NITROGEN SOURCE AND TIMING EFFECT ON CARBOHYDRATE STATUS OF BERMUDAGRASS AND TALL FESCUE

by

ANTHONY LEE GOLDSBY

B.S., Kansas State University, 2004

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Horticulture Forestry and Recreation Resources
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2008

Approved by:

Major Professor
Steven J. Keeley

Abstract

Non-structural carbohydrates (NSC) are important for plant health and recovery from stress. Controlled-release N sources may moderate turfgrass vegetative growth, thereby maximizing NSC levels. Three studies were conducted to determine the effect of N source/timing on NSC levels, turfgrass visual quality, and color of ‘Midlawn’ bermudagrass and turf-type tall fescue. Additionally, the effect on low temperature tolerance of bermudagrass and brown patch incidence on tall fescue was investigated. Nitrogen sources included two polymer-coated ureas (PCU), a polymer-sulfur coated urea (SCU) and urea formaldehyde (UF). Total annual N was applied in either late summer or spring for bermudagrass, and either late summer or split between late summer and spring for tall fescue. Urea, applied at traditional timings, was a control in all studies. NSC status was determined at regular intervals by extracting two cores from each plot, defoliating, and measuring regrowth in a dark growth chamber. Turfgrass color, visual quality and brown patch incidence were rated monthly during the growing season. Bermudagrass low temperature tolerance was evaluated by subjecting plugs to a freezing regime and evaluating regrowth. Over the 2-yr study, N source did not have a significant effect on bermudagrass or tall fescue NSC levels, color, or visual quality. Timing of application, by contrast, did have a significant impact. For bermudagrass, August-applied N resulted in higher overall NSC levels and improved fall color. For tall fescue, split Sept/March applications improved color; but split Sept/ May applications reduced NSC compared to a single Sept application. Brown patch incidence was unaffected by N source or timing, though disease pressure was low. Timing of PCU application did not affect low temperature tolerance of bermudagrass, but PCU improved low temperature survival compared to urea.

Table of Contents

List of Figures

List of Tables

Acknowledgements

I thank Dr. Steve Keeley, Kansas State University, Manhattan, KS for all his time and assistance in developing and completing this project. His guidance was the main reason for the success of this project.

This project was sponsored by Pursell Industries and the Kansas Turfgrass Foundation. We are grateful to Dr. Alan Zuk for his assistance with plot maintenance.

Dedication

I dedicate this to my mother Connie Goldsby.

Chapter 1 - Nitrogen Source and Timing Effect on Carbohydrate Status of Bermudagrass

Non-structural carbohydrates (NSC) are the energy source for turfgrass growth and recovery; therefore, NSC levels have often been used as an indicator of the physiological health and/or stress tolerance of a turfgrass (Hull, 1992). Several studies have shown higher NSC levels in winter improve low-temperature survival of various turfgrass species (Shahba et al., 2003; Ball et al., 2002; Fry et al., 1993). Similarly, cool-season turfgrass quality during summer has been related to higher NSC content in shoots and roots (Xu and Huang, 2003; Liu and Huang, 2000). Spring regrowth after winter dormancy and turfgrass recovery from excessive traffic and other stresses is also dependent on an adequate supply of NSC (Fry and Huang, 2004).

Turfgrass cultural practices can have a significant effect on plant health by altering NSC levels. For example, lower mowing heights reduce leaf area for photosynthesis, which ultimately results in a reduction in rooting (Liu and Huang, 2002). Turfgrass fertilizer regimes can also play a role in NSC levels. Nitrogen fertilizer is essential for high quality turfgrass, but multiple studies have documented decreased NSC levels with higher N rates (Gonzlaez et al., 1989; Watschke and Waddington, 1974; Zanoni et al., 1969; Brown and Blaser, 1965). This reduction in NSC likely occurs because nitrogen promotes vegetative growth, which has been shown to deplete NSC levels (Green and Beard, 1969; Youngner and Nudge, 1976; Fry and Huang, 2004). Thus, turfgrass stands receiving high N may be less able to tolerate and/or recover from various stresses. Slow-release nitrogen fertilizers have the potential to provide a solution to this problem by moderating turfgrass vegetative growth. In comparison with fast-release sources, slow-release N sources may also require fewer applications, produce more uniformity, and have a lower burn hazard (Moberg et al., 1970).

