitrogen Influence on Percent of Applied Nitrogen Leached During the 1998 Bermudagrass Sprig Establishment Lysimeter Study in Blacksburg, VA.

Weekly Applied Nitrogen	Total Applied Nitrogen	Leachate Collection (Weeks)[1]					
		1 Week	2 Weeks	3 Weeks	4 Weeks	5 Weeks	6 Weeks
--------------kg ha^{-1}	----------------	----------------Percent Applied Nitrogen Leached[2]----------------					
19.5	156.2	13.09	1.18	57.90	15.70	1.81	3.77
39.0	312.3	8.27	0.99	47.25	10.76	2.08	9.55
48.8	390.4	6.94	0.76	39.64	9.08	2.08	7.83

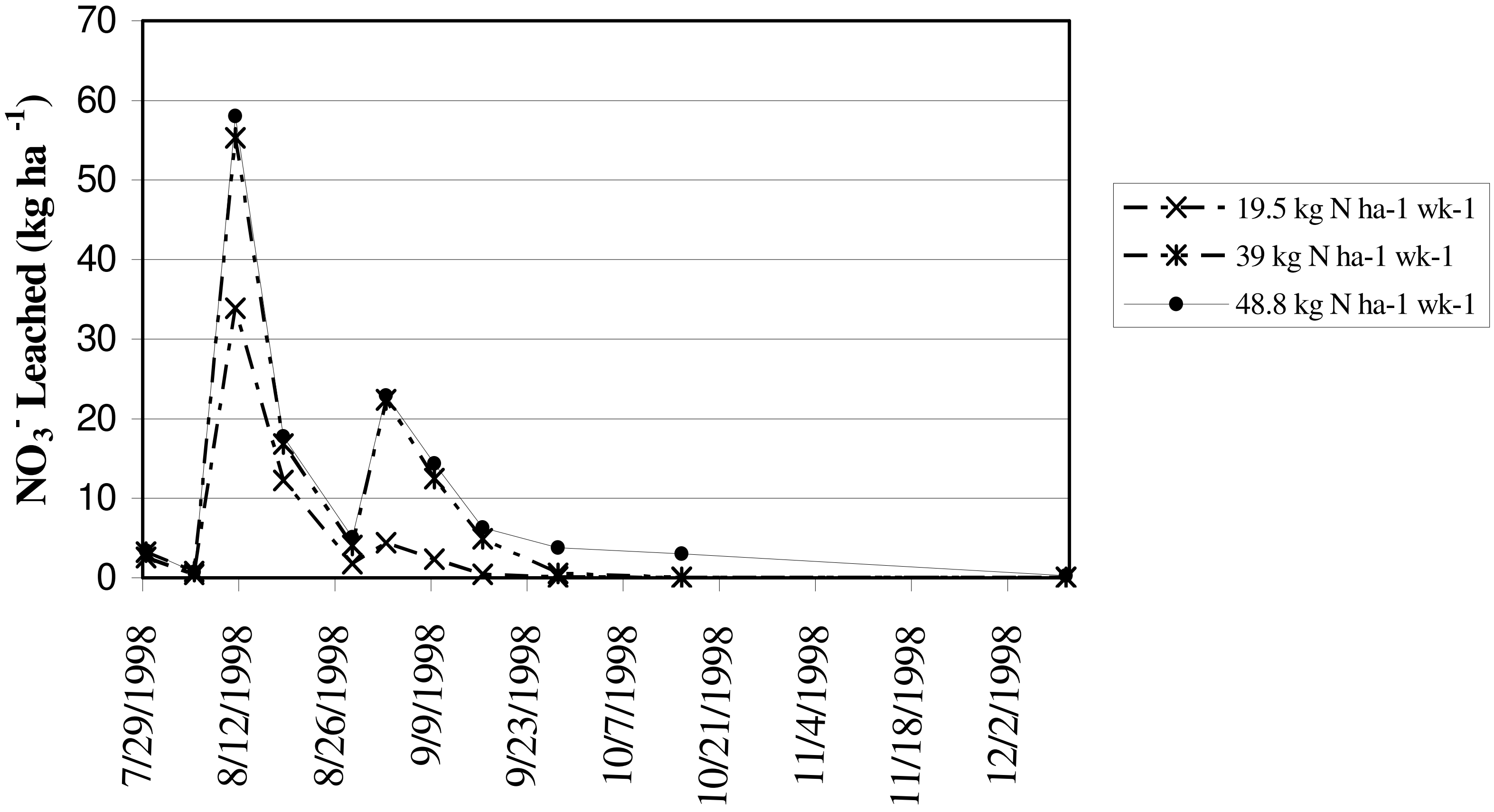
Weekly Applied Nitrogen	Total Applied Nitrogen	Leachate Collection (Weeks)[1]					Percent Leached
		7 Weeks	8 Weeks	4-Nov[3]	18-Nov	2-Dec	Total
--------------kg ha^{-1}	----------------	----------------Percent Applied Nitrogen Leached[2]----------------					
19.5	156.2	1.71	0.03	0.06	0.03	0.02	37.3
39.0	312.3	4.57	1.57	0.18	0.01	0.01	38.6
48.8	390.4	4.19	1.61	0.96	0.76	0.07	34.7

[1] Nitrogen Treatment began on July 24, 1998 and ended on September 11, 1998.

[2] This is the percentage of applied nitrogen leached, as NO_3-N, up to each sampling date.

[3] Three samplings occurred well after nitrogen treatments ended to quantify NO_3-N lost post-establishment.

Figure 2.1 Weekly Applied Nitrogen Influence on Nitrate Leaching During the 1998 Bermudagrass Sprig Establishment Lysimeter Study in Blacksburg, VA.



At the four week sampling date, once again high levels of nitrate-N leached (Table 2.3). However, there were no differences in the amount of nitrate-N leached between treatments (Table 2.3). Once again, a relatively large percent of total applied nitrogen leached and it is apparent that even the low rate of 19.5 kg N ha^{-1} wk^{-1} can cause significant nitrate-N loss during the early post-sprigging establishment period.

After the five week sampling date much lower levels of nitrate-N leached, however, the 39.0 and the 48.8 kg N ha $^{-1}$ wk^{-1} treatments leached a significantly greater amount of nitrate than the 19.8 kg N ha $^{-1}$ wk^{-1} treatment (Table 2.3). The percent of applied nitrogen leached as nitrate is much lower after five weeks than it was previously, however the potential for very high rates of nitrate-N loss even in the later weeks of establishment can still exist as is evident at the six week sampling date (Table 2.4).

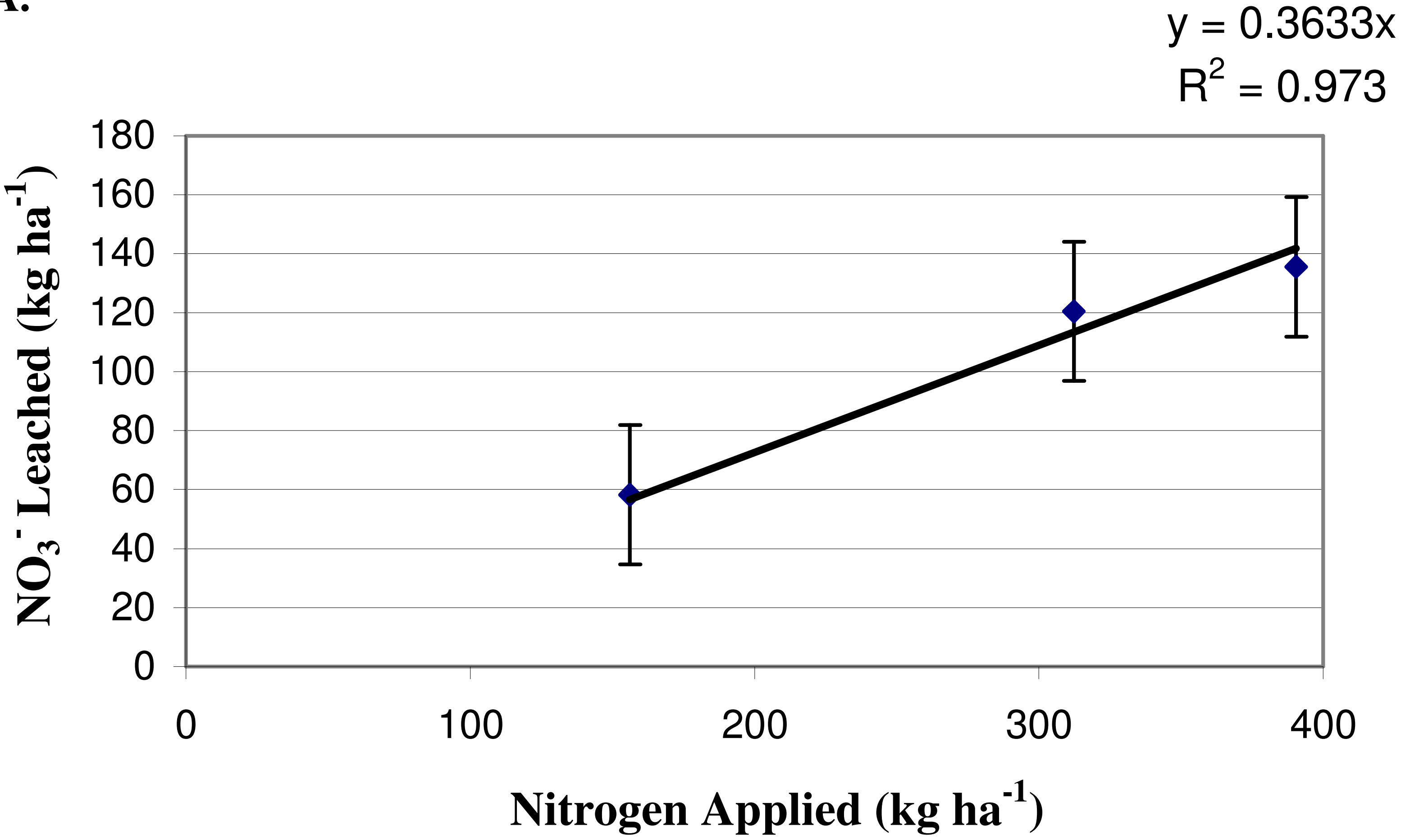
Just prior to the six week sampling date, another significant precipitation event occurred (3 cm), as is evident by the second peak in Figure 2.1. As in the previous week, the 39.0 and the 48.8 kg N ha $^{-1}$ wk^{-1} treatments leached a significantly greater amount of nitrate than the 19.8 kg N ha $^{-1}$ wk^{-1} treatment (Table 2.3). Also, the 39.0 and the 48.8 kg N ha $^{-1}$ wk^{-1} treatments leached 9.5 percent and 7.8 percent, respectively, of the total applied nitrogen up to this point as nitrate-N (Table 2.4). Therefore, even in the later stages of establishment, a significant amount and percent of applied nitrogen total can be lost as nitrate-N on sand-based soil.

