CHAPTER 2

ABOVE GROUND RESPONSES OF THREE COOL-SEASON LAWN SPECIES TO NITROGEN FERTILIZATION

Abstract

Lawns represent the largest managed turf areas in the United States and generally require a minimum of one annual nitrogen (N) application to maintain aesthetically pleasing green color and to promote sufficient vigor to recover from environmental stress and pest damage. This two and one half year field study evaluated the effects of eight N programs which varied by N amount, 0 – 196 kg N ha^{-1} yr^{-1}, and seasonal application timing on the above-ground plant responses of the three principal cool-season lawn species: Kentucky bluegrass (*Poa pratensis* L.) (KBG), perennial ryegrass (*Lolium perenne* L.) (PRG), and turf-type tall fescue (*Festuca arundinacea* Schreb.) (TTTF). As expected, dry matter yield (DMY), visual turfgrass quality (TQ), leaf tissue N content, and canopy greenness increased with increasing N rate. Significant DMY differences between species were measured, with total DMYs of 9,426, 7,750, and 7,011 kg ha^{-1} for TTTF, KBG, and PRG, respectively. KBG possessed the greenest canopy, as measured by reflectance, when averaged across all N-treatments followed by TTTF and PRG. Leaf tissue N was generally highest for PRG, 32.7-36.8 g kg^{-1} compared to 30.0-37.7 g kg^{-1} and 27.3-34.6 g kg^{-1} for KBG and TTTF, respectively. Visual TQ averaged across all N-treatments and study years was greatest and most consistent for TTTF followed by KBG and PRG. Although, overall TQ was lower in KBG compared to TTTF, primarily due to slow spring green-up and summer disease, KBG TQ was superior to TTTF on many dates during active growth. Perennial ryegrass had significantly lower TQ compared to TTTF and KBG due to substantial turf cover losses, 14-57 % in 2004 and 2005 from summer diseases. This data indicates that a predominantly KBG or PRG lawn in the cool-humid

region requires $\geq$ 123 kg N ha^{-1} yr^{-1} to maintain acceptable TQ and color. For PRG, even 196 kg N ha^{-1} may not be enough to promote significant vigor to contend with summer diseases. If the goal in lawn management is to maximize turfgrass responses with minimal N inputs, the most consistent species appears to be TTTF, since this species had acceptable TQ, color, and less disease at relatively low, 73 - 123 kg ha^{-1} yr^{-1}, N levels.

Introduction

Lawns represent the largest managed turf acreage in the United States and generally require a minimum of one annual nitrogen (N) application to maintain an aesthetically pleasing green color and promote sufficient vigor to recover from environmental stress and pest damage. Consequently, there is continued public concern regarding the misuse of N fertilizer by home owners and lawn professionals, posing a risk to surface and ground water contamination. Nitrogen fertilizer is not applied to turf to maximize dry matter yield, which would increase mowing frequency, but to promote a vigorous and healthy lawn. Nitrogen fertility programs for home owners should be designed specifically to moderate the supply of N to maintain turf growth at submaximal levels (Bowman, 2003). The timing, therefore, of N application is an important consideration when developing N fertility programs, especially programs that are environmentally responsible with minimal impact on water quality. The goal is still to produce a dense, green, healthy lawn, but N fertility programs need to consider this application timing to optimize the amount of N uptake by the plant thereby reducing N losses (Petrovic, 1990). In fact, N applied in excess of what the plant utilizes may cause N leaching below the root zone (Stout and Jung, 1992). There is limited research however, on the relative effectiveness of different N fertilization schedules with exception of late fall fertilization (Miltner et al., 2001). Nitrogen fertility programs designed around a more judicious use of N fertilizer should be evaluated to determine their effect on overall turfgrass health as related to above ground characteristics such as shoot growth, plant uptake, and turfgrass quality and color.

Historical Perspective: Nitrogen Fertilization

Nitrogen fertilization management strategies are influenced by climatic zone within the United States. Each climatic zone has varying air and soil temperatures which affect the growth cycle of turfgrasses and therefore determines what turfgrasses can be grown in that region. Indiana spans the cool-humid zone and part of the upper transition zone. In the north central region of Indiana, cool-season turfgrass species such as Kentucky bluegrass (*Poa pratensis* L.) (KBG), perennial ryegrass (*Lolium perenne* L.)

(PRG), and turf-type tall fescue (*Festuca arundinacea* Schreb.) (TTTF) are better adapted for use in the heart of the cool-humid zone. Cool-season grasses are typically used for home lawns because they do not turn an undesirable brown color in the winter months (dormancy), like warm-season turfgrass species.

Prior to the 1970's, N was applied heavily in the spring when the turf was rapidly growing and moderate N applications were applied in the fall, to match cool-season seasonal shoot growth patterns (Christians, 2004). This approach to N fertilization often caused the turf to rapidly deteriorate in the late summer. Currently, a minimum once per year N fertilizer application is recommended to occur late summer (e.g. September 1-15th) for a mature turf to encourage recovery from summer stresses and improve density through the autumn months (Reicher and Throssell, 1998). If applying twice annually, it is generally recommended that the second application occur mid to late spring after the early flush of growth. In recent decades, turfgrass scientists have advocated the use of a late-season N application from mid-October to mid-December when the turf has stopped actively growing (Turgeon, 2002).

Initially, late-fall fertilization was thought to reduce winter hardiness (Beard, 1973). However, research has demonstrated the physiological benefits of late-season (Oct.-Dec.) N applications to cool-season species. These include: increased carbohydrate reserves, reduced disease incidence, improved late season color retention, increased root growth and earlier spring green-up (Powell et al., 1967; Wilkinson and Duff, 1972; Wehner et al., 1988). Wilkinson and Duff (1972) found that N fertilization on KBG on 15 November enhanced growth and color in mid-April more than plants fertilized earlier in the fall. Koski and Street (1985) reported extensive root growth from late-fall fertilization which improved spring color on KBG reducing the need for an early spring N application. Nitrogen application timing of late-fall fertilization (mid-October to mid-December) seems to be location or climate dependent. Along the north east coast of the United States, late-fall recommendations have been for mid-October. In the mid-west, late-fall fertilization has historically been applied in mid-November to minimize pink snow mold (*Microdochium nivale*) severity associated with excessive turfgrass growth due to N application. Powell et al. (1967) reported that soluble N fertilizer applied in late-fall or winter improved turfgrass color during the winter and maintained it longer, whereas an October application of soluble N was not as efficient in retaining fall color. Wehner and Haley (1993) reported that soluble N applications in either December or January provided better turf color and yields than a November application or an October application, and that a November application was better than an October application. Mangiafico and Guillard (2006) reported that fertilizing turf on 15 October or later with 49 kg N ha^{-1} with soluble N improved turf color and density, however, optimizing turf color or density is not always a priority over water quality concerns. Recently, late-season N applications have received much attention because of the risk for leaching potential associated with slow turf growth rates and less plant uptake (Petrovic et al., 1986; Miltner et al., 1996; Liu et al., 1997; Magnifico and Gulliard, 2006). Mangiafico and Guillard (2006) suggested that water quality concerns would dictate an early or low rate fall N application if soluble N was used, or no late-fall N application. Most research on late-fall fertilization has been conducted primarily on KBG (Wilkinson and Duff, 1972; Wehner et al., 1988), however, other cool-season turfgrass species like PRG and TTTF are frequently planted in lawns and need to be evaluated for their N leaching potential.

Turfgrass Species

Kentucky bluegrass may be the most desirable turfgrass species for use in a home lawn, but is notoriously slow to germinate and establish from seed. During landscape construction, contractors typically add PRG to KBG when seeding lawns due to the quick germination and establishment of PRG, which stabilizes the soil. The problem with using PRG is that it is very competitive as a seedling and often crowds out KBG resulting in a predominately PRG lawn. Perennial ryegrass is susceptible to numerous diseases, which for the typical homeowner are difficult to control and manage without the use of fungicides. Historically tall fescue (TF), has been used as a forage crop or in low maintenance utility turf areas, rarely for high quality lawns. Early turf-type cultivars were light yellow in color, with wide leaf blades and heavy spring growth, characteristics associated with forage cultivars. In recent decades, breeding has improved this species and many high-quality darker green, TTTF cultivars are available for lawn use. Compared to KBG, TF germinates quickly, stabilizes the soil and is comparatively deep rooted requiring less irrigation at maturity.

Individual species requirements for N are different. The particular turfgrass genotype (species and cultivar) influences the amount of N required to sustain growth and the ability to absorb nitrate (Beard, 1973; Cisar et al., 1989; Petrovic, 1990). It is generally believed that KBG requires more N for adequate growth and development followed by PRG and TF, respectively. Since KBG is the most widely planted lawn species, much research has been conducted to evaluate N uptake, N use efficiency, and N recovery (Selleck et al., 1980; Hummel and Waddington, 1981; Starr and DeRoo, 1981; Mosdell et al., 1987; Liu et al, 1993; Miltner et al., 1996; Jiang and Hull, 1998; Jiang et al., 2000; Zemenchik and Albrecht, 2002; Engelsjord et al., 2004; Frank et al., 2006). Less information exists for PRG (Liu et al., 1993; Jiang et al., 2000; Miltner et al., 2001; Bowman, 2003; Engelsjord et al., 2004), and TF (Liu et al., 1993; Jiang et al., 2000; Hall et al., 2003). Even less research exists on TTTF. Species differences in N requirements for growth and development need to be considered when determining a specific N fertility program.

Nitrogen Fertility Programs

Previous research on N fertilization has focused on plant response to specific N application rates, fertilizer sources, or impacts of fertilizer N on water quality (Ledeboer and Skogley, 1973; Star and DeRoo, 1980; Waddington and Turner, 1980; Hummel and Waddington, 1984; Petrovic et al., 1986; Landschoot and Waddington, 1987; Watson, 1987; Morton et al., 1988; Gold et al., 1990; Gross et al., 1990; De Nobili et al., 1992; Geron et al., 1993; Harrison et al. 1993; Miltner et al, 1996; Engelsjord and Singh, 1997; Liu et al., 1997; Bowman et al., 2002; Kopp and Guillard, 2002; Frank et al., 2006; Mangiafico and Guillard, 2006). With exception of the evaluation of late-fall fertilization, there is limited information concerning the relative effectiveness of different application timings or programs (Wehner and Haley, 1993; Miltner et al., 2001; Kopp and Guillard, 2002; Bowman, 2003). With respect to N fertilizer timing, calendar dates for N were based on the growth cycle of turfgrass. Cool-season turfgrasses have two peak growth periods, one in the spring and the other to a lesser extent in the early fall. Spring N application timing is critical to avoid enhancing the growth flush which may compromise summer turf health, due to promoting shoot growth rather than root growth. Root growth during the spring months is essential, especially as the turfgrass plants transition into the summer months where the air and soil temperatures increase to a point where shoot and root growth is minimal and the turf plant may be merely surviving. Timings and N-fertilizer quantities are important as well, because heavy N applications in the late-spring are generally believed to deteriorate turf quality and encourage the incidence of spring and summer time diseases like brown patch (*Rhizoctonia solani* Kuhns), and *Pythium* blight (*Pythium* spp.) (Couch, 1995). By contrast, insufficient N-fertilizer can also increase the incidence of spring and summer time diseases such as dollar spot (*Sclerotinia homoeocarpa* F.T. Bennett), red thread (*Laetisaria fuciformis* (McAlpine) Burdsall), and rust ((*Puccinia* spp. and *Uromyces* (Link) Unger (Couch, 1995)). Early-summer to mid-summer N applications are generally avoided, so as to minimize turf stress, but applied if the turf becomes chlorotic. The fall N application timing is also very important and should be applied when the turfgrass plant is still actively growing. The purpose of fall N is to provide the turfgrass plant with N to be stored over the winter months as carbohydrates. Late-fall N applications are applied once shoot growth ceases. Although shoot growth has stopped root growth and N uptake continues. Carbohydrates are still produced and translocated to the stems and underground storage structures to be stored until the following spring.

Nitrogen fertility programs should be based on the rate and frequency at which N is required for the plant and desired plant growth responses. Nitrogen is a component of many biochemical constituents in the plant such as chlorophyll, amino acids, proteins, enzymes, vitamins, and many other materials critical to their function (Marschner, 1995). Nitrogen is the nutrient on which most fertility programs are based and is therefore applied in the greatest quantity and requires the greatest expense. There are several above ground indicators such as dry matter yield, leaf tissue N content, turfgrass color, disease incidence or severity, and turfgrass quality to help determine N requirements. The most important indicator is dry matter yield because shoot growth slows when N is deficient. Another indicator is leaf tissue N content, which shows how much N the plant is using. Turfgrass color can be an indicator due to the role N plays in chlorophyll production. When N is deficient the turf becomes chlorotic or yellow. Disease incidence or development, identified by necrosis or blight on plant tissue, can be used as an indicator because it varies with N level. Visual turfgrass quality provides information on the overall turfgrass appearance, however, it is a subjective measurement of both visual and functional turfgrass characteristics (Turgeon, 2002). Beard (1973) stated that visual quality is often defined as an integrated value of shoot density, texture, color, uniformity, smoothness, and growth habit. Conversely, functional quality includes resiliency, rigidity, elasticity, regrowth capacity, verdure (plant tissue remaining after mowing), and clipping yield (Turgeon, 2002). The public typically associates exceptional turfgrass quality with a dark-green, dense, actively growing turf.

By evaluating these above ground responses to N fertility programs, we can begin to determine minimum N requirements and recommend environmentally responsible N fertility programs for lawns that maximize turfgrass quality, sustain plant vigor with minimal N inputs without risk of contributing to surface and groundwater contamination. The specific research objective was to:

1. Determine the minimum N requirements for maintaining acceptable turfgrass quality of the three most commonly planted cool-season lawn grasses in the cool-humid region. Above ground responses to N fertilization were determined by measuring dry matter yield, leaf tissue N content, canopy greenness and visually rating turfgrass quality and disease incidence and severity.