However, many slow-release N sources are dependent on microbial activity for N release, which makes the timing and rate of release somewhat difficult to predict. Nitrogen release from natural organic N sources and urea formaldehyde is increased when conditions favor microbial decomposition, consequently most release occurs during periods of elevated temperatures and adequate moisture (Watschke and Waddington, 1974). Polymer-coated nitrogen fertilizers have been developed that are not dependent on microbial activity for N release. Therefore, they should provide a more predictable and precise rate of N release (Christians, 2004).

Because turfgrass NSC levels are known to fluctuate seasonally (Narra et al., 2004; Miller and Dickens, 1996; Youngner et al., 1978) it is important that NSC sampling be conducted throughout the year in order to provide a clear picture of a fertilizer regime's effects on turfgrass NSC levels.

The objective of our study was to evaluate the effect of spring vs. late summer applications of polymer-coated N sources, in comparison to traditional N sources, on the NSC status, turf quality and color of 'Midlawn' bermudagrass (*Cynodon dactylon* L. Pers. x *C. transvaalensis* Burtt-Davy).

Materials and Methods

Study site and experimental design

This study was conducted on a 5-yr old stand of Midlawn bermudagrass, from August 2005 to September 2007, at the Rocky Ford Turfgrass Research Center near Manhattan, Kansas, USA (39°13'53" N, 96°34'51" W). The soil at the site was a Chase silt loam (fine, smectitic, mesic, Aquertic Argiudoll) with a pH of 6.9. A soil test indicated P and K levels were adequate. Prior to the study the plot area had been maintained at a 14 mm mowing height and fertilized with a soluble N-source, such as urea, at a rate of 49 kg N ha^{-1} per growing month to give a total of 147 to 196 kg N ha^{-1} yr^{-1}.

The treatments, consisting of various N sources applied in either spring or late summer, were arranged in a completely randomized design with four replications. Plot size was 1.5 by 3.0 m. Nitrogen sources included two polymer-coated ureas (PCU) which varied in coating thickness (the thicker-coated product had 41% N on a w/w basis, and the thinner-coated product had 43% N), sulfur-coated urea (SCU), and urea formaldehyde(UF). Each N source was applied in single yearly applications at 196 kg N ha^{-1} in either April or August. Thus, August treatments were applied in 2005 and 2006, while April treatments were applied in 2006 and 2007. A check treatment consisted of urea applied at 49 kg N ha^{-1} in May, June, July and August. Immediately after N sources were applied, the plots were irrigated with approximately 10 mm of water.

Plot Maintenance

The stand was maintained at a mowing height of 14 millimeters, at a frequency of three times per week during the growing season. Irrigation was supplied as needed to prevent moisture stress. Typically, plots received about 25 mm of water per week during the growing season.

Measurements

Non-structural carbohydrate levels were evaluated using the method described by Burton (1995) with minor revisions. Briefly, two cores, 10-cm dia. x 18-cm deep, were extracted from each plot on a bimonthly basis throughout the study, and were defoliated and placed in a dark growth chamber at 24 C. Etiolated regrowth was then measured over an 8-wk regrowth period, by excising shoot growth biweekly, drying the clippings at 80 C for 48 h, and recording the dry weights. Because regrowth occurred in darkness, energy for regrowth necessarily came from NSC. The soil moisture level of the cores was maintained near field capacity during the regrowth period by watering as needed based on volumetric water content measurements obtained with a time domain reflectometry (TDR) unit. In order to enhance the utilization of NSC for regrowth during the 8-wk period, each core was fertilized with 9.8 kg N ha^{-1}, using urea dissolved in water, upon being placed in the growth chamber (Adams et al., 1974).