After seven weeks, once again the 39.0 and the 48.8 kg N ha $^{-1}$ wk^{-1} treatments leached a significantly greater amount of nitrate-N than the 19.8 kg N ha $^{-1}$ wk^{-1} treatment (Table 2.3). Also, these two treatments leached over 4 percent of the total applied nitrogen after seven weeks of nitrogen treatment (Table 2.4). After eight weeks of the study, which was the end of nitrogen applications, the ISP treatment leached a significantly greater amount of nitrate-N than the 19.8 kg N ha $^{-1}$ wk^{-1} treatment (Table 2.3). The percent of total applied nitrogen leached at this sampling is low, however, a large rain event may still cause excessive nitrate-N leaching (Table 2.4). Also, at this stage plant density is much greater, root systems are well established, and the bermudagrass stand can use nitrogen more readily than was possible during the early post-sprigging establishment period.

Nitrogen treatments ended on September 17, 1998, however, additional sampling dates evaluated the further loss of nitrate-N through time. However, the three additional samplings that occurred post-establishment revealed no differences between treatments (Table 2.3). Also, the percent of total applied nitrogen leached as nitrate-N was also very low (Table 2.4). Once again, due to extensive root systems and increased density, bermudagrass can readily use plant available nitrogen. However, the ISP nitrogen rate applied weekly especially shortly after sprigging appears excessive in sand-based soil and could lead to excess nitrate-N loss and increase the influx of nitrate-N into surface and groundwater sources.

By observing the percent of applied nitrogen leached total, all treatments leached around 35 percent of total nitrogen applied as nitrate-N. This amount of nitrate-N lost is excessive and it appears the bermudagrass sprigs cannot readily use all the applied nitrogen. Obviously, the ISP treatment will leach the greatest quantity of nitrate-N even if the percent leached between treatments are similar. Therefore, an estimate of the amount of nitrogen leached can be attained. In 1998, on a sand-based soil $y=.36x$ where x is the total applied nitrogen and y is the amount of nitrogen leached as nitrate-N (Figure 2.2).

Figure 2.2 Total Applied Nitrogen Leached After the 1998 Bermudagrass Sprig Establishment Lysimeter Study in Blacksburg, VA.



Nitrogen Treatment Effects on Percent Cover

After four weeks of nitrogen treatment, significant differences with respect to percent cover were not found (Table 2.5). All treatments remaining (first three nitrogen regimes were removed) have turfgrass cover similar to the ISP (Table 2.5). In this scenario, a 40 percent reduction in total applied nitrogen revealed no differences with respect to percent cover after four weeks. By applying only the amount of nitrogen necessary for sprig development could minimize leaching and runoff threats.

At the eight week rating (when nitrogen treatments finished), significant differences with respect to total percent cover did not exist (Table 2.5). Therefore, in 1998, a 40 percent reduction in total nitrogen applied achieved percent cover similar to the ISP treatment on sand-based soil.

Lysimeters were visually rated for percent cover after ten weeks of growth to further evaluate bermudagrass establishment. Once again, no significant differences were found with respect to total percent cover (Table 2.5). In 1998, a 40 percent reduction in total nitrogen applied, achieved percent cover similar to the ISP treatment on sand-based soil.

Nitrogen Treatment Effects on Turfgrass Color

After four weeks, visual differences with respect to turfgrass color were not discernable. Also, eight weeks after sprigging when nitrogen treatments ended, significant differences were not found with respect to turfgrass color (Table 2.6). Therefore after eight weeks of bermudagrass sprig development, a 40 percent reduction

Table 2.5 Effect of Nitrogen Regime on Percent Cover for the 1998 Bermudagrass Sprig Establishment Lysimeter Study in Blacksburg, VA.

Weekly Applied Nitrogen	Total Applied Nitrogen	Percent Cover Week 4	 Week 8	 Week 10
------------------kg ha^{-1}------------------				
19.5	156.2	36.3 NS[1]	99.5 NS	100.0 NS
39.0	312.3	41.3	100.0	100.0
48.8	390.4	42.5	100.0	100.0

[1] NS= Not significant according to Tukey' s Studentized Range test at the 0.05 level of probability.

Table 2.6 Effect of Nitrogen Regime on Turfgrass Color for the 1998 Bermudagrass Sprig Establishment Lysimeter Study in Blacksburg, VA.

Weekly Applied Nitrogen	Total Applied Nitrogen	Turfgrass Color[2] Week 8	Turfgrass Color[2] Week 10
-------------------kg ha^{-1}	-------------------		
19.5	156.2	7.0 NS[1]	6.8 a
39.0	312.3	7.0	7.0 a
48.8	390.4	7.0	7.0 a

[1] NS= Not significant according to Tukey' s Studentized Range test at the 0.05 level of probability.

[2] Turf Color data was recorded on a 1 to 9 scale (1=brown turf, 5=acceptable, 9=dark green turf)

in applied nitrogen had no significant effect on percent cover or turfgrass color. Therefore, it is apparent that much less nitrogen than the ISP will provide suitable turfgrass color on sand-based soil.

Lysimeters were visually rated for percent cover after ten weeks to further evaluate bermudagrass establishment. At the ten-week rating, turfgrass color values were very similar to those after eight weeks. Once again, a 40 percent reduction in applied nitrogen achieved percent cover and turfgrass color similar to the ISP treatment (Table 2.6).

Nitrogen Treatment Effects on Turfgrass Density

After four weeks, visual differences with respect to turfgrass density were negligible. Also, significant differences did not occur for turfgrass density at the eight week rating. Therefore, after 8 weeks of sprig development, a 40 percent reduction in total applied nitrogen achieved percent cover, color, and, density ratings similar to the ISP.

After a 10-week grow-in period in 1998, a 40 percent reduction in total applied nitrogen provided percent cover, turfgrass color, and turfgrass density similar to the ISP nitrogen rate (Table 2.7). Also, if necessary, turfgrass density could be enhanced after the grow-in period with supplemental nitrogen applications.

1999 Results

Mean daily temperatures during the months of July, 1999 through October, 1999 were slightly warmer compared to the thirty year mean daily normal temperatures for

Table 2.7 Effect of Nitrogen Regime on Turfgrass Density for the 1998 Bermudagrass Sprig Establishment Lysimeter Study in Blacksburg, VA.

Weekly Applied Nitrogen	Total Applied Nitrogen	Turfgrass Density[2] Week 8	Turfgrass Density[2] Week 10
-------------------kg ha^{-1}-------------------			
19.5	156.2	6.0 NS[1]	6.5 NS[1]
39.0	312.3	6.5	6.5
48.8	390.4	6.8	6.8

[1] NS= Not significant according to Tukey' s Studentized Range test at the 0.05 level of probability.

[2] Turf Density was recorded on a 1 to 9 scale (1=no turf, 5=acceptable, 9=dense, uniform turf)

Table 2.8 Thirty Year Mean Daily Temperature (^{0}C) Normals and and Mean Daily Temperatures (^{0}C) for 1999 in Blacksburg, Virginia.