Materials and Methods

A field experiment was conducted from September 2003 through December 2005 at the Purdue University, W. H. Daniel Turfgrass Research and Diagnostic Center, West Lafayette, Indiana on a Stark silt-loam (fine-silty mixed mesic Aeric Ochraqualfs) with a pH of 7.4, 67 kg P ha^{-1}, 147 kg K ha^{-1}, and 47 g kg^{-1} organic matter. Prior to planting, the entire study area was fumigated with methyl bromide to minimize existing weed competition. Cultivar blends of the three primary cool-season lawn turfgrass species: TTTF (*Festuca arundinacea* Schreb. 'Triple A'), KBG (*Poa pratensis* L. 'Premium Sod Blend'), and PRG (*Lolium perenne* L. 'Medalist Gold') were established by seed at rates of 391 kg ha^{-1}, 98 kg ha^{-1}, and 292 kg ha^{-1}, respectively in May 2003. Seed was supplied by Jacklin Seed Co. and the cultivar blends consisted of the following; 'Triple A' TTTF: [Quest (33 %), Pixie (33 %), and Arid III (33%)], 'Premium Sod Blend' KBG: [Absolute (25 %), Rugby II (25 %), Bluemoon (25 %), and Nuglade (25 %)], 'Medalist Gold' PRG; [Monterey II (33 %), Caddieshack (33 %), and Goalkeeper (33%)]. After seeding the entire study area received an application of 73 kg P ha^{-1} from 6-24-24 (N-P-K) and was covered with Agrofabric Pro17 germination blanket (American Agrifabrics, Alpharetta, GA) for 2 wks to conserve moisture, promote germination, and prevent species contamination from adjacent plots. The study area was frequently irrigated approximately three times daily via an overhead sprinkler system to promote germination and seedling establishment.

The nitrogen fertilizer treatments were initiated on 10 September 2003. Overall, eight nitrogen fertility programs were evaluated, which varied in annual N, ranging from 0, 49, 73, 123, and 196 kg N ha^{-1} yr^{-1}, and in application timing (Table 2-1). These programs were categorized as: "Low":(49 kg N ha^{-1}, September or 73 kg N ha^{-1} November only), "Medium" (123 kg N ha^{-1}, applied either spring only Apr., May, and July (AMJ), Sept. and Nov. (SN), or Sept., Oct., and May (SOM)), and "High" (196 kg N ha^{-1}, applied Sept., Oct., Nov., April, and May (SONAM) or Sept., Nov., May, and July (SNMJ)). Nitrogen was supplied either as sulfur coated urea (SCU: controlled-release, 31-0-0), urea (water soluble, 46-0-0) or a 50:50 (w/w) mixture depending on the season of application. The specific N application dates and N-sources are footnoted in Table 2-1.

Dry Matter Yield and Leaf N Content

Turf response to the N programs was measured through dry matter yields (DMY), clipping N concentration and visual ratings. Dry matter yield was determined by harvesting fresh clippings from the entire plot to a height of 6.35 cm using a rotary bagging mower (JS60, John Deere) weekly throughout the growing season. Fresh clippings were oven-dried at 82°C in a forced-draft oven for 72 h and then weighed. Leaf tissue N content was determined using a representative sub-sample of approximately 0.05 g from each plot. Dried leaf tissue was ground in an UDY Mill (UDY Corp., Ft. Collins, CO) to pass through a 0.5 mm screen and analyzed for tissue N content using the LECO CHN-2000 analyzer (LECO Corp., St. Joseph, MI). There were 8, 26, and 23 clipping harvests for 2003, 2004, and 2005 respectively.

Visual Ratings

Turfgrass appearance was evaluated using visual ratings and quantifying canopy greenness. Turfgrass quality (TQ) was visually rated weekly throughout the growing season using a 1 to 9 scale, where 1 = completely brown dead turf, 6 = minimally acceptable lawn turf, and 9 = optimum uniformity, density and greenness. Canopy greenness was quantified as reflectance using a hand-held chlorophyll meter (FieldScout CM-1000, Spectrum Technologies Inc.). Five measurements were taken using a systematic grid pattern which measured the four corners and center portions of each plot. The five measurements were averaged to produce a single plot rating and are reported as a chlorophyll index. Periodically, TQ was impacted by diseases such as dollar spot (*Sclerotinia homoeocarpa*), brown patch (*Rhizoctonia solani*), and red thread (*Laetisaria fuciformis*). When a disease outbreak occurred, the plots were rated for percentage blight on a linear 0 to 100 % scale where 0 = no damage and 100 = complete blight, dead turf.

General Plot Maintenance

The study site was located in full-sun with no obstructions, which was conducive to rapid drying of the canopy in the early morning hours. Plots were mowed weekly (6.35 cm) throughout the growing season with clippings removed. In the absence of significant rainfall (12 mm per week), overhead irrigation was supplementally applied each night (approximately 5 mm) to promote growth and maintain the soil at or near field capacity during the growing season (Apr. –Nov.). Herbicides were periodically applied for weed control, broadleaf weeds, annual grassy weeds, and a single curative fungicide application was applied in July of each year for disease control.

Experimental Design and Statistical Analysis

Plot size was 1.5 x 1.5 m with 0.3 m borders of hard fescue (*Festuca tryachyphylla* [Hackel] Krujina). Each treatment was replicated three times and plots were arranged in a randomized complete-block design. Data was pooled into four seasonal growth periods per year: early spring (Apr.-June), summer (July-Aug.), early fall (Sept.-Oct.), and late-fall (Oct.-Nov.). All data was subjected to analysis of variance (ANOVA) using the general linear model procedure in SAS (SAS Institute, Cary, NC) and treatment means for individual species separated using Fisher's protected LSD. Percentage data was arcsine transformed where necessary (Steel et al., 1997).

Environmental Conditions

Weather data was collected from the Purdue University Airport, West Lafayette, IN. Environmental conditions, precipitation measured as rainfall, air temperature, and soil temperature, varied dramatically between the two study years (Figure 2-1). Rainfall totaled 951 mm and 577 mm per year for 2004 and 2005, respectively. Rainfall was greater in the spring months of 2004 (584 mm) compared to 2005 (176 mm). Additionally, during the autumn months (Oct.-Nov.) 2004 (97 mm) was greater than in 2005 (43 mm). Average air temperatures were slightly higher during the summer 2005 than 2004 averaging 23°C and 21°C, respectively. Furthermore, the higher air temperatures persisted longer into the autumn (Sept.) in 2005 (20°C) than in 2004 (19°C). Soil temperatures with 10 cm of grass cover were consistently the same for both years averaging 12°C.

Results and Discussion

Turfgrass species responses to N application measured as dry matter yield (DMY), visual turfgrass quality (TQ), disease incidence and severity, canopy greenness measured as reflectance, and percentage leaf tissue N were dramatically affected by study year, season, species and N program.

Dry Matter Yield

Nitrogen fertilization and data collection began in fall 2003, but because of the various N application timings many treatment effects were not apparent until the spring 2004 (Table A-2 toA-4). There were significant differences among species for DMYs. When averaged across study years and N programs, TTTF had greater DMY than KBG which was greater than PRG with total DMYs of 9,430, 7,750, and 7,010 kg ha^{-1}, respectively. Kentucky bluegrass had overall greater DMY than PRG except during the spring (Apr.-June) of both years where DMY was 750 kg ha^{-1} for KBG and 930 kg ha^{-1} for PRG. The low DMYs for PRG in both years, was attributed to substantial loss of summer stand density, as much as 50 %, due to disease.

For TTTF, study DMY totals ranged from 5,460 to 11,700 kg ha^{-1} depending on N-treatment (Table 2-3). There were few differences among N-treatments except for the low September and November treatments and the unfertilized treatment which had DMYs of 5,780 kg ha^{-1}, 8,910 kg ha^{-1}, and 5,460 kg ha^{-1}, respectively. For all clipping collection periods in 2004, the high, medium, and the low November N-treatments were similar (Table 2-2).

In 2005 for the spring clipping harvest period, both high N-treatments and the two medium N-treatments receiving fall applied N (SOM and SN) had the highest DMYs for TTTF, ranging from 1,510 to 1,830 kg ha^{-1} (Table 2-3). This growth response would be expected since these plots had received a late fall N application in Oct. or Nov., 2004. During the remaining harvest periods, the medium SOM N-treatment and the medium SN N-treatment were similar to the high N-treatments. Throughout 2005, the low Sept. N and unfertilized treatment were statistically the lowest for DMYs. The low November N-treatment was statistically similar to the low September N-treatment and the unfertilized N-treatment during the Oct.-Nov. harvest period, because DMYs were collected prior to the November N application.

For KBG, the two high N-treatments produced the greatest DMY for the entire study ranging from 10,100-11,200 kg ha^{-1} (Table 2-5). The low September (5,550 kg ha^{-1}) and low November (5,970 kg ha^{-1}) N-treatments and the unfertilized treatment (4,561 kg ha^{-1}) produced the lowest DMYs.

The DMY totals for 2004 show that the medium SOM (3,134 kg ha^{-1}), low September (2,185 kg ha^{-1}), and low November (2,750 kg ha^{-1}) N-treatments were not different than the unfertilized treatment (Table 2-4). Furthermore, the medium AMJ (3,496 kg ha^{-1}) and SN (3,438 kg ha^{-1}) N-treatments were not statistically different than the two high N-treatments (SONAM, 3,980 and SNMJ, 4,647 kg ha^{-1}) for 2004. During the spring of 2004, the medium SOM (512 kg ha^{-1}), medium AMJ (546 kg ha^{-1}), and low September (304 kg ha^{-1}) N-treatments were not significantly different than the unfertilized treatment (330 kg ha^{-1}). The medium SN (895 kg ha^{-1}) N-treatment produced DMYs similar to the high SONAM (1,180 kg ha^{-1}) N-treatment. For the July-Aug. harvest period, the two low September and November (Sept., 816 and Nov., 1060 kg ha^{-1}) N-treatments were similar to the unfertilized treatment (625 kg ha^{-1}). Additionally, the AMJ N-treatment (1,510 kg ha^{-1}) was similar to the two high N-treatments (SNMJ, 1,440 and SONAM, 1,700 kg ha^{-1}) for this same collection period. During the Oct.-Nov. collection period, nearly all N-treatments were similar to the unfertilized treatment (427 kg ha^{-1}). The exception occurred with the medium N-treatment of SOM (705 kg ha^{-1}) and the two high treatments (788 and 806 kg ha^{-1}).

For the 2005 DMY totals, there are clear differences between the high (SNMJ, 4,820 and SONAM, 5,600 kg ha^{-1}), medium (AMJ, 3,590, SOM, 3,730, and SN, 3,700 kg ha^{-1}), and low (Sept., 2,410 and Nov., 2,401 kg ha^{-1}) N-treatments. The low September and November N-treatments are similar to the unfertilized (1,790 kg ha^{-1}) treatment (Table 2-5). For the Apr.-June collection period in 2005, the medium AMJ (381 kg ha^{-1}), low November (586 kg ha^{-1}), and the low September (492 kg ha^{-1}) N-treatments were not significantly different compared to the unfertilized treatment. The high SONAM N-treatment (1,730 kg ha^{-1}) produced significantly more DMY than all other treatments for the first collection period in 2005. The other high SNMJ (1,213 kg ha^{-1}) N-treatment was statistically similar to the SOM (946 kg ha^{-1}) and SN (1,097 kg ha^{-1}) medium N-treatments. During the July-Aug. collection period, the medium SN (751 kg ha^{-1}), low November (471 kg ha^{-1}), and the low September (523 kg ha^{-1}) N-treatments were similar to the unfertilized treatment. The medium AMJ (981 kg ha^{-1}) N-treatment was similar to the two high N-treatments (1,073 and 1,279 kg ha^{-1}). During the Sept.-Oct. collection period, low November (825 kg ha^{-1}), and the low September (642 kg ha^{-1}) N-treatments were similar to the unfertilized treatment. The medium AMJ N-treatment was similar to the high N-treatment of SNMJ, and 30 % greater than the high N-treatment of SONAM. During the Oct.-Nov. time period, only the low November (440 kg ha^{-1}) was similar to the unfertilized treatment. Again, these DMYs were collected prior to the low November N application.

For PRG, two medium N-treatments (AMJ, 7,643 and SOM, 8,830 kg ha^{-1}) were similar to the high N-treatments (SONAM, 8,860 and SNMJ, 8,240 kg ha^{-1}), and produced the greatest amount of DMY for the duration of the study (Table 2-7). By contrast, the September (5,082 kg ha^{-1}) N-treatment was similar to the unfertilized (3,820 kg ha^{-1}) N-treatment producing the least DMY.

For the 2004 DMY totals, the low September (1,960 kg ha^{-1}) N-treatment was similar to the unfertilized (1,640 kg ha^{-1}) treatment. The low November (2,890 kg ha^{-1}), medium AMJ (3,720 kg ha^{-1}), and the medium SOM (3,740 kg ha^{-1}) N-treatments were similar to the two high (SONAM, 3,720 and SNMJ, 3,760 kg ha^{-1}) N-treatments (Table 2-6). During the early spring of 2004, the low SN (434 kg ha^{-1}) N-treatment was similar to the unfertilized (455 kg ha^{-1}) treatment. The low November (1,129 kg ha^{-1}) and the two high (SNMJ, 1,127 and SONAM, 1,408 kg ha^{-1}) N-treatments were similar. For the July-Aug. collection period, the medium SN (725 kg ha^{-1}) and both the low November (812 kg ha^{-1}) and September (545 kg ha^{-1}) N-treatments were similar to the unfertilized (493 kg ha^{-1}) treatment. The medium AMJ (1,300 kg ha^{-1}) and SOM (1,179 kg ha^{-1}) N-treatments were similar to the two high (SONAM, 1,101 and SNMJ, 1,123 kg ha^{-1}) N-treatments during this harvest period. The medium SN (429 kg ha^{-1}) and both the low November (532 kg ha^{-1}) and September (402 kg ha^{-1}) N-treatments were similar to the unfertilized (311 kg ha^{-1}) treatment during the Sept.-Oct. collection period. The medium AMJ (913 kg ha^{-1}) and SOM (708 kg ha^{-1}) N-treatments were similar to the high SNMJ (1,123 kg ha^{-1})

N-treatment for this collection period. For the Oct.-Nov. collection period, only the medium SOM (896 kg ha^{-1}) and the two high (SONAM, 669 and SNMJ 780 kg ha^{-1}) N-treatments were statistically different than the other N-treatments and the unfertilized treatment. The medium SOM and the high SONAM N-treatments were significantly different from each other.