Turfgrass color and quality were recorded on a monthly basis, during the growing season, by the same researcher throughout the study. The rating scale for color was 1-9, where 1= brown and 9= dark green. The rating scale for visual quality was also 1-9, where 1= brown, dead turfgrass and 9= highest quality, based on color, density, texture and uniformity (Emmons, 2000).

Statistical analysis

Data were analyzed with the MIXED procedure of SAS (SAS Institute Inc., Cary, NC). In cases where the F-test for treatment differences was significant, 95% confidence intervals were used for comparison of individual treatment means. The GLM procedure was used to analyze orthogonal contrasts between specific treatment groups. Designated level of significance for this study was ($p \leq 0.10$).

Results and Discussion

Non-Structural Carbohydrate Levels

Nitrogen source. Analysis of variance indicated a significant ($p \leq 0.05$) treatment effect on only 2 of 12 sampling dates (Table 1.1). Both instances were from samples collected in January (2006 and 2007), when etiolated regrowth was near its seasonal peak (Figure 1.1). However, similar differences were not observed for the November sampling dates, which were associated with even higher regrowth. In most cases, there were no differences among N sources that had been applied at the same timing. The one exception (April-applied UF vs. SCU for the January 2007 sampling period) did not occur at any other time during the study. Thus, N source was not an important factor in enhancing NSC levels. One of our objectives was to compare polymer-coated N sources to more traditional N sources, and our results showed no increase in etiolated regrowth with the polymer-coated sources.

One might have expected that our urea “check” treatment would have lower regrowth, because it is a soluble N source, and such N sources are known to promote vegetative growth (Fry and Huang, 2004). Vegetative growth, in turn, has been shown to deplete NSC levels in turfgrass (Green and Beard, 1969; Youngner and Nudge, 1976; Fry and Huang, 2004). Indeed, some have recommended circumventing this problem by using N sources that release nitrogen slowly (Fry and Huang, 2004). We saw no such advantage in our study. It is possible that we would have seen higher NSC levels with slow release N sources, if we had split the total N into two or more applications, instead of applying the total amount in a single application. Such a strategy would, however, negate the labor savings to be gained from applying the entire annual N in a single application. This labor savings has been touted as one of the primary advantages in using polymer-coated N sources.

Application timing. In contrast to the lack of a significant N-source effect, application timing significantly ($p \leq 0.10$) affected etiolated regrowth on 5 of the 12 sampling dates, and for the total regrowth summed over all dates (Table 1.1 and Figure 1.1). The higher regrowth levels in the August applied treatments are not surprising for November 2005, January 2006 and March 2006, because the April-applied treatments were not applied for the first time until April 2006 (although, as described in the methods, those plots had been fertilized with a "traditional" regime of 49 kg N ha^{-1} per growing month prior to initiation of the study in August 2005). Clearly, the late-season N from the August-applied treatments enhanced NSC storage in the bermudagrass, compared with treatments not receiving August-applied N. Notably, the urea check treatment, which received 49 kg N ha^{-1} in August 2005, had similar amounts of regrowth, for the aforementioned sampling periods, compared to the other August-applied treatments (Table 1.1).

The April-applied treatments, first applied in April 2006, did not lead to higher etiolated regrowth for the subsequent sampling periods (May and July 2006; Table 1.1 and Figure 1.1). This may be because the bermudagrass, which grows most actively during the warm months of late spring and summer (May through August in our location), was using available carbohydrates for shoot and root growth rather than storage.

After the second round of August-applied treatments in 2006, etiolated regrowth was again higher for those treatments during the November sampling period, but not for the January or March sampling periods (Table 1.1 and Figure 1.1). It is possible that the lack of significant differences in the two latter months, in contrast to the previous year, may have been partially related to temperature differences in the December to March period from one year to the next (Figure 1.2). It may also have been related to the lower overall level of regrowth during those months, as compared with the previous year (Figure 1.1). In any case, the fact that the August-applied treatments were the only ones that led to significantly higher etiolated regrowth was likely due to the fact that the bermudagrass growth slows in the months following August in our location, so a higher percentage of carbohydrates formed by photosynthesis would have been stored in the plant. This scenario is, in fact, the same as that thought to occur in cool-season grasses, and which undergirds the recommendation for late-season fertilization in cool-season regions (Christians, 2004, pp. 129-30).