Month	1999	
	Mean Normal	Mean Daily
July	21.7	23.5
August	20.9	21.2
September	17.3	20.2
October	11.1	12.4

Blacksburg, Virginia (Table 2.8). However, in all months of the grow-in it is important to note that average temperatures were still below that necessary for ideal bermudagrass growth and development (24°C) to occur (Duble, 1989).

Nitrogen Treatment Effects on Nitrate Leaching

In 1999, there were no differences in amount of nitrate leached for the first two sampling dates (Table 2.9). This is mainly a result of minimal leaching. Also, the percent of total applied nitrogen leached up to this point was very low (Table 2.10). After the first week of nitrogen treatments, the percent of applied nitrogen leached was less than .1 % and after two weeks all treatments leached less that 2.5 percent as nitrate-N (Table 2.10). After three weeks of nitrogen treatment, the ISP treatment (48.8 kg N ha^{-1} wk^{-1}) possessed relatively high nitrate-N values, however, nitrate-N values were similar to the 39.0 kg N ha^{-1} wk^{-1} treatment (Table 2.9). All other treatments leached less nitrate-N than the ISP treatment (Table 2.9). The 39.0 and 48.8 kg N ha^{-1} wk^{-1} treatments leached 5.7 percent and 7 percent, respectively of the total applied nitrogen up to this point (Table 2.10).

Prior to the week four sampling date, a large rain event occurred (7.0 cm), therefore, extremely high nitrate-N values were found in the leachate (Table 2.9). This is evident by observing the first peak in Figure 2.3. The ISP treatment had significantly higher nitrate-N values compared to all other treatments and leached approximately 32 percent of the total applied nitrogen up to this point (Table 2.9, Table 2.10). However, the 19.5 and 39.0 kg N ha^{-1} wk^{-1} treatments, while being significantly lower than the ISP treatment in kg NO_3-N ha^{-1} leached had a similar percent of applied nitrogen leached total

Table 2.9 Weekly Applied Nitrogen Influence on Nitrate Leaching During the 1999 Bermudagrass Sprig Establishment Lysimeter Study in Blacksburg, VA.

Weekly Applied Nitrogen	Total Applied Nitrogen	Leachate Collection (weeks)[3] 1 Week	2 Weeks	3 Weeks	4 Weeks
--------------kg ha^{-1}	----------------	---------------NO_3-N Leached (kg ha^{-1})			----------------
0.0	0.0	0.20 NS[2]	0.74 NS	1.87 c[1]	2.10 c
4.9	39.0	0.21	0.97	2.25 c	3.67 c
9.8	78.1	0.21	0.93	2.10 c	4.20 c
19.5	156.2	0.07	1.07	3.30 bc	24.18 bc
39.0	312.3	0.20	0.99	8.48 ab	40.24 b
48.8	390.4	0.27	2.13	12.17 a	64.54 a

Weekly Applied Nitrogen	Total Applied Nitrogen	Leachate Collection (weeks)[3] 6 Weeks	8 Weeks	29-Sep[4]
--------------kg ha^{-1}	----------------	---------------NO_3-N Leached (kg ha^{-1})		----------------
0.0	0.0	0.70 c	0.18 b	0.16 b
4.9	39.0	0.71 c	0.08 b	0.03 b
9.8	78.1	0.89 c	0.18 b	0.04 b
19.5	156.2	8.91 c	1.88 b	1.43 b
39.0	312.3	56.46 b	13.11 a	7.60 a
48.8	390.4	75.54 a	17.18 a	8.36 a

[1] Means in the same column followed by the same letter are not significantly different according to Tukey' s Studentized Range test at the 0.05 level of probability.

[2] NS = Not significat according to Tukey' s Studentized Range test at the 0.05 level of probability.

[3] Nitrogen Treatment began on July 29, 1999 and ended on September 20, 1999.

[4] One final sampling occurred after nitrogen treatments ended to quantify NO_3-N lost post-establishment.

Table 2.10 Weekly Applied Nitrogen Influence on Percent of Applied Nitrogen Leached During the 1999 Bermudagrass Sprig Establishment Lysimeter Study in Blacksburg, VA.

Weekly Applied Nitrogen	Total Applied Nitrogen	Leachate Collection (Weeks)[1] 1 Week	2 Weeks	3 Weeks	4 Weeks
--------------kg ha^{-1}----------------		--------------------Percent Applied Nitrogen Leached[2]--------------------			
0.0	0.0				
4.9	39.0	0.1	2.4	2.6	8.0
9.8	78.1	0.1	1.0	0.8	5.4
19.5	156.2	0.0	0.9	2.4	28.3
39.0	312.3	0.0	0.3	5.7	24.4
48.8	390.4	0.1	1.4	7.0	32.0

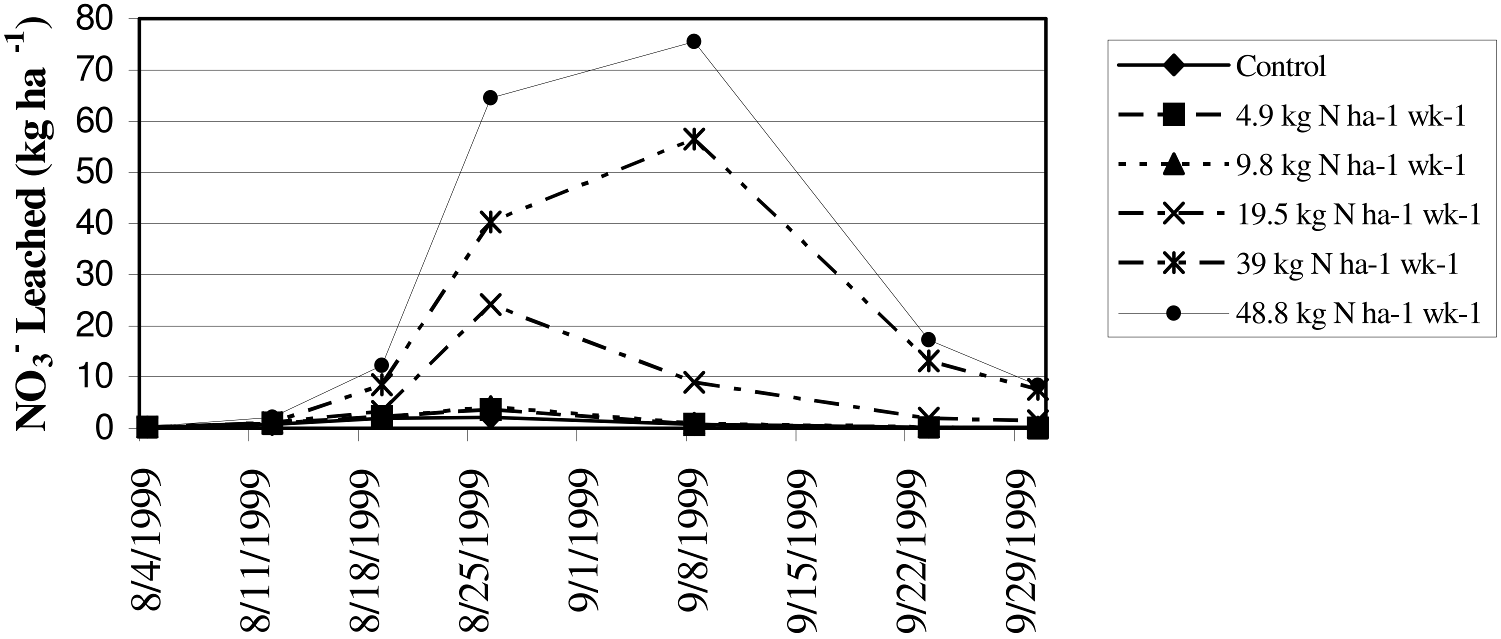
Weekly Applied Nitrogen	Total Applied Nitrogen	Leachate Collection (Weeks)[1] 6 Weeks	8 Weeks	29-Sep[3]	Percent Leached Total
--------------kg ha^{-1}----------------		-------Percent Applied Nitrogen Leached[2]----------			
0.0	0.0				
4.9	39.0	0.1	0.0	0.0	5.0
9.8	78.1	0.3	0.0	0.0	3.3
19.5	156.2	7.0	1.1	0.8	22.3
39.0	312.3	23.8	4.1	2.4	38.8
48.8	390.4	25.6	4.4	2.1	44.6

[1] Nitrogen Treatment began on July 29, 1999 and ended on September 20, 1999.

[2] This is the percentage of applied nitrogen leached, as NO_3-N, up to each sampling date.

[3] One final sampling occurred after nitrogen treatments ended to quantify NO_3-N lost post-establishment.

Figure 2.3 Weekly Applied Nitrogen Influence on Nitrate Leaching During the 1999 Bermudagrass Sprig Establishment Lysimeter Study in Blacksburg, VA.