The DMY totals for 2005 demonstrated that the low September (1,728 kg ha^{-1}) N-treatment was not different than the unfertilized (1,232 kg ha^{-1}) treatment and the high (SONAM, 3,357 and SNMJ, 3,076 kg ha^{-1}) and medium (Spring 2,818, SN 2,904, and SOM 3,005 kg ha^{-1}) N-treatments produced the greatest DMYs, but there was no N-treatment separation (Table 2-7). For the 2005 DMY collection period of Apr.-June, the low Sept. (541 kg ha^{-1}) N-treatment was similar to the unfertilized (241 kg ha^{-1}) treatment. The two medium SN (1,201 kg ha^{-1}) and SOM (1,252 kg ha^{-1}) N-treatments were similar to the high SNMJ (1,534 kg ha^{-1}) N-treatment. For the July-Aug. collection period, all the N-treatments were significantly different than the unfertilized treatment with the two medium AMJ (862 kg ha^{-1}) and SOM (740 kg ha^{-1}) N-treatments similar to the two high N-treatments (SONAM, 788 and SNMJ, 847 kg ha^{-1}).

Hall et al. (2003) reported that DMY for TF averaged 432 kg ha^{-1}, however, in this study the unfertilized control was closer to that value averaging 468 kg ha^{-1} in 2005 for the unfertilized control. In fact, for the duration of this study, DMY for TTTF averaged 648 kg ha^{-1} to 1462 kg ha^{-1} for the unfertilized control and the high SONAM N-treatment, respectively. Frank et al. (2006) for KBG reported total clipping yields of 2091 kg ha^{-1} and 3531 kg ha^{-1}, for a low N rate (98 kg N ha^{-1} yr^{-1}) and high N rate (245 kg N ha^{-1} yr^{-1}) respectively. In this study, our DMYs for KBG were higher at slightly lower N rates. However, more N mineralization could be occurring due to the higher soil temperatures and longer growing season in Indiana compared to Michigan. The low 49 kg N ha^{-1} treatment averaged 2,775 kg ha^{-1} yr^{-1} and our high 196 kg N ha^{-1} treatment averaged 4,512 kg ha^{-1} yr^{-1}. Our differences could be due to the fact their study was located further north, in Michigan where the growing season is shorter, possibly resulting in fewer clipping harvests. Engelsjord et al. (2004) reported that KBG produced the greatest yields in the summer, while PRG grew better in October and November

Kentucky bluegrass had greater DMY during the summer months than PRG due to disease incidence (Engelsjord et al., 2004), but in our study PRG grew better in the early spring months than KBG due to the slow spring greening. Our Oct.-Nov. data for KBG and PR are not consistent from year to year. Perennial ryegrass produced greater DMY than KBG in 2004 but not in 2005. Engelsjord et al. (2004) also reported that total yearly clipping yields did not differ between the two species KBG 7680 kg ha^{-1} and PRG yielded 7850 kg ha^{-1}. In our study, KBG and PRG were significantly different for total DMYs.

Turfgrass Quality

Of the three species, TTTF had the most consistent annual turfgrass quality (TQ). Turfgrass quality averaged 7.2 for TTTF, 6.8 for KBG, and 6.3 for PRG. Turf-type tall fescue TQ ratings ranged from 6.2-7.1 and 6.0-8.0 in 2004 and 2005, respectively. For TTTF, TQ followed the seasonal growth pattern for cool season turfgrasses with greater TQ in the spring, decreasing during the summer and improving in the fall. Kentucky bluegrass TQ values ranged from 5.9-7.4 and 5.9-7.8 in 2004 and 2005, respectively, and seasonal values were not as consistent throughout each study year. In early spring (Apr.-June) of both years, KBG was the slowest of the species to green-up resulting in lower TQ ratings, which often were unacceptable (< 6.0) ranging from 4.2-5.4 in 2004 and from 2.8-6.0 in 2005. Throughout the fall, however, Kentucky bluegrass had the highest TQ values of the three species ranging from 6.8-8.3 in 2004 and 6.8-8.6 in 2005. Perennial ryegrass TQ values ranged from 6.0-6.8 and 5.5-6.5 in 2004 and 2005, respectively. The lower ratings associated with PRG were primarily due to poor shoot density and a lack of green color which were dramatically affected by late spring and summer disease. During the summer, TQ ratings for PRG ranged from 5.5-7.8 in 2004 and 4.1-6.6 in 2005. Even fall ratings when cool-season turfgrasses often grow best were < 7.0 for PRG due to low shoot density and poor recovery from summer disease.

For TTTF 2004 totals, the low Sept. (6.3) N-treatment was similar to the unfertilized (6.2) treatment (Table 2-8) and the medium AMJ (7.3) and medium SN (7.0) N-treatments were similar to the two high (SONAM, 7.1 and SNMJ, 7.0) N-treatments

(Table 2-8). During the Apr.-June 2004 rating period, the low September (6.0) N-treatment was similar to the unfertilized (5.7) treatment, whereas, the low November (6.5), medium SN (6.7), medium SOM (6.5), and the two high (SONAM, 6.6 and SNMJ (6.4)) N-treatments had the best quality. For the July-Aug. time period, both low N-treatments and the unfertilized treatment had the poorest TQ ranging from 5.6-5.8. Among the medium AMJ (7.0), medium SN (6.5), and medium SOM (6.7) were similar to the high SNMJ (6.9) N-treatment. The medium SOM (7.1), low September (6.7), and low November (6.9) N-treatments were similar to the unfertilized (6.7) treatment and the medium AMJ (8.1) N-treatment produced the best quality being significantly different than all other N-treatments for the Sept.-Oct. rating period. For the Oct.-Nov. rating period, the low September (6.9) and low November (6.9) N-treatments were similar to the unfertilized (6.5) treatment and the medium AMJ (7.7) and medium SN (7.4) were similar to the two high (SONAM, 7.6 and SNMJ, 7.9) N-treatments.

For the 2005 year, the low September (6.3) N-treatment was similar to the unfertilized (6.0) treatment and the medium AMJ (7.9) and two high (SONAM, 7.9 and SNMJ, 8.0) N-treatments were similar (Table 2-9). In 2005 for the Apr.-June time period, the low September (5.7) N-treatment was similar to the unfertilized (4.9) treatment. The low November (7.4), medium AMJ (6.7), medium SN (7.4), and the two high (SONAM 7.5 and SNMJ, 7.7) N-treatments were statistically similar. For the July-Aug. rating period, the September (6.5) and November (6.7) low N-treatments were similar to the unfertilized (6.3) treatment. The medium AMJ (8.0) and the two high (SONAM, 7.8 and SNMJ, 7.7) N-treatments were similar and significantly greater than all other N-treatments. In the early fall period Sept.-Oct., the low September (6.1) N-treatment was similar to the unfertilized (6.2) treatment. The medium AMJ (8.6) and the high SNMJ (8.4) N-treatment was similar. For the Oct.-Nov. period, both low N-treatments were similar to the unfertilized treatment. The medium AMJ (7.9) and the medium SOM (8.0) were similar the two high (SONAM, 8.3 and SNMJ, 8.1) N-treatments.

For KBG 2004 totals, the low September (5.9), low November (6.3), and medium AMJ (6.5) N-treatments were not significantly different than the unfertilized (5.9) treatments (Table 2-10). The medium SOM (6.7) was statistically similar to the

(SONAM, 7.4 and SNMJ, 7.2) N-treatments (Table 2-10). Spring ratings (Apr.-June) of 2004 resulted in the lowest TQ values. During this time the medium AMJ (4.2), low November (4.5), and the low September (4.0) N-treatments were similar to the unfertilized (4.2) treatment. Even though the medium SN (4.9) and the two high (SONAM, 5.2 and SNMJ, 5.4) N-treatments were significantly different than the unfertilized treatment they were still unacceptable, < 6.0. For the July-Aug. period, the low September (5.5) N-treatment was similar to the unfertilized (5.6) treatment. The medium AMJ (6.8) N-treatment was similar to the two high (SONAM, 7.4 and SNMJ, 7.0) N-treatments. For the Sept.-Oct. period, only the medium AMJ (7.7) and the two high (SONAM, 8.2 and SNMJ, 8.2) N-treatments were significantly different than the unfertilized (6.8) treatments.

In 2005, all N fertilized KBG plots had significantly greater TQ than the unfertilized treatment with the two high (SONAM, 7.8 and SNMJ, 7.7) N-treatments resulting in the best TQ (Table 2-11). In Apr.-June of 2005, the medium AMJ (3.4) and the low September (3.1) N-treatments were similar to the unfertilized (2.8) treatment. The medium SN (5.0) N-treatment was statistically similar to the two high (SONAM, 6.0 and SNMJ, 5.3) N-treatments although only the SONAM was considered acceptable. For the July-Aug. period, the low September (6.5) N-treatment was similar to the unfertilized (6.1) treatment. The medium AMJ (7.8) and the medium SOM (7.6) N-treatments were similar the two high (SONAM, 8.0 and SNMJ, 7.8) N-treatments. Only the medium AMJ (8.4), medium SOM (7.7), and the two high (SONAM, 8.3 and SNMJ (8.7) were significantly different than the unfertilized (6.9) treatment for the Sept.-Oct. period. In the Oct.-Nov. period, only the low November (7.1) N-treatment was similar to the unfertilized (6.8) treatment.

For PRG 2004 totals, the low September (6.0) N-treatment was similar to the unfertilized (6.0) treatment and the medium AMJ (6.7) and the medium SOM (6.7) was similar the two high (SONAM 6.7 and SNMJ 6.8) N-treatments (Table 2-12). For the Apr.-June period, all low (Sept., 5.2 and Nov., 5.9) and medium (AMJ 5.6, SN 6.0, and SOM 5.8) N-treatments were statistically similar to the unfertilized (5.6) treatment. The two high N-treatments (SONAM, 6.4 and SNMJ, 6.2) were significantly better. For the

July-Aug. period, both low N-treatments September (5.7) and November (5.6) and the medium SN (5.7) N-treatments were similar to the unfertilized (5.5) treatment. For the same period, the medium AMJ (6.2) and the medium SOM (6.1) were similar to the two high (SONAM 6.1, SNMJ 6.2) N-treatments. In early fall (Sept.-Oct.), the low September (6.4) and the medium SN (6.7) N-treatments were similar to the unfertilized (6.7) treatment. The medium AMJ (7.8) and the medium SOM (7.3) was similar to the high SNMJ (7.3) N-treatment. The unfertilized (6.0) treatment was significantly lower than all other treatments for the Oct.-Nov. period while the medium SOM (7.5) was similar to the high SNMJ (7.3) N-treatment.

In 2005, the only significant difference for TQ occurred during the Apr.-June and July-Aug. rating periods (Table 2-13), due to the weather and disease pressure. The low September (5.9) was similar to the unfertilized (5.7) treatment for the Apr.-June period. The low November (7.1), medium SN (7.2), medium SOM (7.0) N-treatments were similar to the two high (SONAM 7.3 and SNMJ 7.2) N-treatments. For the July-Aug. period, both low September (5.8) and November (6.0) N-treatments and the medium SN (6.1) N-treatments were similar as the unfertilized (5.7) treatments. The medium AMJ (6.7), medium SOM (6.2), and the two high (SONAM 6.3 and SNMJ 6.5) N-treatments were similar. For all other time periods and for the yearly total, TQ values never exceeded 7.0 regardless of N-treatment.

Turf quality was affected by species, N program, and season. In this study, TTTF had the best annual TQ because it was more consistent than the other two species, KBG and PRG. Perennial ryegrass was devastated by disease in both years but even more so in 2005 substantially decreasing TQ in the summer and fall. Recovery from disease was slower for PRG due to its bunch-type growth. Kentucky bluegrass overall TQ was greatly affected by spring green-up, however, in 2005 the benefits of late-fall fertilization for the medium SN and low November N application, were evident and improved TQ for all species. The medium AMJ N-treatment in the summer and early fall months was equal to if not better than the two high N-treatments for all species. This N-treatment was especially important for PRG TQ. The low September N-treatment was no different than the unfertilized treatment for most of the study. In 2005, not only is there a benefit for fall fertilization, but the buildup of residual N in the soil increased overall TQ for TTTF, KBG.

Disease Incidence and Severity

Significant differences among turfgrass species and to a lesser extent N program on disease incidence and severity were observed in both years. Turf damage assessed as stand blight was attributed primarily due to dollar spot (*Sclerotinia homoeocarpa*) however, traces of red thread (*Laetisaria fuciformis*) and brown patch (*Rhizoctonia solani*) were also observed but not independently rated because they were visually difficult to discern. Turfgrass species was significant for all rating periods in both years except for 16 June 2004 (Tables 2-14). Nitrogen treatment was significant in all of 2004 except on 20 May when disease pressure was low (Table 2-14). By contrast in 2005 N-treatment was significant only on two dates (19 July and 7 August) during peak disease activity (Table 2-15). Due to large differences between species, each species was analyzed individually. An interaction between species and N-treatment was observed in 2004 for the 28 May, 12 June, and 16 June rating dates but not in 2005. In 2004, TTTF had significantly more disease than KBG on all rating dates. Turf-type tall fescue was statistically similar to PRG only on the 28 May and 12 June rating dates. Turf blight during this period was generally less than 4 % of the plot area and these results would not be practically important for all three species except on 20 May where TTTF had > 9 % blight (Table 2-14).

In 2005, the PRG plots generally had significantly more blight (14-57 %) than both KBG and TTTF (0-2 %) (Table 2-15). Nitrogen treatment was significant only on two out of the six rating dates from 20 June through 7 Aug. The exception occurred on 20 June where TTTF was similar to PRG, and 0 % blight was observed in KBG. Disease severity however, was only 0.7 % versus 0.3 % for PRG and TTTF respectively.