The very low etiolated regrowth levels in May and July of 2007 followed a spring in which the bermudagrass began to emerge from dormancy during a warm March, but was then subjected to a severe freeze in early April 2007, causing dieback of the shoot tissue. Thus, the bermudagrass essentially emerged from dormancy twice that spring, which likely consumed most of the NSC.

Turfgrass Color and Visual Quality

Nitrogen source. There was generally no difference in turfgrass color or visual quality among N sources when applied at the same timing (Table 1.2 and 1.3). The lone exception occurred during August 2006, when August-applied UF resulted in slightly darker color than other August-applied N sources. Given that the difference was slight and occurred only in that single month, it is of little note. All the N sources appeared to deliver adequate N.

Application timing. Application timing was, once again, the dominant factor affecting turfgrass color and visual quality. Contrasts showed that August-applied treatments had darker color in the one to two months immediately following their application in 2005 and 2006 (Table 1.2), which was expected. More interesting, however, is the fact that April-applied treatments did not have better turfgrass color or visual quality than the August-applied treatments in the spring of 2006 or 2007. It was not until July 2006, nearly a full year after the August-applied treatments had been made, that the April-applied treatments resulted in better turfgrass color.

Indeed, contrasts revealed that the August-applied treatments actually resulted in better bermudagrass visual quality in May 2006, compared to the April-applied treatments (Table 1.3). Our turfgrass color and visual quality results, taken together, favor the application of N fertilizers during late summer, rather than spring. We did not see a similar effect of application timing on bermudagrass visual quality in May 2007, however, this may have been related to the previously described freeze of April 2007, recovery which probably drained NSC in the bermudagrass (Table 1.1 and Figure 1.1).

There appears to be a benefit to bermudagrass from late-season N applications, similar to that described for cool-season grasses (Christians, 2004, pp. 129-30). Of course, late-season N applications to bermudagrass should be applied earlier in the season than cool-season grasses because their growth cycles are different. For example, in Manhattan, KS, late-season N fertilization of cool-season grasses occurs in October or November, whereas our late-season applications to bermudagrass, in this research, occurred in August.

Conclusions

In summary, N source did not have a significant effect on bermudagrass NSC levels, turfgrass color, or visual quality. In particular, polymer-coated N sources performed similarly to the other N sources.

Timing of application, by contrast, had a significant impact. August-applied N resulted in higher NSC levels on several sampling dates, along with improved color in the late-season months. August-applied N resulted in similar turfgrass color in the spring, compared with April-applied treatments, and actually resulted in improved bermudagrass visual quality in May 2006. If turfgrass managers wish to save labor by making a once-per-year application of a controlled-release N source on bermudagrass, late-summer application is recommended.

Figures and Tables

Figure 1.1- Cumulative etiolated regrowth of all N sources as affected by application timing over the course of the two-year study. Significance at p= 0.1, 0.05, and 0.01 is indicated by *, **, and *, respectively.**