(Table 2.9, Table 2.10). The 19.5 and 39.0 kg N ha^{-1} wk^{-1} treatments, leached approximately 28 percent and 24 percent of the total applied nitrogen after four weeks, respectively (Table 2.10). It is evident that during the early post-sprigging establishment period that large quantities of nitrate-N and a large percent of applied nitrogen can be leached as nitrate-N on high sand-based soil, especially if a large precipitation event occurs. With low bermudagrass density and immature root systems, the ISP nitrogen rate is not required and excessive. Treatments receiving 9.8 kg N ha^{-1} wk^{-1} or less leached much less nitrate-N and a much lower percent of applied nitrogen leached total after four weeks.

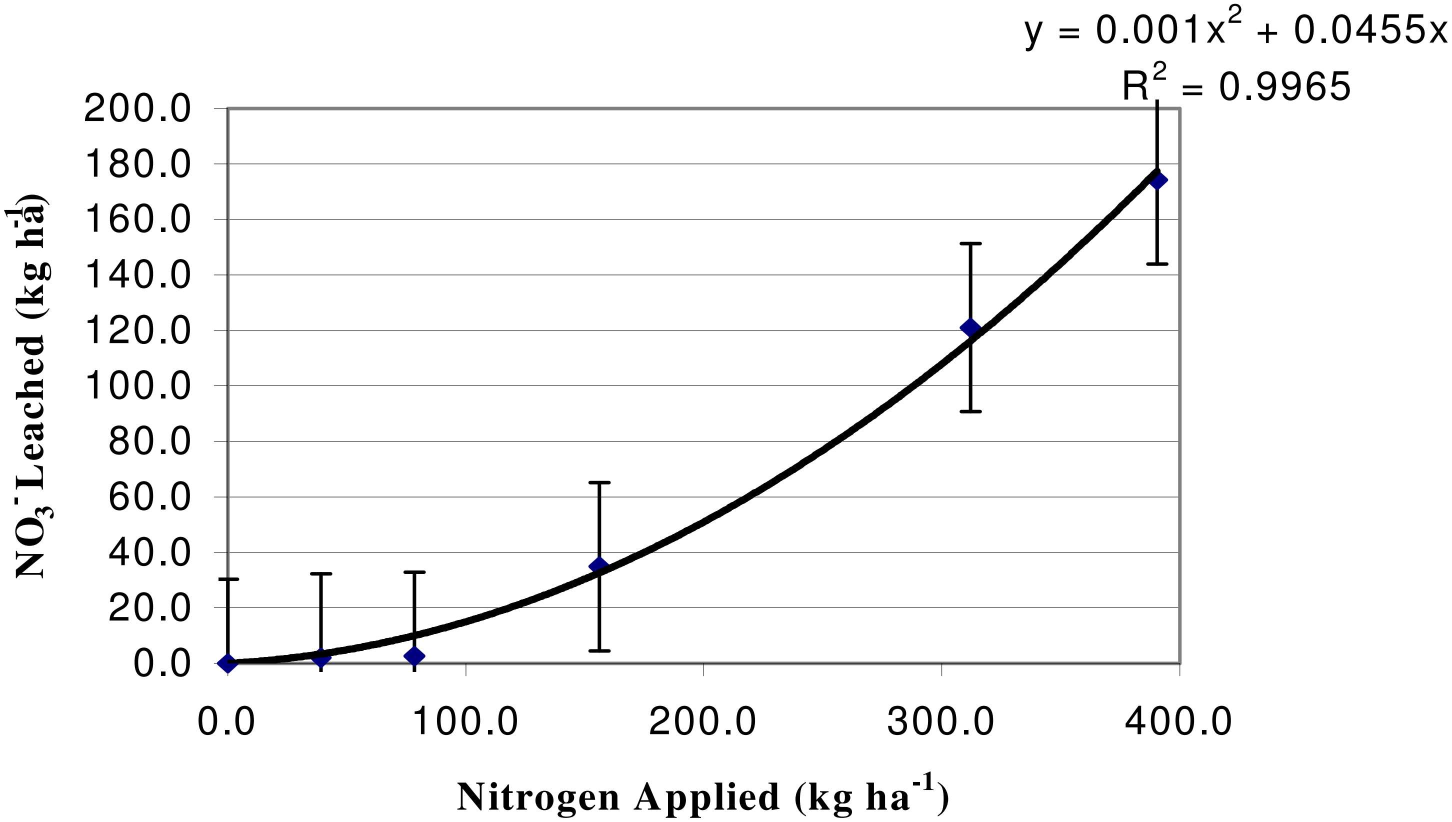
Prior to the six week sampling date, another heavy rain event occurred (7.5 cm), which caused another large leaching event as is evident by the second peak in Figure 2.2. As after the four week leachate collection, the ISP treatment had higher nitrate-N values than all other treatments and leached approximately 25 percent of the total applied nitrogen (Table 2.9, Table 2.10). However, the 39.0 kg N ha^{-1} wk^{-1} treatment, while being significantly lower than the ISP treatment also leached very high nitrate-N quantities (Table 2.9). Also, the 39 kg N ha^{-1} wk^{-1} treatment leached approximately 24 percent of the total applied nitrogen after six weeks (Table 2.10). Leaching from both of these treatments is high, and sprigs certainly are not utilizing much of the applied nitrogen. All other treatments had a much lower percent of applied nitrogen leached total, this could infer that as plant density increased and root systems matured nitrogen uptake substantially increased from the four to six week sampling.

At the eight week sampling (when nitrogen treatments ended), the ISP treatment (48.8 kg N ha^{-1} wk^{-1}) and the 39.0 kg N ha^{-1} wk^{-1} treatment leached significantly higher nitrate-N quantities than all other treatments (Table 2.9). Also, the 39.0 kg N ha^{-1} wk^{-1} and the ISP treatment both leached approximately 4.0 percent of the total applied nitrogen (Table 2.10). The 19.0 kg N ha^{-1} wk^{-1} treatment leached approximately 1.1 percent of the total applied nitrogen and all other treatments leached a negligible amount suggesting that bermudagrass sprigs were able to utilize most of the applied nitrogen.

One last sampling date occurred shortly after the establishment period to evaluate further loss of nitrate. Once again, the ISP treatment and the 39.0 kg N ha^{-1} wk^{-1} treatment leached significantly higher nitrate-N than all other treatments (Table 2.9). At this sampling date, each of these treatments leached slightly more than 2 percent of the total applied nitrogen (Table 2.10).

By observing the percent of applied nitrogen leached total, the ISP treatment leached approximately 44 percent of applied nitrogen as nitrate-N and the 39.0 kg N ha^{-1} wk^{-1} treatment leached approximately 39 percent of the applied nitrogen as nitrate-N (Table 2.10). The amount of nitrate-N lost is excessive especially if it is not necessary for adequate establishment, but obviously the ISP treatment will leach the greatest quantity of nitrate-N even if the percent leached between treatments are somewhat similar. Even the 19.0 kg N ha^{-1} wk^{-1} treatment leached slightly greater than 22 percent of the total applied nitrogen (Table 2.10). All other treatments leached much lower quantities of nitrate-N as sprigs were likely able to utilize most of the applied nitrogen. An estimate of the amount of nitrogen leached can be determined from the quadratic relationship in Figure 2.4. In 1999, on a sand-based soil $y=.001x^2 + .0455x$ where x is the total applied nitrogen and y is the amount of nitrogen leached as nitrate-N

Figure 2.4 Total Applied Nitrogen Leached After the 1999 Bermudagrass Sprig Establishment Lysimeter Study in Blacksburg, VA.



(Figure 2.4). A similar relationship may have been evident in 1998 if the treatments receiving the lower nitrogen rates were not removed due to a misapplication.

Nitrogen Treatment Effects on Percent Cover

After four weeks of sprig development, significant differences with respect to percent cover were apparent (Table 2.11). Interestingly enough, the two treatments that received the greatest quantity of nitrogen (39.0 kg ha^{-1} wk^{-1} and the ISP) possessed lower percent cover values statistically when compared with all other treatments (Table 2.11). This is most likely attributed to sprig variability or uneven sprig mortality, however, it is apparent that little nitrogen is used by establishing sprigs up to this point.

After eight weeks significant differences with respect to total percent cover existed (Table 2.11). However, all treatments receiving 9.8 kg N ha^{-1} wk^{-1} or greater achieved percent cover similar to the ISP treatment (Table 2.11). Therefore, after 8 weeks, an 80 percent reduction in total applied nitrogen achieved percent cover ratings similar to the ISP treatment on this high sand content soil.

Plots were visually rated for percent cover after ten weeks to further evaluate bermudagrass establishment. Significant differences with respect to total percent cover existed and results were very similar to week eight (Table 2.11). All treatments receiving 9.8 kg N ha^{-1} wk^{-1} or greater achieved percent cover ratings similar to the ISP treatment (Table 2.11). Once again, an 80 percent reduction in applied nitrogen provided percent cover values similar to the ISP treatment on sand-based soil.