For TTTF analyzed alone, the low September N-treatment and the unfertilized N-treatment resulted in greatest blight in 2004. The low November resulted in similar disease levels on all six rating dates (Table 2-16). On 20 May, the high SONAM (19.6 %) resulted in the greatest amount of disease as the two low N-treatments and the unfertilized treatment. In 2005, N-treatment was not significant except on 27 July and 7 Aug. The unfertilized treatment had significantly greater blight (4.0 %) than all other treatments on the 27 July rating date. On 7 Aug, the low September (0.7 %) N-treatment was similar to the unfertilized (0.9 %) treatment (Table 2-17).

For KBG, N-treatment was only significant on three of the six rating dates in 2004 (Table 2-18). The September N-treatment was not significantly different from the unfertilized treatment on 28 May, 12 June, and 23 June 2004. For the 12 June time period, the medium AMJ (1.0 %) N-treatment was similar to the low September (3.1 %) N-treatment and the unfertilized treatment (3.5 %) which had the greatest amount of disease. On 23 July rating date, the November (1.9 %) and September (5.2 %) N-treatments and the unfertilized (5.0 %) treatment were the same. In 2005, N-treatment was not significant and disease levels ranged from 0 to 6 % blight for any given rating date (Table 2-19).

For PRG in 2004, the medium SN (10.7 %) N-treatment had the greatest amount of blight followed by the medium SOM (7.2 %) and the low September (5.2 %) N-treatment on the 16 June rating date (Table 2-20). Again on the 23 June 2004, the SN N-treatment had the greatest percent blight (4.1 %) followed by the low September (4.0 %) and the low November (0.9 %) N-treatments which were similar to the unfertilized (2.0 %) treatment. In 2005 N-treatment was not significant, however disease severity due to dollar spot was extremely high ranging from 31 % to 82 % blight on the worst rating date, 19 July (Table 2-21). It is possible that N effects were not apparent because disease simply overwhelmed the PRG regardless of N-treatment. Plot blight decreased after this date due to a curative fungicide application on 22 July, 2005 which aided in recovery from 78 % on 19 July to 10 % on 7 Aug.

Disease incidence was affected by species and N rate in 2004. Only once in this study did a high N-treatment increase disease, the high SONAM treatment on 20 May 2004 for TTTF during the first year of fertilization. Consistently applying N in Sept., Oct., Nov., Apr., and May might have increased soil N favoring disease incidence although blight was < 20 % (Table 2-16). Disease blight for PRG was similar to TTTF on three out of six rating dates (Table 2-14). In 2005, disease was most affected by species but not N program (Table 2-17). With late-fall N applications such as the medium SN and low November treatments improved TQ in the spring, however, due to their low N rates increased disease blight for KBG but especially for PRG where the medium SN N-treatment had the greatest blight. The medium AMJ N-treatment also improved TQ during the summer but for KBG increased disease incidence. For KBG, the low September and the unfertilized treatment consistently had greater disease incidence, indicating that more N is required for KBG to compete with disease like dollar spot.

Canopy Greenness

Species and N program had dramatic effects on canopy greenness. This information is important because generally the public perceives a dark green turf to be most healthy and aesthetically pleasing. When averaged across all N-treatments, KBG had the highest chlorophyll index making it the greenest of the three turfgrass species ranging from 374-560 for 2004 and 324-556 for 2005 (Tables 2-24 and 2-25). Turf-type tall fescue followed ranging from 325-477 in 2004 and 256-476 in 2005. Perennial ryegrass had the lowest chlorophyll index ranging from 294-437 in 2004 and 265-394 in 2005. In general increasing N rate resulted in increasing greenness, however, there were several exceptions.

For TTTF in 2004, the medium Apr., May, and July (477) N-treatment produced the greenest turf, but was not different than the other two medium (SOM, 422 and SN, 452) N-treatments and the two high (SONAM, 476 and SNMJ, 474) N-treatments (Table 2-22). The low September (334) N-treatment was similar to the unfertilized (325) treatment. The lowest values occurred for the September N-treatment and the unfertilized treatment for all time periods (Table 2-22). Additionally, the low November N-treatment was similar to the low September N-treatment and unfertilized treatment for three out of the four time periods. The low November (469) N application improved canopy greenness in the early spring being similar to the medium SN (541) and two high (SONAM, 547, SNMJ, 491) N-treatments. The medium AMJ N-treatment was the greenest for the July-Aug. and Sept.-Oct. time periods, but was not significantly different than the medium SOM N-treatment and two high N-treatments for the July-Aug. time period and the medium SOM, medium SN N-treatment and two high N-treatments for the Sept.-Oct. time period. For all other time periods, the two high N-treatments were the greenest but not significantly different from one another.

In 2005 the effect of N fertilization versus the unfertilized turf was more pronounced (Table 2-23). For example, the low September N-treatment was similar to the unfertilized treatment on only two out of the four time periods and the low November N-treatment was similar to the unfertilized treatment in only one period, Oct.-Nov. For the 2005 year, the medium AMJ (453) N-treatment was similar to the two high (SONAM, 476 and SNMJ, 469) N-treatments. In the Apr.-June time period, the low November (452) and medium SN (457) N-treatments where similar to the two high (SONAM, 518 and SNMJ, 481) N-treatments. For the July-Aug. and Sept.-Oct. time periods, the medium AMJ N-treatment was similar to the high SONAM N-treatment which were significantly different than all other N-treatments. In the Oct.-Nov. time period, the medium SOM (437) N-treatment was similar to the two high (SONAM, 486 and SNMJ, 463) N-treatments.

For KBG, the low September N-treatment was the similar to the unfertilized treatment on all rating periods in 2004 (Table 2-24). The low November N-treatment was similar to the unfertilized treatment for three out of four time periods. As expected, the two high N-treatments were consistently the greenest plots. The SOM (484) was similar to the two high (SONAM, 560 and SNMJ, 535) N-treatments. The medium SN (437) N-treatment was similar to the two high (SONAM, 491 and SNMJ, 419) N-treatments for the Apr.-June time period. The AMJ (568 and 532) N-treatment was similar to the two high (SONAM 598 and 580, SNMJ 552 and 577) N-treatments for the July-Aug. and Sept-.Oct. time periods respectively. The SON (536) was similar to the two high (SONAM, 564 and SNMJ, 586) N-treatments for the Oct-Nov. time period.

In 2005 the low September N-treatment was similar to the unfertilized treatment except for Oct.-Nov time period (Table 2-25). The low November N-treatment was similar to the unfertilized treatment on two of the four time periods (Sept.-Oct. and Oct.-Nov.). Again, the two high N-treatments were consistently the greenest plots. For 2005, the medium AMJ (503) was similar to the two high (SONAM, 537 and SNMJ, 556) N-treatments. The medium SN (433) N-treatment, however, was similar to the two high (SONAM, 486 and SNMJ, 460) N-treatments for the Apr.-June time period. The AMJ (562 and 648) N-treatment was similar to the two high (SONAM 520 and 584, SNMJ 510 and 676) N-treatments for the July-Aug. and Sept-.Oct. time periods respectively.

For PRG, the low September (except Oct.-Nov.) N-treatment was similar to the unfertilized treatment in three out of four time periods in 2004 and the low November (Sept.-Oct. and Oct.-Nov.) N-treatment was similar to the unfertilized treatment in two of those time periods (Table 2-26). The medium AMJ (437) and the medium SOM (404) N-treatments were similar to the two high (SOANM, 404 and SNMJ, 422) N-treatments. For the Apr-June time period, the low November (434), medium AMJ (413), and the medium SN (414) N-treatments were similar to the two high (SONAM, 457 and SNMJ, 439) N-treatments. The medium AMJ (450) N-treatment was the greenest in the July-Aug time period. Again during the Sept.-Oct. time period, the medium AMJ (509) N-treatment was the greenest but similar to the high SNMJ (451) N-treatment. The medium SOM (404) N-treatment was similar to the two high (SONAM 362 and SNMJ 402) N-treatments for the Oct-Nov. time period.

In 2005 greenness trends were similar to 2004 (Table 2-27), the low September N-treatment was similar to the unfertilized treatment for all time periods and the low November (except Apr.-May) N-treatment was similar to the unfertilized treatment in three out of four time periods (Table 2-27). The medium AMJ (388) and the medium SOM (356) N-treatments were similar to the two high (SONAM 392 and SNMJ 394) N-treatments indicating that additional N did not result in increased greenness. For the Apr-June time period, the low November (453), medium AMJ (445), and the medium SN (465) N-treatments were similar to the two high (SONAM, 496 and SNMJ, 456) N-treatments. The medium AMJ (405) N-treatment was the greenest in the July-Aug. time period, being significantly different than all other N-treatments. During the Sept.-Oct. time period, the medium AMJ (327) N-treatment was similar to the two high (SONAM, 324 SNMJ, 378) N-treatments. The medium SOM (430) N-treatment was similar to the two high (SONAM, 398 and SNMJ, 398) N-treatments for the Oct-Nov. time period.

In a similar study, Wehner et al. (1993) reported significantly higher color ratings and DMY due to higher N rates (98 kg N ha^{-1}) than lower N rates (49 kg N ha^{-1}). In this study, our results showed the same trend, as N rate increased so did canopy greenness. Mangiafico and Guillard (2006) reported that fall fertilization tended to improve spring turf color and quality. For TTTF and PRG, the low November and medium SN N-treatments improved canopy greenness in the spring. The medium SN N-treatment retained its color longer than the low November N-treatment which was similar to the unfertilized treatment for most of the remaining rating periods for both species due to September N application. For KBG, only the medium SN N-treatment significantly improved spring color. Wehner et al. (1993) reported that urea applications in November provided better turf color and DMY than an October application. Also, Wilkinson and Duff (1972) found greater spring chlorophyll in mid-April in turf fertilized in November or December than in October. Our study generated similar results. The medium SOM N-treatment did not improve spring color as well as those N-treatments receiving a November application. The medium AMJ and low September N-treatments are the only two programs that do not receive a late-fall N application. The medium AMJ N-treatment did result in a greener canopy in the spring than the low September N application due to its higher annual N rate. However, for TTTF, KBG, and PRG the medium AMJ N applications produced as green a turf as the two high N-treatments through the summer and early fall.

This data shows that of the three species, KBG was slower than PR and TTTF to green-up in the spring (Tables 2-24 and 2-25). However, spring green-up did improve for the two high N-treatments and the medium SN N-treatment where a majority of N is applied in the fall. This indicates that where early spring green-up is desired, more N needs to be applied in the fall in order to achieve a lawn that greens-up similar to PRG and TTTF. Overall however, KBG is the greenest of the three species throughout the active growth period.

Leaf Tissue Nitrogen

As expected leaf tissue N varied with species, season, and N-treatment (Tables 2-28 to 2-33). Among species, PRG had higher leaf N than TTTF and KBG ranging from 32.8-36.3 in 2004 and 32.7-36.8 g kg $^{-1}$ in 2005, 30.9-35.8 g kg $^{-1}$ in 2004 and 30.0-37.7 g kg $^{-1}$, and 27.3-32.3 g kg $^{-1}$ in 2004 and 27.5-34.6 g kg $^{-1}$ in 2005 for PRG, KBG, and TTTF, respectively. Typically following a N application, leaf tissue N content would increase two weeks after application, longer if using only a slow release N source. Bowman (2003) reported that fairly large pulses of N reach leaf tissue shortly after an intermittent N supply event, and conceivably it might take several days or more for the N to stimulate growth and have full value in the plant. With frequent mowing, the N may be removed before reaching peak. This would be especially true with frequent mowing. Less frequent (monthly) N supply caused wide fluctuations in growth and tissue N pools, but had little or no effect on long-term productivity and N use efficiency compared with daily addition at the same total rate. Combinations however between slow and fast release N sources would tend to diminish the fluctuations associated with episodic N supply.

For TTTF, the low September N-treatment was similar to the unfertilized treatment for all 4 time periods in 2004 whereas the low November N-treatment, the three medium N-treatments, and the two high N-treatments were the same (Table 2-28). For both the Apr.-Jun. and Jul.-Aug. time periods, the low November N-treatment, the three medium N-treatments, and the two high N-treatments were the same. This occurred again during the Sept.-Oct. time period but the medium SOM (30.4 g kg $^{-1}$) N-treatment was also statistically similar to the low September (27.7 g kg $^{-1}$) N-treatment and the unfertilized (28.3 g kg $^{-1}$) plots. For the Oct.-Nov. time period, only the three medium N-treatments and the two high N-treatments were the same.

In 2005, the low September N-treatment was similar to the unfertilized treatment 3 out of 4 time periods (Table 2-29). For the Apr.-Jun. time period, the medium AMJ (30.1 g kg $^{-1}$) and the medium SN (30.1 g kg $^{-1}$) N-treatments were similar to the high SONAM (32.4 g kg $^{-1}$) N-treatment. During the Jul.-Aug. time period, the AMJ (29.1 g kg $^{-1}$) N-treatment was similar to the two high (SONAM, 29.8 and SNMJ, 29.1 g kg $^{-1}$) N-treatments. For the Sept.-Oct. time period, both the medium AMJ (35.2 g kg $^{-1}$) and the

SN (32.3 g kg $^{-1}$) N-treatments were similar to the two high (SONAM, 34.7 and SNMJ, 34.2 g kg $^{-1}$) N-treatments. All the medium and high N-treatments were the same for the Oct.-Nov. time period. For 2005, the medium AMJ (33.6 g kg $^{-1}$) N-treatment was similar to the two high (SONAM, 34.6 and SNMJ, 33.8 g kg $^{-1}$) N-treatments.

Kentucky bluegrass was less affected by N program or treatment than the other two turfgrass species (Table 2-30). During only two time periods in 2004 were N-treatments significant for Jul.-Aug. and Oct.-Nov. During the Jul.-Aug. time period, all the N-treatments were similar to the unfertilized (27.7 g kg $^{-1}$) plots except the medium AMJ (30.3 g kg $^{-1}$) N-treatment and the high SONAM (33.0 g kg $^{-1}$) N-treatment (Table X). The medium SN (39.3 g kg $^{-1}$) and SOM (39.9 g kg $^{-1}$) N-treatments were similar to the two high (SONAM 40.8 and SNMJ 41.2 g kg $^{-1}$) N-treatments for the Oct.-Nov. time period.