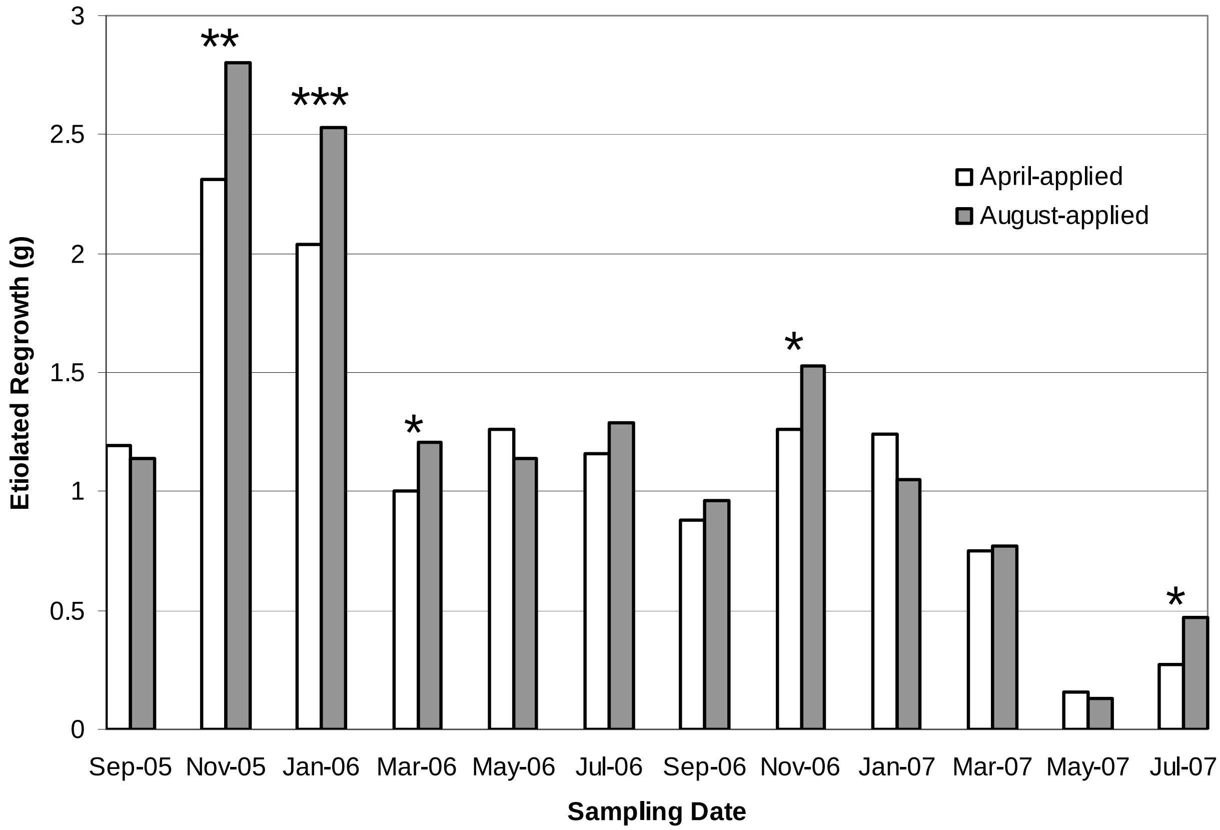

Figure 1.2- Average air temperature at the research site for the 2005-06 and 2006-07 seasons.