Table 2.11 Effect of Nitrogen Regime on Percent Cover for the 1999 Bermudagrass Sprig Establishment Lysimeter Study in Blacksburg, VA.

Weekly Applied Nitrogen	Total Applied Nitrogen	Percent Cover Week 4	Percent Cover Week 8	Percent Cover Week 10
--------------------kg ha^{-1}--------------------				
0.0	0.0	47.5 NS[2]	57.5 c[1]	60.0 c
4.9	39.0	47.5	83.8 b	86.3 b
9.8	78.1	58.8	97.5 a	97.5 a
19.5	156.2	60.0	96.3 a	100.0 a
39.0	312.3	43.8	95.0 ab	98.3 a
48.8	390.4	45.0	100.0 a	100.0 a

[1] Means in the same column followed by the same letter are not significantly different according to Tukey' s Studentized Range test at the 0.05 level of probability.

[2] NS= Not significant according to Tukey' s Studentized Range Test at the 0.05 level of probability.

Nitrogen Treatment Effects on Turfgrass Color

After four weeks of sprig development, visual differences with respect to turfgrass color were negligible between all treatments. After eight weeks, all treatments receiving 19.5 kg N ha^{-1} wk^{-1} or greater had turfgrass color similar to the ISP treatment (Table 2.12). It is important to note that the 9.8 kg N ha^{-1} wk^{-1} treatment while having significantly lower turfgrass color than the ISP treatment had color ratings of 5.8, which is acceptable although statistically less than treatments receiving more nitrogen (Table 2.12).

Plots were visually rated after ten weeks of grow-in to continue to evaluate bermudagrass establishment. Turfgrass color values were very similar to those after eight weeks (Table 2.12). All treatments receiving 19.5 kg N ha^{-1} wk^{-1} or greater had turfgrass color similar to the ISP treatment (Table 2.12). The 4.9 and the 9.8 kg N ha^{-1} wk^{-1} treatments while having significantly lower turfgrass color than the ISP treatment still had acceptable color ratings (Table 2.12). Therefore, in 1999, 10 times less nitrogen than the ISP could be applied and still achieve acceptable color ratings. An 80 percent reduction in applied nitrogen achieved percent cover similar to the ISP treatment and acceptable turfgrass color.

Nitrogen Treatment Effects on Turfgrass Density

After four weeks, visual differences with respect to turfgrass density were negligible. After eight weeks of sprig development, the ISP treatment had significantly greater turfgrass density than all other treatments (Table 2.13). However, all treatments that received 9.8 kg N ha^{-1} wk^{-1} or greater may not have had density ratings similar to the

Table 2.12 Effect of Nitrogen Regime on Turfgrass Color for the 1999 Bermudagrass Sprig Establishment Lysimeter Study in Blacksburg, VA.

Weekly Applied Nitrogen	Total Applied Nitrogen	Turfgrass Color[2] Week 8	Turfgrass Color[2] Week 10
--------------------kg ha^{-1}	--------------------		
0.0	0.0	4.0 c[1]	4.0 d
4.9	39.0	4.8 c	5.0 cd
9.8	78.1	5.8 b	5.8 bc
19.5	156.2	6.5 ab	6.8 ab
39.0	312.3	6.8 a	6.8 ab
48.8	390.4	7.0 a	7.0 a

[1] Means in the same column followed by the same letter are not significantly different according to Tukey' s Studentized Range test at the 0.05 level of probability.

[2] Turf Color data was recorded on a 1 to 9 scale (1=brown turf, 5=acceptable, 9=dark green turf)

Table 2.13 Effect of Nitrogen Regime on Turfgrass Density for the 1999 Bermudagrass Sprig Establishment Lysimeter Study in Blacksburg, VA.

Weekly Applied Nitrogen	Total Applied Nitrogen	Turfgrass Density[2] Week 8	Turfgrass Density[2] Week 10
-------------------kg ha^{-1}	-------------------		
0.0	0.0	3.8 d[1]	4.0 c
4.9	39.0	4.5 cd	4.3 c
9.8	78.1	5.5 bc	5.5 b
19.5	156.2	6.5 b	6.5 a
39.0	312.3	6.3 b	6.3 ab
48.8	390.4	7.8 a	7.0 a

[1] Means in the same column followed by the same letter are not significantly different according to Tukey' s Studentized Range test at the 0.05 level of probability.

[2] Turf Density was recorded on a 1 to 9 scale (1=no turf, 5=acceptable, 9=dense, uniform turf)

ISP but did have acceptable turfgrass density ratings (Table 2.13). Therefore, in 1999, an 80 percent reduction in total applied nitrogen may not lead to turfgrass density similar to the ISP treatment after eight weeks of grow-in but provided percent cover similar to the ISP, and acceptable turfgrass color and density.

Plots were visually rated for turfgrass density after ten weeks to further evaluate bermudagrass establishment. All treatments receiving 19.5 kg N ha^{-1} wk^{-1} or greater had turfgrass density similar to the ISP treatment (Table 2.13). However, all treatments receiving 9.8 kg N ha^{-1} wk^{-1} or greater, while being significantly lower than the ISP treatment, did possess density values suitable for golf course fairway situations (Table 2.13). Therefore, in 1999, after a ten week sprig establishment period, an 80 percent reduction in total applied nitrogen achieved similar percent cover and adequate turfgrass color and turfgrass density on sand-based soil (Table 2.13). If necessary turfgrass density could be enhanced after the grow-in period with supplemental nitrogen applications, thereby, reducing nitrogen necessary during sprig establishment.

Nitrogen Treatment Effects on Total Root Production

In November 1999, total root weights were evaluated well after the bermudagrass entered dormancy. Nitrogen treatment effect on root weight can be found in Table 2.14. Only the 39.0 kg N ha^{-1} wk^{-1} treatment had root weight similar to the ISP treatment (Table 2.14). Both of these treatments had very high turfgrass density, which would suggest an ability to develop a larger root system. This is interesting considering the amount of phosphorous remained constant between treatments and phosphorous was not limiting root development. However, treatments receiving 9.8 and 19.5 kg N ha^{-1} wk^{-1}

Table 2.14 Effect of Nitrogen Regime on Root Production for the 1999 Bermudagrass Sprig Establishment Lysimeter Study in Blacksburg, VA.

Weekly Applied Nitrogen	Total Applied Nitrogen	Root Production[2]
--------------------kg ha^{-1}	--------------------------------	-------------kg ha^{-1}-----------
0.0	0.0	10.0 d[1]
4.9	39.0	13.8 bcd
9.8	78.1	15.8 abc
19.5	156.2	13.2 cd
39.0	312.3	18.8 ab
48.8	390.4	19.2 a

[1] Means in the same column followed by the same letter are not significantly different according to Tukey' s Studentized Range test at the 0.05 level of probability.

may have had lower root weights than the ISP treatment, but still possessed desirable percent cover, color, and turfgrass density. Therefore, in 1999, an 80 percent reduction in applied nitrogen provided more than acceptable bermudagrass establishment and development.

Conclusions

Loss of nitrate to ground and surface waters can cause major health and environmental threats. Numerous nitrogen loss studies have been completed on established turfgrass systems, however, very little attention has been paid to nitrogen loss during turfgrass establishment (Petrovic, 1990). Specifically, a potential source on nitrate contamination exists during bermudagrass sprig establishment. Since the ISP is to apply 48.8 kg N ha^{-1} wk^{-1} of water-soluble nitrogen during the eight to ten week grow-in period the potential for nitrogen loss is great.

This study suggests that by applying the ISP nitrogen rate, to a high sand content soil, that large quantities of nitrate-N can be leached through the turfgrass system during bermudagrass spring establishment. In 1998 and 1999 very high levels of nitrate-N leached, especially during the early post-sprigging establishment period when root systems are immature and there are very few plants per unit area. Bermudagrass sprig nitrogen utilization appears minimal because it readily leaches below their shallow root zone.

In 1999, relatively little nitrogen leached early on due to lack of precipitation. However, when a large precipitation event occurred the three treatments receiving the greatest quantity of nitrogen leached greater than 24 percent of the total applied nitrogen after four weeks. All other treatments receiving supplemental nitrogen leached less than 8 percent of the total applied nitrogen as NO_3-N. It is apparent that during early post-sprigging the potential for nitrogen loss is great because sprigs are using very little nitrogen due to immature root systems and low sprig density. This potential for loss was demonstrated in the high sand content soil used in this study.

In 1998, after the completion of the study all remaining treatments (those receiving the greatest quantity of nitrogen) leached greater than 35 percent of the total applied nitrogen. Once again in 1999, the 19.5, 39.0, and the 48.8 kg N ha^{-1} wk^{-1} treatment (ISP treatment) leached approximately 22 percent, 39 percent, and 45 percent of the total applied nitrogen, respectively. In 1999, other treatments receiving less than 19.5 kg N ha^{-1} wk^{-1} leached 5 percent of the total applied nitrogen or less eluding that developing sprigs were better able to utilize the applied nitrogen.