In 2005, the medium SN (33.6 g kg $^{-1}$) was similar to both high (SONAM 35.8 and SNMJ 33.9 g kg $^{-1}$) N-treatments for the Apr.-Jun. time period (Table 2-31). For the Jul.-Aug. time period, the medium AMJ (31.4 g kg $^{-1}$) and the medium SOM (31.1 g kg $^{-1}$) N-treatments are similar to the two high (SONAM, 33.7 and SNMJ, 33.1 g kg $^{-1}$) N-treatments. The Sept.-Oct. time period was not significant for N-treatment. The low September (43.3 g kg $^{-1}$) and the medium N-treatments of AMJ (43.8 g kg $^{-1}$) and SOM (44.9 g kg $^{-1}$) were similar to both high (SONAM, 44.2 and SNMJ, 45.9 g kg $^{-1}$) N-treatments for the Oct.-Nov. time period.

For PRG, the low September N-treatment was similar to the unfertilized treatment three out of four time periods in 2004 (Table 2-32). The low November N-treatment was similar to the unfertilized treatment for all four time periods. The medium AMJ (36.3 g kg $^{-1}$) and the medium SOM (36.0 g kg $^{-1}$) N-treatment were similar to the two high (SONAM, 35.8 and SNMJ, 35.9 g kg $^{-1}$) N-treatments. For the Apr.-Jun. time period, the medium AMJ (33.5 g kg $^{-1}$) N-treatment was similar to both high (SONAM, 32.9 and SNMJ, 32.0 g kg $^{-1}$) N-treatments. The medium AMJ (33.1 g kg $^{-1}$) and the medium SOM (32.6 g kg $^{-1}$) N-treatment was similar to the two high (SONAM, 32.3 and SNMJ, 32.4 g kg $^{-1}$) N-treatments for the Jul.-Aug. time period. For this same time period, the low N-treatment of November (30.5 g kg $^{-1}$) was statistically similar to the two high N-treatments and the unfertilized (28.6 g kg $^{-1}$) treatment. In the Sept.-Oct. time period, again the medium AMJ (38.8 g kg $^{-1}$) N-treatment was again similar to both high (SONAM, 36.4 and SNMJ, 37.4 g kg $^{-1}$) as well as the medium SOM (37.5 g kg $^{-1}$) N-treatment. The low September (41.4 g kg $^{-1}$) N-treatment and the medium SOM (43.1 g kg $^{-1}$) N-treatment was similar to the two high (SONAM, 42.4 and SNMJ, 42.1 g kg $^{-1}$) N-treatments for the Oct.-Nov. time period.

In 2005, the low September and November N-treatment was similar to the unfertilized treatment for all four time periods in 2004 (Table 2-33). The medium AMJ (36.4 g kg $^{-1}$) and the medium SOM (35.5 g kg $^{-1}$) N-treatment was similar to the two high (SONAM, 36.8 and SNMJ, 36.0 g kg $^{-1}$) N-treatments. For the Apr.-Jun. time period, the medium AMJ (31.5 g kg $^{-1}$) N-treatment was similar to the high SONAM 30.5 g kg $^{-1}$ N-treatment. The medium AMJ (29.7 g kg $^{-1}$) and the medium SOM (27.8 g kg $^{-1}$) N-treatment was similar to the two high (SONAM, 29.0 and SNMJ, 29.7 g kg $^{-1}$) N-treatments for the Jul.-Aug. time period. For the Sept.-Oct. time period, all the treatments are similar to the high N-treatments except the SN (38.0 g kg $^{-1}$) and low September (35.5 g kg $^{-1}$) N-treatments. The medium SOM (47.6 g kg $^{-1}$) N-treatment was similar to the two high (SONAM, 48.6 and SNMJ, 47.1 g kg $^{-1}$) N-treatments for the Oct.-Nov. time period.

Plant N uptake is influenced by numerous factors such as temperature and moisture which dramatically affect plant growth rate, available N pool, N source and rate, and the genetic potential differences between species and/or cultivars (Petrovic, 1990). Liu et al. (1993) compared KBG, PRG, and TF for their N uptake kinetics and found that TF transported more N to its leaves and with its lower overall leaf N concentration combined to produce the highest clipping growth rate and N use efficiency ratio compared to PRG and KBG. They also reported that of the three species, PRG transported less N to its leaves which together with its highest leaf N concentration produced the lowest clipping growth rate and a lower use efficiency. Our data for the three species follows this same pattern in regards to leaf tissue N and DMY. For leaf tissue N content, PRG had greater amounts of N followed by TTTF and KBG. Whereas for DMY, TTTF was greater than KBG followed by PRG. Frank et al. (2006) reported for KBG, percent N in clippings averaged 35 and 38 g kg^{-1} for the low (98 kg N ha^{-1} yr^{-1})

and high N (245 kg N ha^{-1} yr^{-1}) rate treatments, respectively. These values are comparable to our leaf tissue N content values with our low N rate (49 kg N ha^{-1} yr^{-1}) averaging 35 g kg^{-1} and our high N rate (196 kg N ha^{-1} yr^{-1}) averaging 37 g kg^{-1}. Our results are also similar to values reported by Engelsjord et al. (2004) where KBG and PRG averaged 34 and 31 g kg^{-1}, respectively. These values were similar to our lowest N content values of 35 and 33 g kg^{-1} for KBG and PRG respectively. Similar results were reported by Hull (1992) for KBG and PRG ranging 36 to 56 g kg^{-1} and from 40 to 54 g kg^{-1} for KBG and PRG respectively. Hallock et al. (1965) reported similar N tissue concentrations for tall fescue 30 g kg^{-1}. Bowman (2003) found that PRG leaf tissue N ranged from 30 to 45 g kg^{-1} with a critical limit of 27 g kg^{-1} below which growth is predicted to cease. Our unfertilized treatment did have leaf tissue N content < 27 g kg^{-1} for PRG in the summer of 2005 when it was damaged by disease for the medium SN, low SN, and the unfertilized treatment which could explain PRG slow recovery. Miltner et al. (2001) reported that fertilization resulted in increased clipping N concentration, but in some cases it did not. For KBG, N program was not significant for all harvest periods in our study which could also be due to the fact that KBG is an inefficient N user.

Summary

Specific lawn N fertilizer application strategies and annual application rates vary based on desired appearance, management intensity and intended use. Historically, Purdue University and other Universities have recommended that a cool-season lawn located in the cool-humid region should receive a minimum of 49 kg N ha^{-1} yr^{-1}, with an optimum application timing being late-summer (e.g. September 1-15th) (Reicher and Throssel, 1998). This study found that there were a wide variety of differences between species and the N-programs studied. If the goal in turf management is to maintain a turf that produces the highest visual appearance with the fewest N inputs, TTTF provided the most consistent appearance throughout the duration of this study at relatively low annual N rates. Additionally, for TTTF, all three medium (123 kg N ha^{-1} yr^{-1}) N-programs and the two high (196 kg N ha^{-1} yr^{-1}) N-programs provided similar DMYs, canopy greenness, leaf tissue N content, and TQ. The low November N-program also provided similar results as the high and medium N-programs in 2004, but was less consistent in 2005. Based on these results, a TTTF lawn appears to require 73-123 kg N ha^{-1} yr^{-1} to produce a moderate quality lawn.

Kentucky bluegrass, which has been widely regarded as the most desirable species for lawns in the cool-humid region, was the next species in terms of consistent seasonal performance. Although on many rating dates KBG TQ exceeded TTTF, outstanding seasonal performance was limited by poor spring green-up relative to TTTF or PRG. Among KBG N-programs, turf fertilized with the two high N-programs consistently resulted in the greatest DMY, canopy greenness, TQ, and less disease incidence than the medium and low N-programs. Regardless of N-program, the KBG seed blend used in this study required a November N application to encourage spring green-up. A moderate quality KBG lawn appears to require $\geq$ 123 kg N ha^{-1} yr^{-1}, especially where dollar spot incidence is of concern. The worst performing species in this study was PRG and few differences among N-programs were observed. Although this species had faster green-up in the spring than KBG, it was more severely damaged by disease regardless of annual N rates than KBG or TTTF. The minimum N requirement to produce a moderate to high quality PRG lawn appears to be $\geq$ 123 kg N ha^{-1}. Regardless of N application, however, it appears that PRG will not completely resist summer diseases and some loss in summer stand density in the cool-humid region should be expected. If a turf manager desires a one time only N application, our study shows that a November application is more beneficial than a September N application.

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Table 2-1. Eight nitrogen fertility programs varying in application timing and rate for three primary lawn species.

Application Timing	Annual Nitrogen Rate†	Monthly Nitrogen Rate					
		Apr.	May	July	Sept.	Oct.	Nov.
	(kg N ha^{-1})						
Sept. only	49	0	0	0	49	0	0
Nov. only	73	0	0	0	0	0	73
Apr., May, & July	123	49	37	37	0	0	0
Sept. & Nov.	123	0	0	0	50	0	73
Sept., Oct., & May	123	0	25	0	49	49	0
S, N, M, & July	196	0	37	37	49	0	73
S, O, N, A, & May	196	24	25	0	49	49	49
Untreated	0	0	0	0	0	0	0

† Nitrogen (N) was supplied as urea alone in Oct. and Nov., in July sulfur coated urea (SCU) was applied alone, and all other times a 50/50 (w/w) mixture of urea and SCU was applied.

Table 2-2. Dry matter yield responses of turf-type tall fescue to various nitrogen programs, 2004.

Application Timing	Nitrogen Rate†	Dry Matter Yield 2004 Apr.-June	July-Aug.	Sept.-Oct.	Oct.-Nov.	Total	03-04 Total
	kg N ha^{-1}	(kg ha^{-1})					
Sept. only	49	704.6 c	737.2 c	431.3 c	460.0 bc	2333.1 b	3492.8 b
Nov. only	73	1636.6 ab	1297.1 ab	860.4 ab	515.9 bc	4310.0 a	5219.8 a
Apr., May, & July	123	1567.9 ab	1762.0 a	1097.0 a	667.5 ab	5094.5 a	6045.5 a
Sept. & Nov.	123	2001.5 a	1597.0 a	1057.2 a	787.2 a	5442.9 a	6533.0 a
Sept.,Oct., & May	123	1636.2 ab	1586.5 a	949.1 a	705.6 ab	4877.4 a	6190.0 a
S, N, M, & July	196	1427.5 b	1470.4 a	1025.5 a	838.9 a	4762.3 a	5949.5 a
S, O, N, A, & May	196	1801.4 ab	1638.2 a	949.1 a	840.0 a	5228.7 a	6463.1 a
Untreated	0	857.5 c	737.2 c	536.6 bc	351.4 c	2615.1 b	3488.1 b
ANOVA							
Rep		NS	NS	NS	NS	NS	NS
N-Program		**	**	*	**	**	**

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.

Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).

*, **, and NS refer to significant at the 0.05, 0.01, and non-significant respectively.

Table 2-3. Dry matter yield responses of turf-type tall fescue to various nitrogen programs, 2005.

Application Timing	Nitrogen Rate†	Dry Matter Yield					
		2005					
		Apr.-June	July-Aug.	Sept.-Oct.	Oct.-Nov.	Total	03-05 Total
	kg N ha^{-1}	(kg ha^{-1})					
Sept. only	49	788.2 c	530.3 d	451.8 d	399.1 c	2169.5 d	5779.0 c
Nov. only	73	1409.2 b	926.8 c	837.6 c	428.7 c	3602.4 c	8910.0 b
Apr., May, & July	123	1431.2 b	1315.9 a	1457.6 a	760.3 ab	4964.8 a	11169.0 ab
Sept. & Nov.	123	1569.3 ab	1057.0 bc	1035.4 bc	698.6 ab	4360.2 abc	11046.0 ab
Sept.,Oct., & May	123	1510.5 ab	972.5 bc	863.2 c	611.6 b	3957.7 bc	10340.0 ab
S, N, M, & July	196	1632.3 ab	1181.6 ab	1262.6 ab	800.8 a	4877.2 ab	11004.0 ab
S, O, N, A, & May	196	1827.0 a	1342.4 a	1122.5 bc	694.0 ab	4985.8 a	11695.0 a
Untreated	0	690.8 c	440.8 d	373.2 d	367.0 c	1871.7 d	5462.0 c
ANOVA							
Rep		NS	NS	NS	NS	NS	NS
N-Program		***	***	***	***	***	***

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.
Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).
*, **, *** and NS refer to significant at the 0.05, 0.01, 0.001 and non-significant respectively.

Table 2-4. Dry matter yield responses of Kentucky bluegrass to various nitrogen programs, 2004.

Application Timing	Nitrogen Rate†	Dry Matter Yield 2004 Apr.-June	July-Aug.	Sept.-Oct.	Oct.-Nov.	Total	03-04 Total
	kg N ha^{-1}	(kg ha^{-1})					
Sept. only	49	304.3 cd	816.0 cd	568.8	496.3 cde	2185.4 cd	3139.8 de
Nov. only	73	733.6 bc	1055.9 bcd	624.1	336.0 e	2749.6 bcd	3567.8 cde
Apr., May, & July	123	546.2 bcd	1504.4 ab	933.0	512.1 bcde	3495.8 abc	4254.1 bcd
Sept. & Nov.	123	895.3 ab	1160.8 bc	727.4	654.9 abcd	3438.4 abc	4634.4 bc
Sept.,Oct., & May	123	512.0 bcd	1188.5 bc	728.7	705.0 abc	3134.2 bcd	4738.0 abc
S, N, M, & July	196	743.0 b	1443.2 ab	988.3	805.8 a	3980.3 ab	5299.2 ab
S, O, N, A, & May	196	1179.6 a	1697.5 a	981.6	788.4 ab	4647.2 a	6066.9 a
Untreated	0	285.3 d	625.0 d	526.4	426.9 de	1863.6 d	2775.6 e
ANOVA							
Rep		NS	NS	NS	NS	NS	NS
N-Program		**	**	NS	*	*	**

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.

Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).