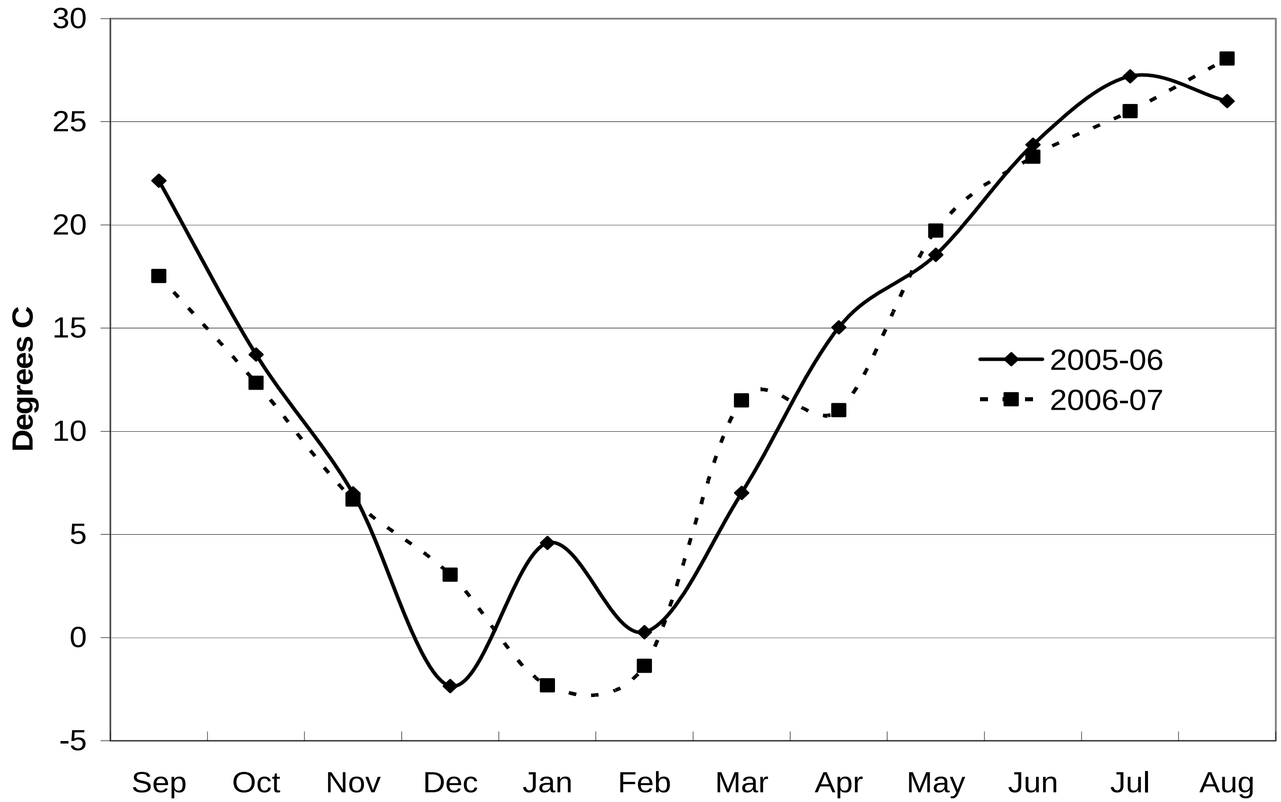

Table 1.1- Etiolated regrowth of 'Midlawn' bermudagrass as affected by nitrogen source and timing of application in Manhattan, KS, USA.

		--Sampling Date (mo/yr)--												
		09/05	11/05	01/06	03/06	05/06	07/06	09/06	11/06	01/07	03/07	05/07	07/07	Total
N source†	Timing	---g dwt---												
PCU(43%N)	April	0.25	0.63	0.48 b‡	0.21	0.36	0.30	0.25	0.31	0.29 abc	0.16	0.03	0.07	3.34
	August	0.27	0.67	0.72 a	0.23	0.27	0.37	0.23	0.39	0.32 abc	0.24	0.02	0.12	3.85
PCU (41%N)	April	0.25	0.62	0.50 ab	0.22	0.28	0.28	0.18	0.36	0.32 abc	0.16	0.04	0.07	3.28
	August	0.28	0.74	0.59 ab	0.38	0.26	0.29	0.27	0.42	0.19 bc	0.17	0.05	0.22	3.87
SCU	April	0.33	0.49	0.44 b	0.30	0.34	0.25	0.23	0.30	0.13 c	0.22	0.05	0.08	3.14
	August	0.29	0.69	0.62 ab	0.29	0.33	0.30	0.22	0.36	0.21 bc	0.18	0.02	0.06	3.55
UF	April	0.36	0.57	0.62 ab	0.27	0.28	0.33	0.22	0.29	0.50 a	0.21	0.04	0.05	3.68
	August	0.30	0.70	0.60 ab	0.31	0.28	0.33	0.24	0.36	0.33 ab	0.18	0.04	0.07	3.80
Urea	Check	0.30	0.66	0.65 ab	0.36	0.33	0.29	0.15	0.38	0.18 bc	0.17	0.02	0.07	3.54
Contrast: August-applied vs. April-applied		NS	0.05	0.01	0.10	NS	NS	NS	0.10	NS	NS	NS	0.10	0.01

†PCU = polymer-coated urea; SCU = sulfur-coated urea; UF = urea formaldehyde. Each N source was applied in single yearly applications at 196 kg N ha^{-1} in either April or August, except for the urea check, which was applied at 49 kg N ha^{-1} in May, June, July and August.