The ISP nitrogen rate, on sand-based soil, can lead to very high quantities of nitrate-N loss. Even treatments receiving less than the ISP nitrogen rate can leach considerable amounts especially during the early post-sprigging establishment period when root systems are immature and sprig density is low. In turn, nitrogen uptake is low. It was demonstrated that even on sand-based soil an 80 percent reduction in weekly applied nitrogen and total applied nitrogen will provide percent cover similar to the ISP treatment and acceptable turfgrass color and density after the eight week establishment date was reached. Therefore, these studies demonstrate the potential to reduce nitrogen applied during spring establishment, on sand-based soils, to minimize nitrogen leaching without compromising turfgrass quality. As mentioned in the previous chapter, a slow release nitrogen source during the first four weeks of sprig development may be more appropriate than applying readily available nitrogen sources at this time, which will leach below immature root systems quite rapidly. However, it appears that even during the later stages of sprig establishment the ISP nitrogen rate may be excessive on a high sand-based soil. It certainly was not required in this study to provide similar percent cover and acceptable turfgrass color and density. The ISP nitrogen rate may only lead to further nitrate-N loss without significantly improving sprig development.

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Chapter 3

Establishment Nitrogen Application Effect on Bermudagrass Sprig Development

Introduction

Bermudagrass (*Cynodon dactylon*) is the dominant turfgrass in the southern United States used for fine turf situations. In the South, it is the primary turfgrass species used on athletic fields and golf course tees, fairways, and roughs. Most improved bermudagrass varieties are typically established vegetatively rather than from seed because of low quantities of viable hybrid seed (Duble, 1989). The most common method of vegetative establishment is to plant rhizome or stolon segments of bermudagrass, commonly referred to as sprigs. Puhalla et al. (1999) define a "sprig" as "a vegetative stem (a rhizome or stolon) that has multiple nodes that will initiate growth when properly planted".

According to Puhalla et al. (1999) a typical sprig establishment period is two months with nitrogen applications of 24.4 kg N ha^{-1} wk^{-1}. However, immediately after sprigging the industry standard practice (ISP) is to apply 48.8 kg N ha^{-1} wk^{-1} of water-soluble nitrogen to ensure rapid establishment (Chalmers, 1998). Shortly after sprigs are planted they do not possess root systems, therefore, they depend on reserve carbohydrates to initialize root development. If recently sprigged areas are being heavily fertilized with water-soluble nitrogen at this time large quantities of nitrogen could be wasted. This loss of nitrogen not only raises monetary concerns but cause health and environmental threats.

Determining when a bermudagrass sprig begins nitrogen uptake and relating this to planting density would help determine a more appropriate nitrogen fertilization regime during bermudagrass sprigging. During the early post-sprigging development period, sprigs are beginning to spread laterally, however, there are very few plants per unit area. Therefore, the Industry Standard Practice (ISP) of applying large quantities of nitrogen may not be necessary to provide adequate sprig development. The potential for nitrogen loss may exist since root systems are immature and plant density is minimal. Determining sprig activity with respect to nitrogen uptake during the grow-in period could lead to obtaining more appropriate nitrogen fertility requirements for bermudagrass sprig establishment. This, in turn, could minimize the chance for nitrogen loss during bermudagrass sprig establishment without compromising the grow-in period.

Objectives

The objective of this study was:

1) To determine the effects of varying nitrogen rates on early post-sprigging bermudagrass shoot and root development.

Materials and Methods

Two separate but identical greenhouse studies were conducted in 1999 at the Virginia Tech greenhouses in Blacksburg, Virginia. Trial 1 began on June 21, 1999 and Trial 2 began on August 8, 1999. This study consisted of four replications of six different nitrogen rates with harvest dates occurring one, two, three, four, and six weeks after nitrogen treatments began (Table 3.1).

Table 3.1 Weekly Nitrogen Treatments for the 1999 Bermudagrass Sprig Establishment Greenhouse Studies in Blacksburg, VA.

Nitrogen Treatments	Total Applied Nitrogen
---kg ha^{-1} wk^{-1}---	---kg ha^{-1}---
0.0	0.0
4.9	29.3
9.8	58.6
19.5	117.1
39.0	234.2
48.8	292.8

Pots were arranged on the greenhouse bench by replication. Each 15.25 cm diameter pot was filled with approximately the same amount of washed medium gravel (.75 cm-1.5 cm) to prevent loss of the rooting media through drained pots. A sand/soil/peat (70/10/20 percent by volume) mixture was used as the growing medium. Initial soil test results (analyzed by the Virginia Tech soil testing laboratory) for the root zone mix reported pH = 5.5, P = 25 ppm (H-), K = 25 ppm (L), Ca = 300 ppm (L+), Mg = 90 (H-). The root zone mix possessed an initial infiltration rate of 49 cm hr^{-1}, aeration porosity of 20.8 percent, and moisture retention at 30 cm of 9.9 percent (E & S Soils, 1998).

Only one sprig of approximately the same size with the same number of nodes (4) was then planted in each pot. Sprigs were allowed to sit for four days before nitrogen fertility trials began. Each pot was fertilized bi-weekly using dissolved urea (46-0-0), according to the nitrogen rates shown in Table 3.1. Fertilization was accomplished by applying 20 ml of the desired nitrogen solution to each pot using a 60 cm^3 syringe. Also, each pot received the low label rate (2.3 L ha^{-1}) of Scott's Fluid Minors Package weekly to ensure other nutrients were not limiting. The Fluid Minors Package contains P (4%), K (4%), Mg (2%), S (3%), B (0.02%), Fe (5%), Mn (0.5%), and Zn (0.05%). Pots were lightly watered in after nitrogen applications to simulate fertigation. Irrigation occurred via an overhead mist system three times daily for a period of two minutes to keep the sprigs moist. Approximately 5.0 cm of irrigation was applied weekly. At each harvest date, six designated pots (one from each nitrogen regime) from each replication (24 total) were removed from the greenhouse (just prior to the next weekly nitrogen application). Each was washed of growing medium and root and shoots separated. Roots and shoots were then oven dried and weighed. Total bermudagrass stolon length, including branching, of each pot was measured. In Trial 1, stolon length was only measured at week six, however, for Trial 2, total stolon length was measured at each harvest date. Pots were harvested after one, two, three, four and six weeks of nitrogen treatment. For Trial 1 this occurred on July 2, 1999, July 10, 1999, July 17, 1999, July 24, 1999, and August 7, 1999. For Trial 2 harvest dates occurred on August 20, 1999, August 27, 1999, September 4, 1999, September 12, 1999, and September 27, 1999.

Data Recorded

Observations recorded throughout the course of the greenhouse study involved harvesting selected groups of pots after each week of nitrogen treatment. Sprigs were washed, root and shoots separated and then oven-dried. Then, upon drying, root and shoot weights in milligrams were taken. After six weeks of the first study and throughout the second study, total stolon length was also measured prior to drying and data was recorded in centimeters. This procedure continued each week until the study was completed. All data recorded was analyzed using Tukey's studentized range test at the 0.05 level of confidence (SAS, 1985).

Results

Mean daily temperatures throughout both studies averaged approximately 26° C. Temperatures were greater than those necessary for ideal bermudagrass growth and development (24 °C) to occur (Duble, 1989). It is important to note that Trial 2 occurred later in the summer with a shorter photoperiod than Trial 1, therefore, as expected, overall bermudagrass development was less in Trial 2 than Trial 1.

Trial 1

After one week differences did not exist with respect to shoot and root development (Table 3.2, Table 3.3). Also, shoot weight and root weight differences between treatments did not exist after two and three weeks of nitrogen treatment (Table 3.2, Table 3.3). At the four and six week harvest dates shoot weight differences occurred but even the control achieved shoot weights similar to the ISP treatment (Table 3.2). Interestingly enough, the 9.8 and the 39.0 kg N ha^{-1} wk^{-1} treatments achieved the greatest shoot weights at the three and four week harvests, respectively, but all treatments receiving nitrogen had shoot weights similar to those treatments (Table 3.2). Root weight differences did not occur at the three and four week harvests (Table 3.3). At this stage of sprig development, reserve carbohydrates appear to be the primary source of energy to initialize sprig root growth and development, therefore, high nitrogen rates appears to have little effect on bermudagrass development. Therefore, high nitrogen rates did not significantly enhance early post-sprigging development since even the control achieved shoot weight similar to the treatment.