*, **, and NS refer to significant at the 0.05, 0.01, and non-significant respectively.

Table 2-5. Dry matter yield responses of Kentucky bluegrass to various nitrogen programs, 2005.

		Dry Matter Yield					
		2005					
Application Timing	Nitrogen Rate†	Apr.-June	July-Aug.	Sept.-Oct.	Oct.-Nov.	Total	03-05 Total
	kg N ha^{-1}	(kg ha^{-1})					
Sept. only	49	492.2 c	522.9 d	641.8 e	753.7 bc	2410.6 c	5550.0 e
Nov. only	73	586.0 c	471.2 d	824.7 de	519.9 de	2401.1 c	5969.0 de
Apr., May, & July	123	381.3 c	980.9 abc	1524.8 a	700.4 cd	3587.5 b	7842.0 cd
Sept. & Nov.	123	1097.1 b	751.3 cd	970.2 cd	880.2 abc	3698.8 b	8333.0 bc
Sept.,Oct., & May	123	946.1 b	922.2 bc	983.4 cd	873.0 abc	3724.7 b	8463.0 bc
S, N, M, & July	196	1212.7 b	1073.0 ab	1476.7 ab	1057.6 a	4820.0 a	10119.0 ab
S, O, N, A, & May	196	1726.1 a	1278.5 a	1158.3 bc	935.8 ab	5098.7 a	11166.0 a
Untreated	0	330.1 c	470.6 d	548.1 e	435.9 e	1785.3 c	4561.0 e
ANOVA							
Rep		NS	NS	NS	NS	NS	NS
N-Program		***	***	***	**	***	***

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.

Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).

*, **, *** and NS refer to significant at the 0.05, 0.01, 0.001 and non-significant respectively.

Table 2-6. Dry matter yield responses of perennial ryegrass to various nitrogen programs, 2004.

Application Timing	Nitrogen Rate†	Dry Matter Yield 2004 Apr.-June	July-Aug.	Sept.-Oct.	Oct.-Nov.	Total	03-04 Total
	kg N ha^{-1}	(kg ha^{-1})					
Sept. only	49	433.5 c	544.5 bc	401.8 c	584.0 bc	1963.7 cd	3218.0 de
Nov. only	73	1129.2 ab	811.8 bc	532.2 bc	412.3 c	2885.5 ab	3854.0 cd
Apr., May, & July	123	906.1 b	1300.3 a	913.0 a	601.0 bc	3720.4 a	4662.2 abc
Sept. & Nov.	123	1005.6 b	724.5 bc	429.2 c	590.3 bc	2749.6 bc	4046.8 bcd
Sept.,Oct., & May	123	953.2 b	1178.6 a	708.0 ab	895.5 a	3735.2 a	5503.7 a
S, N, M, & July	196	1127.2 ab	1123.0 a	733.0 ab	779.5 ab	3762.7 a	4962.1 ab
S, O, N, A, & May	196	1408.1 a	1101.4 a	541.9 bc	669.4 b	3720.8 a	5170.3 a
Untreated	0	455.4 c	492.9 c	311.3 c	381.0 c	1640.7 d	2471.9 e
ANOVA							
Rep		**	*	NS	NS	NS	NS
N-Program		***	**	**	**	***	***

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.

Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).

*, **, *** and NS refer to significant at the 0.05, 0.01, 0.001 and non-significant respectively.

Table 2-7. Dry matter yield responses of perennial ryegrass to various nitrogen programs, 2005.

Application Timing	Nitrogen Rate†	Dry Matter Yield 2005 Apr.-June	July-Aug.	Sept.-Oct.	Oct.-Nov.	Total	03-05 Total
	kg N ha^{-1}	(kg ha^{-1})					
Sept. only	49	540.6 ed	468.1 d	255.5	463.5	1727.7 c	5082.0 de
Nov. only	73	1025.3 bc	575.1 cd	507.5	422.5	2530.4 b	6513.4 cd
Apr., May, & July	123	771.9 cd	861.5 a	609.3	574.8	2817.5 ab	7643.1 abc
Sept. & Nov.	123	1201.1 abc	633.1 bcd	527.8	542.2	2904.2 ab	7106.9 bc
Sept.,Oct., & May	123	1252.0 ab	740.4 abc	407.8	604.6	3004.9 ab	8829.7 a
S, N, M, & July	196	887.3 bcd	847.1 a	628.4	713.0	3075.8 ab	8235.3 ab
S, O, N, A, & May	196	1533.9 a	787.7 a	395.5	639.5	3356.6 a	8861.1 a
Untreated	0	240.9 e	284.2 e	298.2	408.2	1231.5 c	3819.7 e
ANOVA							
Rep		NS	NS	NS	NS	NS	NS
N-Program		***	***	NS	NS	***	***

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.
Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).
*, **, *** and NS refer to significant at the 0.05, 0.01, 0.001 and non-significant respectively.

Table 2-8. The effect of various nitrogen fertility programs on turfgrass quality for turf-type tall fescue, 2004.

Application Timing	Nitrogen Rate†	Turfgrass Quality 2004 Apr.-June	July-Aug.	Sept.-Oct.	Oct.-Nov.	Total
	kg N ha^{-1}	(1-9)				
Sept. only	49	6.0 c	5.6 c	6.7 c	6.9 cde	6.3 de
Nov. only	73	6.5a	5.8 c	6.9 bc	6.9 de	6.5 cd
Apr., May, & July	123	6.0 bc	7.0 a	8.1 a	7.7 ab	7.3 a
Sept. & Nov.	123	6.7 a	6.5 ab	7.4 b	7.4 abc	7.0 ab
Sept., Oct., & May	123	6.5 a	6.7 ab	7.1 bc	7.3 bcd	6.9 bc
S, N, M, & July	196	6.4 ab	6.3 b	7.4 b	7.9 a	7.0 ab
S, O, N, A, & May	196	6.6 a	6.9 a	7.3 b	7.6 ab	7.1 ab
Untreated	0	5.7 c	5.6 c	6.7 c	6.5 e	6.2 e
ANOVA						
Rep		NS	*	NS	NS	NS
N-Program		***	***	**	***	***

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.

Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).

*, **, *** and NS refer to significant at the 0.05, 0.01, 0.001 and non-significant respectively.

Table 2-9. The effect of various nitrogen fertility programs on turfgrass quality for turf-type tall fescue, 2005.

		Turfgrass Quality				
		2005				
Application Timing	Nitrogen Rate†	Apr.-June	July-Aug.	Sept.-Oct.	Oct.-Nov.	Total
	kg N ha^{-1}	(1-9)				
Sept. only	49	5.7 cd	6.5 cd	6.1 d	6.8 c	6.3 c
Nov. only	73	7.4 ab	6.8 bcd	6.8 c	6.8 c	6.9 b
Apr., May, & July	123	6.7 ab	8.0 a	8.6 a	7.9 ab	7.9 a
Sept. & Nov.	123	7.4 ab	7.1 b	7.3 c	7.5 b	7.4 b
Sept., Oct., & May	123	6.5 bc	7.0 bc	7.1 c	8.0 ab	7.2 b
S, N, M, & July	196	7.7 a	7.7 a	8.4 a	8.1 ab	8.0 a
S, O, N, A, & May	196	7.5 a	7.8 a	7.8 b	8.3 a	7.9 a
Untreated	0	4.9 d	6.3 d	6.2 d	6.3 c	6.0 c
ANOVA						
Rep		NS	NS	NS	NS	NS
N-Program		***	***	***	***	***

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.
Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).
*, **, *** and NS refer to significant at the 0.05, 0.01, 0.001 and non-significant respectively.

Table2-10. The effect of various nitrogen fertility programs on turfgrass quality for Kentucky bluegrass, 2004.

		Turfgrass Quality				
		2004				
Application Timing	Nitrogen Rate†	Apr.-June	July-Aug.	Sept.-Oct.	Oct.-Nov.	Total
	kg N ha^{-1}	(1-9)				
Sept. only	49	4.0 e	5.5 d	7.0 bc	7.3	5.9 d
Nov. only	73	4.5 cde	6.3 c	7.3 bc	7.0	6.4 cd
Apr., May, & July	123	4.2 de	6.8 abc	7.7 ab	7.1	6.5 cd
Sept. & Nov.	123	4.9 abc	6.3 c	7.3 abc	7.6	6.6 bc
Sept., Oct., & May	123	4.7 bcd	6.6 bc	7.5 abc	8.1	6.7 abc
S, N, M, & July	196	5.4 a	7.0 ab	8.2 a	8.3	7.2 ab
S, O, N, A, & May	196	5.2 ab	7.4 a	8.2 a	8.3	7.4 a
Untreated	0	4.2 de	5.6 d	6.8 c	7.0	5.9 d
ANOVA						
Rep		NS	NS	NS	NS	NS
N-Program		**	***	*	NS	**

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.
Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).
*, **, *** and NS refer to significant at the 0.05, 0.01, 0.001 and non-significant respectively.

Table 2-11. The effect of various nitrogen fertility programs on turfgrass quality for Kentucky bluegrass, 2005.

		Turfgrass Quality				
		2005				
Application Timing	Nitrogen Rate†	Apr.-June	July-Aug.	Sept.-Oct.	Oct.-Nov.	Total
	kg N ha^{-1}	---(1-9)---				
Sept. only	49	3.1 ef	6.5 cd	7.4 bc	7.7 bcd	6.4 d
Nov. only	73	4.4 bcd	7.1 bc	7.2 bc	7.1 de	6.6 cd
Apr., May, & July	123	3.4 def	7.8 ab	8.4 a	7.9 bc	7.1 bc
Sept. & Nov.	123	5.0 abc	7.2 bc	7.4 bc	7.8 cd	7.0 cd
Sept., Oct., & May	123	4.1 cde	7.6 ab	7.7 b	7.8 bc	7.0 c
S, N, M, & July	196	5.3 ab	7.8 ab	8.7 a	8.6 a	7.7 ab
S, O, N, A, & May	196	6.0 a	8.0 a	8.3 a	8.3 ab	7.8 a
Untreated	0	2.8 f	6.1 d	6.9 c	6.8 e	5.9 e
ANOVA						
Rep		NS	NS	NS	NS	NS
N-Program		***	***	***	***	***

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.
Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).
*, **, *** and NS refer to significant at the 0.05, 0.01, 0.001 and non-significant respectively.

Table 2-12. The effect of various nitrogen fertility programs on turfgrass quality for perennial ryegrass, 2004.

Application Timing	Nitrogen Rate†	Turfgrass Quality 2004 Apr.-June	July-Aug.	Sept.-Oct.	Oct.-Nov.	Total
	kg N ha^{-1}	(1-9)				
Sept. only	49	5.2 d	5.7 bc	6.4 d	6.8 c	6.0 cd
Nov. only	73	5.9 bc	5.6 c	7.1 bc	6.5 c	6.4 bc
Apr., May, & July	123	5.6 c	6.2 a	7.8 a	6.9 bc	6.7 a
Sept. & Nov.	123	6.0 bc	5.7 bc	6.7 cd	6.9 bc	6.4 bc
Sept., Oct., & May	123	5.8 c	6.1 ab	7.3 abc	7.5 a	6.7 ab
S, N, M, & July	196	6.2 ab	6.2 a	7.3 ab	7.3 ab	6.8 a
S, O, N, A, & May	196	6.4 a	6.1 ab	7.0 bc	7.0 bc	6.7 ab
Untreated	0	5.6 cd	5.5 c	6.7 cd	6.0 d	6.0 d
ANOVA						
Rep		NS	NS	NS	NS	NS
N-Program		***	*	**	***	***

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.

Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).

*, **, *** and NS refer to significant at the 0.05, 0.01, 0.001 and non-significant respectively.

Table 2-13. The effect of various nitrogen fertility programs on turfgrass quality for perennial ryegrass, 2005.

Application Timing	Nitrogen Rate†	Turfgrass Quality 2005 Apr.-June	July-Aug.	Sept.-Oct.	Oct.-Nov.	Total
	kg N ha^{-1}	(1-9)				
Sept. only	49	5.9 c	5.8 de	4.1	6.1	5.5
Nov. only	73	7.1 ab	6.0 cde	5.0	5.9	6.0
Apr., May, & July	123	6.7 b	6.7 a	5.6	6.6	6.4
Sept. & Nov.	123	7.2 ab	6.1 bcde	5.2	6.4	6.2
Sept., Oct., & May	123	7.0 ab	6.2 abcd	4.6	7.1	6.3
S, N, M, & July	196	7.2 ab	6.5 ab	5.5	6.7	6.5
S, O, N, A, & May	196	7.3 a	6.3 abc	5.2	7.0	6.5
Untreated	0	5.7 c	5.7 e	4.8	6.1	5.6
ANOVA						
Rep		NS	NS	NS	NS	NS
N-Program		***	**	NS	NS	NS

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.

Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).

*, **, *** and NS refer to significant at the 0.05, 0.01, 0.001 and non-significant respectively.

Table 2-14. Various nitrogen fertility programs effect on disease incidence and severity for three primary cool-season lawn species in 2004.

Species	Disease Incidence					
	2004					
	May 20	May 28	June 12	June 16	June 23	July 29
	(% Blight)					
Kentucky Bluegrass	2.12 b	1.25 b	0.87 b	1.79 b	1.33 b	0.10 b
Perennial Ryegrass	3.82 b	2.23 ab	3.02 a	3.30 ab	1.13 b	0.16 b
Turf-type Tall Fescue	9.76 a	3.69 a	2.10 a	3.65 a	2.69 a	1.17 a
ANOVA						
Rep	NS	NS	NS	**	NS	NS
Species	***	**	**	NS	*	**
N-Program	NS	**	***	***	***	**
Species X N-Program	NS	*	*	*	NS	NS

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.
Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).
*, **, *** and NS refer to significant at the 0.05, 0.01, 0.001 and non-significant respectively.

Table 2-15. Various nitrogen fertility programs effect on disease incidence and severity for three primary cool-season lawn species in 2005.