‡ Means followed by the same letter in a column are not significantly different at p=0.05. Columns with no letters indicate an insignificant F-test.

NS= not significant.

Table 1.2- Turfgrass color of 'Midlawn' bermudagrass as affected by nitrogen source and timing of application in Manhattan, KS, USA.

		Rating Date (mo/yr)															
		09/05	10/05	04/06	05/06	06/06	07/06	08/06	09/06	10/06	04/07	05/07	06/07	07/07	08/07	09/07	Mean
N source†	Timing	1-9 scale‡															
PCU (43% N)	April	4.5 cd§	6.0 ab	6.0	6.0	6.0	5.8	5.8 b	6.0	6.0	6.0	6.0	6.3	7.0	6.5	6.3	6.0
	August	6.0 a	6.5 ab	6.0	6.0	6.3	5.0	6.0 b	6.8	6.5	6.5	6.3	6.0	7.0	7.0	6.0	6.2
PCU (41% N)	April	4.8 bcd	6.0 ab	6.0	6.0	6.5	5.8	6.0 b	6.3	6.3	6.3	6.0	6.0	6.8	7.0	6.5	6.2
	August	6.0 a	6.8 a	6.0	6.0	6.0	5.5	6.0 b	6.5	6.0	6.0	6.0	6.0	7.0	6.5	6.0	6.2
SCU	April	4.3 d	5.8 b	6.0	6.0	6.0	5.8	6.0 b	6.0	6.0	6.0	6.5	6.0	7.0	6.8	6.0	6.0
	August	6.0 a	6.3 ab	6.0	5.8	6.3	5.8	6.0 b	6.0	6.0	6.0	6.0	6.0	7.0	7.0	6.3	6.2
UF	April	4.8 bcd	5.8 b	5.8	5.8	6.0	6.0	6.0 b	6.3	6.0	6.0	6.0	6.0	6.8	7.0	6.0	6.1
	August	5.3 abc	6.0 ab	6.0	5.8	6.5	5.3	6.5 a	6.5	6.0	6.0	6.0	6.0	7.0	7.0	6.3	6.2
Urea	Check	5.5 ab	6.0 ab	5.8	5.8	6.8	5.3	6.0 b	6.5	6.0	6.0	6.0	6.5	7.0	7.0	6.3	6.2
Contrast: August-applied vs. April-applied		0.01	0.05	NS	NS	NS	0.05	0.05	0.05	NS	NS	NS	NS	NS	NS	NS	0.05

†PCU = polymer-coated urea; SCU = sulfur-coated urea; UF = urea formaldehyde. Each N source was applied in single yearly applications at 196 kg N ha^{-1} in either April or August, except for the urea check, which was applied at 49 kg N ha^{-1} in May, June, July and August.

‡A 1-9 scale was used, where 1= brown and 9= dark green.

§Means followed by the same letter in a column are not significantly different at p=0.05. Columns with no letters indicate an insignificant F-test.

NS= not significant.

Table 1.3- Visual quality of 'Midlawn' bermudagrass as affected by nitrogen source and timing of application in Manhattan, KS, USA.

		Rating Date (mo/yr)															
		09/05	10/05	04/06	05/06	06/06	07/06	08/06	09/06	10/06	04/07	05/07	06/07	07/07	08/07	09/07	Mean
N source†	Timing	1-9 scale‡															
PCU (43% N)	April	5.8	6.0	5.3	5.5	6.0	6.0	5.8	6.0	6.0	6.0	6.0	6.0	6.5	7.0	6.0	6.0
	August	6.0	6.0	5.3	6.0	6.0	5.8	6.0	6.0	6.0	6.0	6.3	5.5	6.3	6.8	6.3	6.0
PCU (41% N)	April	5.8	6.0	5.5	5.8	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	7.0	6.8	6.0	6.0
	August	6.0	6.3	5.3	6.0	6.0	6.0	6.0	6.0	5.8	6.0	6.0	6.0	6.8	6.5	6.0	6.0
SCU	April	5.8	6.0	5.8	5.8	6.0	6.0	6.0	6.0	6.0	6.0	6.5	6.0	6.8	6.8	6.0	6.1
	August	6.0	6.0	5.8	6.0	6.0	6.0	5.8	6.0	5.8	6.3	6.0	6.0	6.8	6.8	6.3	6.1
UF	April	5.8	6.0	5.5	6.0	6.3	5.8	5.8	6.0	6.0	6.3	6.0	6.0	6.8	6.8	6.0	6.0
	August	6.0	6.0	5.8	6.0	6.0	5.8	5.8	5.8	6.0	5.8	6.0	6.0	7.0	6.3	6.0	6.0
Urea	Check	5.8	6.0	5.5	5.8	6.0	6.0	5.8	5.8	6.0	5.8	6.0	6.3	6.8	7.0	6.3	6.0
Contrast: August-applied vs. April-applied		0.10	NS	NS	0.05	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