Once again, after six weeks all treatments achieved shoot weights and root weights similar to the ISP treatment (Table 3.2, Table 3.3). With regard to total stolon length after six weeks only the untreated control had lower total stolon length than the ISP treatment (Table 3.4). After six weeks, shoot and root weight similar to the ISP could be attained using no nitrogen and similar shoot length could be attained using only

Table 3.2 Weekly Applied Nitrogen Influence on Shoot Weight During Bermudagrass Sprig Development (trial 1)

Weekly Applied Nitrogen	Harvest Period 1 Week	2 Weeks	3 Weeks	4 Weeks	6 Weeks
---kg ha^{-1} ---	----------Shoot Weight (mg)----------				
0.0	45.0 NS[2]	141.0 NS	113.8 NS	242.0 b[1]	573.0 b
4.9	49.0	129.0	202.8	551.0 ab	2088.0 b
9.8	39.0	186.0	396.5	800.0 ab	1995.0 ab
19.5	47.0	151.0	193.5	716.0 ab	5118.0 a
39.0	47.0	186.0	208.5	1120.0 a	3163.0 ab
48.8	48.0	187.0	295.5	575.0 ab	3562.0 ab

[1] Means in the same column followed by the same letter are not significantly different according to Tukey' s Studentized Range test at the 0.05 level of probability.

[2] NS= Not significant according to Tukey' s Studentized Range test at the 0.05 level of probability

Table 3.3 Weekly Applied Nitrogen Influence on Root Weight During Bermudagrass Sprig Development (trial 1)

Weekly Applied Nitrogen	Harvest Period 1 Week	2 Weeks	3 Weeks	4 Weeks	6 Weeks
---kg ha^{-1} ---	Root Weight (mg)				
0.0	3.0 NS[2]	22.0 NS	29.0 NS	115.0 NS	176.8 b[1]
4.9	3.0	31.0	40.0	111.0	342.5 ab
9.8	2.0	31.0	51.0	129.0	338.8 ab
19.5	2.0	22.0	38.0	135.0	636.5 a
39.0	2.0	33.0	37.0	149.0	528.8 ab
48.8	2.0	33.0	41.0	86.0	320.3 ab

[1] Means in the same column followed by the same letter are not significantly different according to Tukey' s Studentized Range test at the 0.05 level of probability.

[2] NS= Not significant according to Tukey' s Studentized Range test at the 0.05 level of probability

Table 3.4 Weekly Applied Nitrogen Influence on Shoot Length During Bermudagrass Sprig Development (trial 1)

Weekly Applied Nitrogen	**Harvest Period 6 Weeks**
---kg ha^{-1} ---	----------------Shoot Length (cm)----------
0.0	80.7 b[1]
4.9	344.8 ab
9.8	302.3 ab
19.5	683.3 a
39.0	502.3 ab
48.8	570.2 ab

[1] Means in the same column followed by the same letter are not significantly different according to Tukey' s Studentized Range test at the 0.05 level of probability.

10 percent of the ISP nitrogen rate. It is important to note that the sprigged pot which received the ISP treatment (48.8 kg N ha^{-1} wk^{-1}) did not posses the greatest average shoot weights, average root weights, or average stolon lengths at the six week harvest date (Table 3.2, Table 3.3, Table 3.4). The treatment receiving 19.6 kg N ha^{-1} wk^{-1}, only 40 percent of the ISP treatment possessed the greatest average shoot weights, root weights, and total stolon length. This may have been attributed to variability in sprig reserve carbohydrates. In other words, sprigs of approximately the same size may possess inherently more reserve carbohydrates.

Trial 2

Root and shoot weights for the first three weeks were very similar to that of Trial 1 (Table 3.5, Table 3.6). No differences in shoot and root weights occurred at each of the first three harvest dates (Table 3.5, Table 3.6). In Trial 2, shoot lengths were also measured at each sacrifice date. Once again, total stolon length differences did not occur during the first three harvest dates (Table 3.7). Shortly after sprigging, sprigs are beginning to develop root systems and using reserve carbohydrates to initialize growth. Therefore, with immature roots systems nitrogen uptake appears to be very low.

Statistical differences were found at the week four harvest with respect to shoot weight (Table 3.5). The ISP treatment (48.8 kg N ha^{-1} wk^{-1}) achieved greater shoot weight than all other treatments (Table 3.5). Interestingly enough, root weight differences did not occur between treatments (Table 3.6). This is most likely because phosphorous was not limiting due to the Scott's Fluid Minor Package applied. After four weeks, statistical differences existed with respect to total stolon length (Table 3.7). The

Table 3.5 Weekly Applied Nitrogen Influence on Shoot Weight During Bermudagrass Sprig Development (trial 2)

Weekly Applied Nitrogen	Harvest Period 1 Week	2 Weeks	3 Weeks	4 Weeks	6 Weeks
---kg ha^{-1}---	---Shoot Weight (mg)---				
0.0	54.0 NS[2]	46.0 NS	118.0 NS	141.0 b[1]	246.0 b
4.9	46.0	57.0	113.0	350.0 ab	1341.0 ab
9.8	34.0	60.0	94.0	159.0 b	430.0 b
19.5	38.0	69.0	231.0	299.0 ab	1584.0 a
39.0	49.0	69.0	147.0	241.0 ab	1558.0 a
48.8	59.0	94.0	186.0	664.0 a	2066.0 a

[1] Means in the same column followed by the same letter are not significantly different according to Tukey' s Studentized Range test at the 0.05 level of probability.

[2] NS= Not significant according to Tukey' s Studentized Range test at the 0.05 level of probability

Table 3.6 Weekly Applied Nitrogen Influence on Root Weight During Bermudagrass Sprig Development (trial 2)

Weekly Applied Nitrogen	**Harvest Period**				
	1 Week	**2 Weeks**	**3 Weeks**	**4 Weeks**	**6 Weeks**
---kg ha^{-1} ---	---Root Weight (mg)---				
0.0	2.0 NS[2]	2.0 NS	14.0 NS	26.0 NS	52.0 b[1]
4.9	1.0	3.0	14.0	21.0	167.0 a
9.8	1.0	5.0	12.0	25.0	63.0 b
19.5	1.0	4.0	12.0	20.0	123.0 ab
39.0	2.0	5.0	34.0	24.0	107.0 ab
48.8	1.0	3.0	21.0	21.0	155.0 a

[1] Means in the same column followed by the same letter are not significantly different according to Tukey' s Studentized Range test at the 0.05 level of probability.

[2] NS= Not significant according to Tukey' s Studentized Range test at the 0.05 level of probability

Table 3.7 Weekly Applied Nitrogen Influence on Shoot Length During Bermudagrass Sprig Development (trial 2)

Weekly Applied Nitrogen	Harvest Period 1 Week	2 Weeks	3 Weeks	4 Weeks	6 Weeks
---kg ha^{-1} ---	---Shoot Length (cm)---				
0.0	7.6 NS[2]	12.1 NS	14.0 NS	26.7 b[1]	39.4 c
4.9	9.2	16.5	16.5	41.3 b	139.7 bc
9.8	7.6	19.1	17.8	31.8 b	59.7 c
19.5	8.6	13.3	24.8	42.5 b	213.4 ab
39.0	8.9	15.2	17.8	51.4 ab	196.2 ab
48.8	8.6	15.9	21.6	95.9 a	293.4 a

[1] Means in the same column followed by the same letter are not significantly different according to Tukey' s Studentized Range test at the 0.05 level of probability.

[2] NS= Not significant according to Tukey' s Studentized Range test at the 0.05 level of probability

ISP treatment had greater total stolon length than all other treatments reinforcing the total shoot weight data obtained. The ISP treatment did possess the greatest average shoot weight and stolon lengths; however, this was not the case at the six week harvest period.

After six weeks, shoot weight and root weight differences occurred, however, the 4.9 kg N ha^{-1} wk^{-1} treatment, receiving only 10 percent of the ISP nitrogen rate, achieved similar shoot and root weight to the ISP treatment (Table 3.5, Table 3.6). This could be attributed to sprig variability from pot to pot. The 9.8 kg N ha^{-1} wk^{-1} treatment had lower shoot weight and root weight than the ISP treatment (Table 3.6). All other treatments receiving 19.5 kg N ha^{-1} wk^{-1}or greater had shoot weight and root weight values similar to the ISP treatment. By observing total stolon length development, very similar growth could be achieved with much less nitrogen (Table 3.7). Treatments receiving 19.5 kg N ha^{-1} wk^{-1} or greater achieved total stolon length similar to the ISP treatment, a 40 percent reduction in applied nitrogen (Table 3.7).

As in Trial 1, it appears that the ISP of applying 48.8 kg N ha^{-1} wk^{-1} is in excess and similar shoot weight, root weight, and stolon length could be achieved using much less nitrogen. After six weeks of nitrogen treatments, similar shoot and root weight was achieved using only 10 percent of the ISP weekly nitrogen rate and similar stolon length was achieved using 40 percent of the ISP nitrogen rate. It is important to note, that shoot weight and root weight throughout Trial 2 was much lower than that of Trial 1 and may be attributed to a reduced photoperiod. Also, after the last harvest total stolon lengths in Trial 2 were much lower than Trial 1. Once again, this is mostly likely attributed to the shortened photoperiod, thereby, reducing overall bermudagrass growth and development.