Species	Disease Incidence					
	2005					
	June 20	June 27	July 7	July 19	July 27	Aug. 7
	(% Blight)					
Kentucky Bluegrass	0.00 b	0.11 b	0.10 b	1.01 b	1.61 b	0.13 b
Perennial Ryegrass	0.66 a	14.39 a	18.32 a	57.83 a	42.74 a	12.70 a
Turf-type Tall Fescue	0.33 a	0.50 b	0.79 b	2.27 b	0.78 b	0.11 b
ANOVA						
Rep	NS	NS	NS	NS	NS	NS
Species	***	***	***	***	***	***
N-Program	NS	NS	NS	**	NS	*
Species X N-Program	NS	NS	NS	NS	NS	NS

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.
‡Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).
*, **, *** and NS refer to significant at the 0.05, 0.01, 0.001 and non-significant respectively.

Table 2-16. The effect of various nitrogen fertility programs on disease incidence and severity in 2004 for turf-type tall fescue.

		Disease Incidence					
		2004					
Application Timing	Nitrogen Rate†	May 20	May 28	June 12	June 16	June 23	July 29
	kg N ha^{-1}	(% Blight)					
Sept. only	49	11.57 abc	7.30 ab	6.28 ab	12.03 a	10.03 a	0.46
Nov. only	73	10.12 abc	6.95 abc	2.34 bc	6.50 ab	7.30 a	0.15
Apr., May, & July	123	6.13 c	1.67 cd	0.04 c	1.07 c	0.33 b	0.00
Sept. & Nov.	123	4.45 c	1.63 cd	1.10 bc	0.91 c	0.93 b	0.06
Sept., Oct., & May	123	4.90 c	0.53 d	0.83 bc	0.91 c	0.66 b	0.12
S, N, M, & July	196	7.67 bc	2.75 bcd	1.32 bc	2.08 bc	1.04 b	0.02
S, O, N, A, & May	196	19.58 a	2.17 bcd	0.13 c	0.83 c	0.15 b	0.01
Untreated	0	18.67 ab	12.46 a	14.24 a	14.81 a	11.45 a	1.75
ANOVA							
Rep		NS	NS	NS	**	NS	NS
N-Program		*	**	**	**	***	NS

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.
Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).
*, **, *** and NS refer to significant at the 0.05, 0.01, 0.001 and non-significant respectively.

Table 2-17. The effect of various nitrogen fertility programs on disease incidence and severity in 2005 for turf-type tall fescue.

Application Timing	Nitrogen Rate†	Disease Incidence 2005 June 20	June 27	July 7	July 19	July 27	Aug. 7
	kg N ha^{-1}	-----(% Blight)-----					
Sept. only	49	0.50	0.20	3.68	6.99	1.53 b	0.67 ab
Nov. only	73	0.33	0.39	0.24	1.34	0.72 bc	0.02 cd
Apr., May, & July	123	0.12	0.24	0.24	1.46	0.20 c	0.00 d
Sept. & Nov.	123	0.82	0.13	0.10	2.20	0.46 c	0.01 cd
Sept., Oct., & May	123	0.19	1.79	2.11	2.08	0.67 bc	0.20 bc
S, N, M, & July	196	0.06	0.20	0.10	0.73	0.20 c	0.00 d
S, O, N, A, & May	196	0.68	1.92	2.29	0.33	0.35 c	0.06 cd
Untreated	0	0.32	0.35	0.39	6.99	4.00 a	0.89 a
ANOVA							
Rep		NS	NS	NS	NS	NS	*
N-Program		NS	NS	NS	NS	***	***

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.

Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).

*, **, *** and NS refer to significant at the 0.05, 0.01, 0.001 and non-significant respectively.

Table 2-18. The effect of various nitrogen fertility programs on disease incidence and severity in 2004 for Kentucky bluegrass.

Application Timing	Nitrogen Rate†	Disease Incidence					
		2004					
		May 20	May 28	June 12	June 16	June 23	July 29
	$kg\ N\ ha^{-1}$	(% Blight)					
Sept. only	49	3.55	2.61 ab	3.08 ab	5.60	5.19 a	0.52
Nov. only	73	2.59	1.76 bc	0.83 bc	2.22	1.89 ab	0.11
Apr., May, & July	123	1.63	1.65 bc	1.00 abc	1.75	1.08 bc	0.01
Sept. & Nov.	123	3.80	0.67 bc	0.33 c	0.83	0.83 bc	0.03
Sept., Oct., & May	123	1.17	0.20 c	0.39 c	0.73	0.52 bc	0.00
S, N, M, & July	196	1.08	0.30 c	0.16 c	0.50	0.16 bc	0.01
S, O, N, A, & May	196	0.50	0.10 c	0.10 c	0.16	0.06 c	0.00
Untreated	0	4.32	6.52 a	3.46 a	6.87	5.04 a	1.12
ANOVA							
Rep		NS	NS	NS	NS	NS	NS
N-Program		NS	**	*	NS	**	NS

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.
Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).
*, **, and NS refer to significant at the 0.05, 0.01, and non-significant respectively.

Table 2-19. The effect of various nitrogen fertility programs on disease incidence and severity in 2005 for Kentucky bluegrass.

		Disease Incidence					
		2005					
Application Timing	Nitrogen Rate†	June 20	June 27	July 7	July 19	July 27	Aug. 7
	kg N ha^{-1}	(% Blight)					
Sept. only	49	0.01	0.13	0.10	2.20	4.63	0.12
Nov. only	73	0.00	0.13	0.10	2.97	1.88	0.53
Apr., May, & July	123	0.00	0.13	0.10	1.30	0.81	0.02
Sept. & Nov.	123	0.00	0.16	0.10	1.08	1.08	0.13
Sept., Oct., & May	123	0.01	0.04	0.04	0.33	0.53	0.06
S, N, M, & July	196	0.00	0.10	0.10	0.20	6.63	0.02
S, O, N, A, & May	196	0.00	0.10	0.10	0.28	0.24	0.09
Untreated	0	0.04	0.13	0.13	1.19	0.73	0.04
ANOVA							
Rep		NS	*	NS	NS	NS	NS
N-Program		NS	NS	NS	NS	NS	NS

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.
Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).
* and NS refer to significant at the 0.05 and non-significant respectively.

Table 2-20. The effect of various nitrogen fertility programs on disease incidence and severity in 2004 for perennial ryegrass.

		Disease Incidence					
		2004					
Application Timing	Nitrogen Rate†	May 20	May 28	June 12	June 16	June 23	July 29
	kg N ha^{-1}	(% Blight)					
Sept. only	49	2.59	2.47	3.80	5.18 abc	3.98 a	8.93
Nov. only	73	2.59	1.41	2.71	2.33 bc	0.85 ab	0.47
Apr., May, & July	123	1.74	0.85	0.59	1.08 c	0.06 b	0.06
Sept. & Nov.	123	6.69	8.46	7.75	10.68 a	4.13 a	3.58
Sept., Oct., & May	123	5.93	2.49	7.37	7.24 ab	0.24 b	0.19
S, N, M, & July	196	3.08	3.03	1.32	1.39 c	0.66 b	0.50
S, O, N, A, & May	196	2.12	0.47	1.23	0.60 c	0.35 b	0.20
Untreated	0	8.12	1.74	3.05	3.00 bc	1.95 ab	1.44
ANOVA							
Rep		NS	NS	NS	NS	NS	NS
N-Program		NS	NS	NS	*	*	NS

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.
Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).
* and NS refer to significant at the 0.05 and non-significant respectively.

Table 2-21. The effect of various nitrogen fertility programs on disease incidence and severity in 2005 for perennial ryegrass.

		Disease Incidence					
		2005					
Application Timing	Nitrogen Rate†	June 20	June 27	July 7	July 19	July 27	Aug. 7
	kg N ha^{-1}	(% Blight)					
Sept. only	49	1.78	21.22	32.90	81.63	63.35	21.61
Nov. only	73	0.32	20.16	24.53	62.78	41.46	11.51
Apr., May, & July	123	0.89	19.42	21.46	77.62	42.98	9.60
Sept. & Nov.	123	0.11	7.31	8.93	31.34	24.87	9.94
Sept., Oct., & May	123	1.00	15.86	17.61	54.48	46.70	15.36
S, N, M, & July	196	0.22	5.48	10.21	41.11	32.30	10.14
S, O, N, A, & May	196	0.65	6.99	9.60	41.03	41.61	10.83
Untreated	0	1.08	25.13	27.37	68.64	50.00	14.32
ANOVA							
Rep		NS	NS	NS	NS	NS	NS
N-Program		NS	NS	NS	NS	NS	NS

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.
Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).
NS refers to not significant at the 0.05.

Table 2-22. The effect of various nitrogen fertility programs on canopy greenness for turf-type tall fescue in 2004.

Application Timing	Nitrogen Rate†	Canopy Greenness 2004 Apr.-June	July-Aug.	Sept.-Oct.	Oct.-Nov.	Total
	kg N ha^{-1}	-----------------------(chlorophyll index)	-----------------------			
Sept. only	49	305.3 d	311.4 d	338.0 c	386.7 bcd	333.8 cd
Nov. only	73	469.4 abc	379.1 cd	389.3 bc	364.1 cd	400.9 bc
Apr., May, & July	123	456.6 bc	507.6 a	503.5 a	425.7 abc	477.1 a
Sept. & Nov.	123	541.1 ab	435.9 bc	430.1 ab	432.4 ab	452.3 ab
Sept., Oct., & May	123	427.9 c	445.7 abc	421.1 abc	388.8 bcd	422.0 ab
S, N, M, & July	196	490.6 abc	459.0 ab	464.2 ab	486.4 a	473.9 a
S, O, N, A, & May	196	547.3 a	491.9 ab	436.0 ab	435.2 ab	476.2 a
Untreated	0	312.5 d	308.8 d	344.1 c	329.9 d	325.0 d
ANOVA						
Rep		*	NS	NS	NS	NS
N-Program		***	***	*	**	***

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.
Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).
*, **, *** and NS refer to significant at the 0.05, 0.01, 0.001 and non-significant respectively.

Table 2-23. The effect of various nitrogen fertility programs on canopy greenness for turf-type tall fescue in 2005.

Application Timing	Nitrogen Rate†	Canopy Greenness 2005 Apr.-June	July-Aug.	Sept.-Oct.	Oct.-Nov.	Total
	kg N ha^{-1}	(chlorophyll index)				
Sept. only	49	285.9 d	272.5 e	268.7 d	368.7 c	302.6 d
Nov. only	73	451.6 ab	339.1 d	318.4 cd	311.4 d	350.2 c
Apr., May, & July	123	388.6 bc	476.7 a	536.5 a	416.6 bc	453.3 a
Sept. & Nov.	123	457.0 ab	368.4 cd	409.0 b	415.5 bc	409.0 b
Sept., Oct., & May	123	375.6 c	383.2 c	367.9 bc	437.3 ab	394.2 b
S, N, M, & July	196	480.6 a	436.4 b	509.5 a	462.9 ab	468.6 a
S, O, N, A, & May	196	517.9 a	486.3 a	404.3 b	485.8 a	475.6 a
Untreated	0	211.3 e	250.2 e	266.2 d	286.3 d	255.9 e
ANOVA						
Rep		NS	NS	NS	NS	NS
N-Program		***	***	***	***	***

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.

Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).

*, **, *** and NS refer to significant at the 0.05, 0.01, 0.001 and non-significant respectively.

Table 2-24. The effect of various nitrogen fertility programs on canopy greenness for Kentucky bluegrass in 2004.

Application Timing	Nitrogen Rate†	Canopy Greenness				
		2004				
		Apr.-June	July-Aug.	Sept.-Oct.	Oct.-Nov.	Total
	$kg\ N\ ha^{-1}$	(chlorophyll index)				
Sept. only	49	252.5 ef	409.6 de	441.2	475.9 cd	395.2 de
Nov. only	73	405.0 bcd	432.5 de	436.7	383.7 e	417.1 cde
Apr., May, & July	123	325.1 de	568.1 ab	531.5	429.0 de	469.3 bcd
Sept. & Nov.	123	436.9 ab	458.3 cd	459.1	500.1 bcd	462.0 bcd
Sept., Oct., & May	123	354.3 cd	517.0 bc	525.6	536.2 abc	484.3 abc
S, N, M, & July	196	418.6 abc	551.7 ab	577.3	586.4 a	534.7 ab
S, O, N, A, & May	196	490.7 a	598.4 a	580.4	563.9 ab	559.7 a
Untreated	0	239.1 f	373.9 e	443.3	431.4 de	374.8 e
ANOVA						
Rep		NS	NS	NS	NS	NS
N-Program		***	***	NS	**	**

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.
Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).
*, **, *** and NS refer to significant at the 0.05, 0.01, 0.001 and non-significant respectively.

Table 2-25. The effect of various nitrogen fertility programs on canopy greenness for Kentucky bluegrass in 2005.

		Canopy Greenness				
		2005				
Application Timing	Nitrogen Rate†	Apr.-June	July-Aug.	Sept.-Oct.	Oct.-Nov.	Total
	kg N ha^{-1}	(chlorophyll index)				
Sept. only	49	268.5 cd	348.5 d	460.4 cd	499.3 c	399.1 d
Nov. only	73	354.7 b	404.2 c	470.6 cd	405.6 d	408.1 cd
Apr., May, & July	123	307.7 bc	562.2 a	647.7 a	481.4 c	503.4 ab
Sept. & Nov.	123	432.6 a	420.4 c	488.2 bc	493.2 c	458.3 bc
Sept., Oct., & May	123	353.9 b	474.9 b	542.2 bc	530.7 bc	480.0 b
S, N, M, & July	196	459.6 a	510.1 ab	675.6 a	585.6 a	556.1 a
S, O, N, A, & May	196	485.7 a	520.2 ab	583.6 ab	557.6 ab	537.1 a
Untreated	0	223.4 d	295.2 d	383.7 d	385.3 d	324.9 e
ANOVA						
Rep		NS	NS	NS	NS	NS
N-Program		***	***	***	***	***

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.
Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).
*, **, *** and NS refer to significant at the 0.05, 0.01, 0.001 and non-significant respectively.

Table 2-26. The effect of various nitrogen fertility programs on canopy greenness for perennial ryegrass in 2004.