Conclusions

Nitrogen use during bermudagrass sprig development has not been identified and appropriate nitrogen rates during sprig establishment has not been determined. Puhalla et al. (1999) recommends nitrogen applications of 24.4 kg N ha^{-1} wk^{-1} for an eight week period, however, the ISP is to apply 48.8 kg N ha^{-1} wk^{-1} of water-soluble nitrogen to ensure a rapid establishment (Chalmers, 1998). The goal of this study was to identify how much nitrogen a developing bermudagrass sprig can utilize.

In Trial 1, during the first three weeks after sprigging it appears that an individual sprig utilizes little if any applied nitrogen because shoot weight and root weight differences did not exist between the control (no nitrogen) and the ISP treatment. After four and six weeks of nitrogen treatment only 4.8 kg N ha^{-1} wk^{-1} was necessary to achieve similar shoot weight and root weight compared to the ISP nitrogen rate, a 90 percent reduction in applied nitrogen. Also, after six weeks of nitrogen applications even the control achieved total stolon length similar to the ISP treatment.

In Trial 2, as in Trial 1, during the first three weeks after sprigging it appears that an individual sprig utilizes little if any nitrogen because shoot weight, root weight, and total stolon length differences did not exist between the control (no nitrogen) and the ISP treatment. After four weeks, the ISP nitrogen rate did possess higher shoot weight and stolon length than all other treatments. At this point, root systems may have developed enough to uptake nitrogen and aid sprig development; however, this is inconsistent with Trial 1 so further research should be conducted to evaluate these findings. Root weight differences did not occur after four weeks.

This study concluded that the ISP of applying 48.8 kg N ha^{-1} wk^{-1} does not significantly enhance overall shoot weight, stolon length, and root weight development especially during the first three weeks post-sprigging. Nitrogen rate influence may have been reduced since the sandy rooting media used in this study may have resulted in applied nitrogen leaching through the soil. In fact, in both studies, during the first three weeks post-sprigging an individual sprig utilized little if any nitrogen because differences did not exist between the control (no nitrogen) and the ISP. The first few weeks post-sprigging, the bermudagrass sprigs are just starting to get established and using reserve carbohydrates to initialize root growth. Therefore, high supplemental soluble nitrogen applications appear unnecessary during this time period. However, as sprig density increases and the bermudagrass begins to spread laterally during the last half of the establishment period, there is more plant material per unit area and root systems are more established. At this time, higher nitrogen rates may be more appropriate to enhance sprig establishment. In other words, even after six weeks of sprig development an individual sprig may not need the ISP nitrogen rate, however, higher nitrogen rates are most likely necessary because there are more plants (sprigs) per unit area. Individual sprigs appear to not require the ISP nitrogen rate shortly after sprigging when plant density and nitrogen uptake (due to minimal root development) are low. Therefore, high nitrogen rates at this time are impractical, excessive, and prone to leaching losses.

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Summary

Chapter 1

The objective of this research was to determine early post-sprigging nitrogen requirements. Overall, is it apparent that the ISP nitrogen rate over an eight week period does not significantly increase percent cover, turfgrass color, or turfgrass density. In both 1998 and 1999, most treatments receiving far less nitrogen than the ISP possessed desirable percent cover and more than acceptable turfgrass color and density.

During the early post-sprigging establishment period the ISP nitrogen rate is excessive and may lead to environmental contamination. This is when the least amount of nitrogen is needed during sprig establishment. At this stage of sprig development nitrogen uptake is minimal due to immature root systems and low sprig density. It appears impossible for growing sprigs to effectively utilize the ISP nitrogen rate during the early post-sprigging period. For that matter, Puhala's (1999) recommended rate of 24.4 kg N ha^{-1} wk^{-1} may also be excessive at that time. Applying little nitrogen (less than 48.8 kg ha^{-1} total for the four weeks) or a slow-release nitrogen source may be all that is required to not hinder sprig establishment

After the establishment period ended, once again it was apparent that weekly applications of the ISP were not necessary during the later stages of sprig development. Treatments receiving far less applied nitrogen achieved percent cover similar to the ISP treatment and more than acceptable turfgrass color and density. As a safe recommendation during sprig establishment, the general trend of little if any nitrogen during the first four weeks followed by the ISP nitrogen rate during the last four weeks of establishment should provide adequate percent cover and more than acceptable turfgrass color and density. Such a sprig establishment fertilization program should not hinder sprig development while also being more environmentally sensitive. Quite possibly, an application of 48.8 kg N ha^{-1} of a slow release nitrogen source at sprigging would most likely provide enough nitrogen during the first four weeks of sprig development. Applying this fertilization regime during sprig establishment should minimize nitrogen leaching without compromising the eight to ten week sprig establishment period.

Chapter 2

The ISP nitrogen rate during sprig establishment can certainly pose great risk to our ground and surface waters. This study concluded that very high rates of nitrogen could be leached as nitrate-N especially during the early post-sprigging establishment period, on a high sand content soil. At this stage of sprig development, high nitrogen rates are impractical because root systems are immature and there are few sprigs per unit area. Due to low nitrogen uptake, the potential for nitrogen leaching is excessive, especially if a large precipitation event occurs. Applied nitrogen does not have to leach very deep into the soil profile to be out of reach of immature bermudagrass sprig root systems.

Also, it was concluded that the ISP nitrogen rate was not necessary to provide desirable percent cover, and acceptable turfgrass color and density by the end of the establishment period. Specifically, in both years of the study an 80 percent reduction in weekly and total applied nitrogen achieved percent cover similar to the ISP treatment and acceptable turfgrass color and density. In the experiments, the ISP lost 34.7 and 44.6

percent of applied nitrogen in 1998 and 1999, respectively. Therefore, there is no need to apply the ISP nitrogen rate especially during the early post-sprigging establishment period. As in Chapter 1, very low rates of nitrogen during the first four weeks post-sprigging followed by ISP nitrogen rates would minimize leaching threats without compromising the eight to ten week establishment period. Furthermore, a slow release nitrogen source applied at sprigging would further limit the potential for early post-sprigging nitrogen leaching.

Chapter 3

The purpose of this study was to quantify how much nitrogen an individual sprig could use, especially during the early post-sprigging establishment period. This would more fine-tune how much nitrogen to apply early on if differences were found between treatments. Results of this study were quite surprising. In both trials, during the first three weeks of nitrogen treatment differences were not found between the ISP treatment and all other treatments. Therefore, an individual sprig appears to utilize little if any nitrogen during this time. Sprigs are using reserve carbohydrates to initialize growth and nitrogen uptake appears to be very low.

In Trial 1, after four weeks of nitrogen treatment, a 90 percent reduction in applied nitrogen achieved shoot weight and root weight similar to the ISP treatment. In Trial 2, the ISP nitrogen rate possessed significantly greater shoot weight and shoot length but is most likely attributed to sprig variability. In other words, sprigs of approximately the same size may inherently possess more reserve carbohydrates because after six weeks of nitrogen treatments, in both studies, a 90 percent reduction in weekly applied nitrogen achieved similar shoot weight. Similar individual shoot length in Trial 2 was achieved using only 40 percent of the ISP nitrogen rate. Therefore, one could greatly minimize the amount of nitrogen applied early post-sprigging and not be detrimental to overall sprig development

High supplemental nitrogen applications during the early post-sprigging establishment period are not necessary. It is apparent that an individual sprig simply does not utilize much nitrogen early on but as plant density increases later in the establishment period, greater nitrogen rates may be necessary due to increased sprig density and more extensive root systems. Chapter 2 did show, however, that an 80 percent reduction in total applied nitrogen would not significantly inhibit sprig development even on a high sand content soil after the eight to ten week grow-in period. However, as a safe recommendation, low nitrogen rates during the first four weeks following sprigging followed by ISP nitrogen rates during the last four weeks should provide for desirable bermudagrass establishment. Potential for nitrate leaching during the last four weeks of nitrogen treatment still exists but a turfgrass manager, in most cases, wants the area to be established and ready for use as soon as possible. They would have a hard time taking the chance of applying extremely low rates of nitrogen throughout the establishment period but can minimize loss through proper timing and irrigation.

Vita

Jon Eric Zalewski was born on March 2, 1975 in Havre de Grace, MD. He is the son of John and Diane Zalewski who reside in Bel Air, MD. He graduated from C. Milton Wright High School in 1993 to pursue a career in environmental studies at Virginia Tech. He graduated with a B.S. in Environmental Resource Management: Soil and Water Concentration in 1997 from Virginia Tech and subsequently entered the Crop and Soil Environmental Sciences Graduate Program. There he worked closely with Dr. David Chalmers earning a M.S. degree in Turfgrass Management/Agronomy. He was married to Katherine A. Morgan in April 2001 and they are currently expecting their first child. They now reside in Burlington, Vermont where Jon Zalewski is General Manager of a NaturaLawn of America franchise.