		Canopy Greenness				
		2004				
Application Timing	Nitrogen Rate†	Apr.-June	July-Aug.	Sept.-Oct.	Oct.-Nov.	Total
	kg N ha^{-1}	(chlorophyll index)				
Sept. only	49	276.2 c	315.8 cd	329.3 d	346.9 b	316.9 de
Nov. only	73	434.3 ab	343.9 c	378.0 cd	278.5 c	362.8 bc
Apr., May, & July	123	412.5 ab	450.2 a	508.5 a	341.1 b	436.6 a
Sept. & Nov.	123	413.9 ab	318.7 cd	331.6 d	344.8 b	351.1 cd
Sept., Oct., & May	123	379.8 b	402.8 b	424.7 bc	404.0 a	404.3 ab
S, N, M, & July	196	439.2 ab	385.8 b	451.0 ab	401.5 a	422.2 a
S, O, N, A, & May	196	456.6 a	404.7 b	390.1 bcd	361.8 ab	403.8 ab
Untreated	0	283.6 c	300.4 d	333.2 d	238.6 c	293.7 e
ANOVA						
Rep		NS	NS	NS	NS	NS
N-Program		***	***	***	***	***

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.
Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).
*, **, *** and NS refer to significant at the 0.05, 0.01, 0.001 and non-significant respectively.

Table 2-27. The effect of various nitrogen fertility programs on canopy greenness for perennial ryegrass in 2005.

		Canopy Greenness				
		2005				
Application Timing	Nitrogen Rate†	Apr.-June	July-Aug.	Sept.-Oct.	Oct.-Nov.	Total
	kg N ha^{-1}	(chlorophyll index)				
Sept. only	49	296.4 c	242.0 d	186.5 d	353.5 bcd	274.3 cd
Nov. only	73	453.4 a	271.1 d	244.3 bcd	318.5 d	317.3 bc
Apr., May, & July	123	445.4 a	405.1 a	327.0 ab	374.0 bc	388.1 a
Sept. & Nov.	123	465.2 a	272.8 d	276.1 bcd	363.1 bcd	340.0 b
Sept., Oct., & May	123	379.5 b	318.6 c	281.3 bc	429.9 a	356.0 ab
S, N, M, & July	196	455.5 a	357.3 bc	377.5 a	398.0 ab	393.8 a
S, O, N, A, & May	196	495.5 a	361.3 b	324.1 ab	398.4 ab	391.9 a
Untreated	0	271.1 c	234.7 d	221.3 cd	323.3 cd	265.4 d
ANOVA						
Rep		NS	NS	NS	NS	NS
N-Program		***	***	*	**	***

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.
Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).
*, **, *** and NS refer to significant at the 0.05, 0.01, 0.001 and non-significant respectively.

Table 2-28. The effect of various nitrogen fertility programs on leaf tissue nitrogen content for turf-type tall fescue in 2004.

		Leaf Tissue N Content				
		2004				
Application Timing	Nitrogen Rate†	Apr.-June	July-Aug.	Sept.-Oct.	Oct.-Nov.	Total
	kg N ha^{-1}	---(g kg^{-1})---				
Sept. only	49	25.8	23.5 b	27.7 c	33.6 bcd	27.3 b
Nov. only	73	30.4	27.8 a	31.1 ab	32.5 cd	30.3 a
Apr., May, & July	123	30.6	30.2 a	32.6 a	35.3 abc	32.1 a
Sept. & Nov.	123	31.6	27.9 a	31.6 a	37.0 a	31.7 a
Sept., Oct., & May	123	29.7	27.6 a	30.4 abc	36.1 ab	30.6 a
S, N, M, & July	196	29.7	28.2 a	31.7 a	37.6 a	31.5 a
S, O, N, A, & May	196	31.9	30.0 a	31.4 a	37.7 a	32.3 a
Untreated	0	26.8	24.1 b	28.3 bc	31.1 d	27.4 b
ANOVA						
Rep		NS	NS	NS	NS	NS
N-Program		NS	**	*	**	**

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.

Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).

*, **, and NS refer to significant at the 0.05, 0.01, and non-significant respectively.

Table 2-29. The effect of various nitrogen fertility programs on leaf tissue nitrogen content for turf-type tall fescue in 2005.

		Leaf Tissue N Content				
		2005				
Application Timing	Nitrogen Rate†	Apr.-June	July-Aug.	Sept.-Oct.	Oct.-Nov.	Total
	kg N ha^{-1}	----------	----------	($g\ kg^{-1}$)	----------	----------
Sept. only	49	26.2 cd	22.4 e	28.7 de	37.3 b	28.6 de
Nov. only	73	29.1 b	25.2 d	31.5 cd	36.5 b	30.5 cd
Apr., May, & July	123	30.1 ab	29.1 ab	35.2 a	39.6 a	33.6 ab
Sept. & Nov.	123	30.1 ab	27.3 bc	32.3 abc	40.3 a	32.5 bc
Sept., Oct., & May	123	28.2 bc	27.0 cd	31.8 bc	40.2 a	31.9 bc
S, N, M, & July	196	29.6 b	29.1 ab	34.2 abc	41.7 a	33.8 ab
S, O, N, A, & May	196	32.4 a	29.8 a	34.7 ab	41.5 a	34.6 a
Untreated	0	25.7 d	22.6 e	28.4 e	33.4 c	27.5 e
ANOVA						
Rep		NS	NS	NS	NS	NS
N-Program		***	***	***	***	***

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.
Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).
*, **, *** and NS refer to significant at the 0.05, 0.01, 0.001 and non-significant respectively.

Table 2-30. The effect of various nitrogen fertility programs on leaf tissue nitrogen content for Kentucky bluegrass in 2004.

Application Timing	Nitrogen Rate†	Leaf Tissue N Content 2004 Apr.-June	July-Aug.	Sept.-Oct.	Oct.-Nov.	Total
	kg N ha^{-1}	(g kg^{-1})				
Sept. only	49	30.7	28.4 b	31.5	37.7 bc	31.7
Nov. only	73	33.8	28.6 b	31.2	34.3 d	31.6
Apr., May, & July	123	34.1	30.3 ab	33.5	35.1 cd	33.1
Sept. & Nov.	123	35.1	28.6 b	31.8	39.3 ab	33.0
Sept., Oct., & May	123	32.7	29.8 b	33.0	39.9 ab	33.4
S, N, M, & July	196	34.0	29.8 b	34.1	41.2 a	34.3
S, O, N, A, & May	196	37.0	33.0 a	34.4	40.8 ab	35.8
Untreated	0	30.8	27.7 b	31.6	34.4 d	30.9
ANOVA						
Rep		NS	NS	NS	NS	NS
N-Program		NS	*	NS	**	NS

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.
Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).
*, **, and NS refer to significant at the 0.05, 0.01, and non-significant respectively.

Table 2-31. The effect of various nitrogen fertility programs on leaf tissue nitrogen content for Kentucky bluegrass in 2005.

		Leaf Tissue N Content				
		2005				
Application Timing	Nitrogen Rate†	Apr.-June	July-Aug.	Sept.-Oct.	Oct.-Nov.	Total
	kg N ha^{-1}	(g kg^{-1})				
Sept. only	49	28.8 cd	26.8 cd	32.7	43.3 ab	33.0
Nov. only	73	30.8 bc	27.1 cd	51.3	39.4 cd	37.3
Apr., May, & July	123	30.5 bc	31.4 ab	35.7	41.1 cb	34.8
Sept. & Nov.	123	33.6 ab	28.8 bc	33.6	43.8 a	34.8
Sept., Oct., & May	123	32.0 bc	31.1 ab	33.9	44.9 a	35.6
S, N, M, & July	196	33.9 ab	33.1 a	37.4	45.9 a	37.7
S, O, N, A, & May	196	35.8 a	33.7 a	34.3	44.2 a	37.0
Untreated	0	26.0 d	24.5 d	30.8	38.2 d	30.0
ANOVA						
Rep		NS	NS	NS	NS	NS
N-Program		**	***	NS	***	NS

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.

Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).

*, **, *** and NS refer to significant at the 0.05, 0.01, 0.001 and non-significant respectively.

Table 2-32. The effect of various nitrogen fertility programs on leaf tissue nitrogen content for perennial ryegrass in 2004.

		Leaf Tissue N Content				
		2004				
Application Timing	Nitrogen Rate†	Apr.-June	July-Aug.	Sept.-Oct.	Oct.-Nov.	Total
	kg N ha^{-1}	----------------	----------------	(g kg^{-1})	----------------	----------------
Sept. only	49	29.1 e	28.8 c	35.0 bc	41.4 ab	33.4 c
Nov. only	73	31.1 cd	30.5 abc	36.0 bc	37.8 d	33.9 bc
Apr., May, & July	123	33.5 a	33.1 a	38.8 a	39.0 cd	36.3 a
Sept. & Nov.	123	30.6 cde	29.6 bc	35.6 bc	40.5 bc	33.9 bc
Sept., Oct., & May	123	31.2 bcd	32.6 a	37.5 ab	43.1 a	36.0 a
S, N, M, & July	196	32.0 abc	32.4 a	37.4 ab	42.1 ab	35.9 ab
S, O, N, A, & May	196	32.9 ab	32.3 ab	36.4 abc	42.4 ab	35.8 ab
Untreated	0	30.1 de	28.6 c	34.4 c	38.5 cd	32.8 c
ANOVA						
Rep		NS	*	NS	NS	NS
N-Program		*	*	*	*	*

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.
Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).
* and NS refer to significant at the 0.05 and non-significant respectively.

Table 2-33. The effect of various nitrogen fertility programs on leaf tissue nitrogen content for perennial ryegrass in 2005.

		Leaf Tissue N Content				
		2005				
Application Timing	Nitrogen Rate†	Apr.-June	July-Aug.	Sept.-Oct.	Oct.-Nov.	Total
	kg N ha^{-1}	(g kg^{-1})				
Sept. only	49	25.2 d	23.7 b	35.5 bc	45.8 bc	32.8 c
Nov. only	73	27.9 bcd	25.1 b	37.4 abc	42.9 d	33.4 bc
Apr., May, & July	123	31.5 a	29.7 a	39.4 a	44.5 cd	36.4 a
Sept. & Nov.	123	27.9 bcd	25.0 b	35.2 c	45.0 bcd	33.4 c
Sept., Oct., & May	123	27.1 cd	27.8 a	38.0 a	47.6 ab	35.5 ab
S, N, M, & July	196	28.4 bc	29.0 a	37.8 ab	47.1 ab	36.0 a
S, O, N, A, & May	196	30.5 ab	29.7 a	37.6 ab	48.6 a	36.8 a
Untreated	0	26.0 cd	23.3 b	37.5 ab	43.5 cd	32.7 c
ANOVA						
Rep		NS	*	NS	NS	NS
N-Program		**	***	*	**	**

† Nitrogen was supplied as urea alone in Oct. and Nov., in July SCU was applied alone, and all other times a 50/50 (w/w) mixture of urea and sulfur coated urea was applied.

Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD (P=0.05).

*, **, *** and NS refer to significant at the 0.05, 0.01, 0.001 and non-significant respectively.

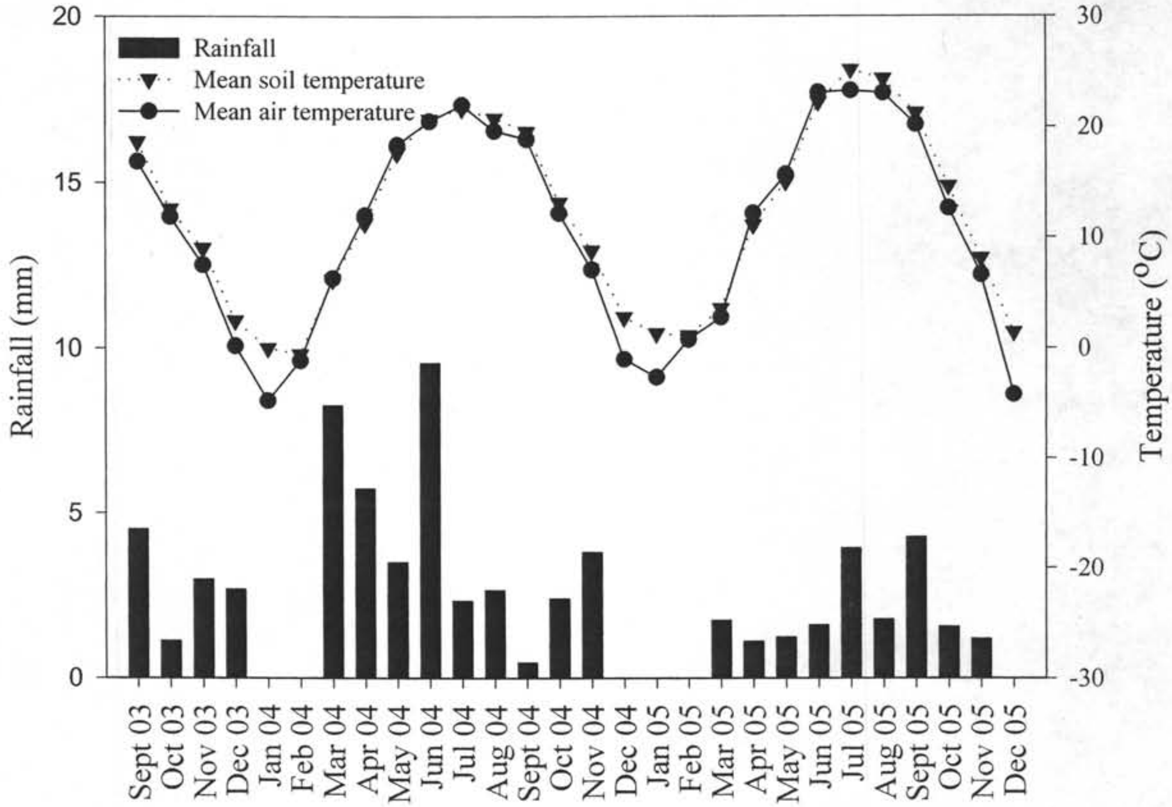

Figure 2-1. Rainfall, air and soil (grass cover, 10 cm) temperatures from Sept., 2003 to Dec., 2005.