†PCU = polymer-coated urea; SCU = sulfur-coated urea; UF = urea formaldehyde. Each N source was applied in single yearly applications at 196 kg N ha^{-1} in either April or August, except for the urea check, which was applied at 49 kg N ha^{-1} in May, June, July and August.

‡A 1-9 scale was used, where 1= poorest and 9= best.

NS= not significant.

Chapter 2 - Nitrogen Source and Timing Effect on Low Temperature Tolerance of Bermudagrass

Non-structural carbohydrates (NSC) are the energy source for turfgrass growth and recovery; consequently, NSC levels have often been used as an indicator of the physiological health and/or stress tolerance of a turfgrass (Hull, 1992). Several research studies have shown that higher NSC levels in winter improve low-temperature survival of various turfgrass species (Shahba et al., 2003; Ball et al., 2002; Fry et al., 1993). Spring regrowth after winter dormancy and turfgrass recovery from excessive traffic and other stresses are also dependent on an adequate supply of NSC (Fry and Huang, 2004).

There are a several published studies which debate the affects of late-season applications of Nitrogen to warm-season grasses. Some believe these late application timings may affect not only the level of Non-Structural Carbohydrates in the plant, but also the color and quality of the stand late into the growing season and upon greenup in the spring. Turfgrasses with high tissue nitrogen were shown to be less resistant to winter injury than those from low-nitrogen plots (Carroll, 1943). Likewise, Beard (1982) reported late-season N applications have been linked to increased vulnerability to winterkill and disease infestation of Tifgreen and 'Tifdwarf' bermudagrass (as cited in Goatley et. al, 1994).

In conflicting studies performed by (White and Schmidt, 1990; Schmidt and Chalmers, 1993; Richardson, M.D., 2001; Munshaw et. al, 2006) late-season applications of Nitrogen were shown to have no affect on winter recovery of bermudagrass. Similar results were documented in studies conducted by (Goatley et. al., 1994; Goatley et. at.,1998) which found water- soluble N had little effect on NSC levels of 'Tiflawn' and 'Tifgreen' bermudagrass receiving late-season fertilization. Turfgrass stands receiving late-season N were found to also have enhanced turf greening the following spring (Schmidt et al., 1989; Goatley et. al., 1998). Some feel the benefits attained from late-season applications of N outweigh the potential negative effects making these application types more commonplace. However, further investigations into the relationship between NSC and low temperature tolerance may provide more insight into the affects of late-season nitrogen applications.

The objective of our study was to determine the effect on ‘Midlawn’ bermudagrass (*Cynodon dactylon* L. Pers. x *C. transvaalensis* Burtt-Davy) low-temperature tolerance of, 1) applying the total annual N in either spring or late summer, using a polymer-coated N source and, 2) to compare the effect of the polymer-coated N regimes with a traditional N fertilization regime using urea.

Materials and Methods

Study site and experimental design

This study was conducted on a 5-yr old stand of Midlawn bermudagrass, from August 2005 to September 2007, at the Rocky Ford Turfgrass Research Center near Manhattan, Kansas, USA (39°13'53" N, 96°34'51" W). The soil at the site was a Chase silt loam (fine, smectitic, mesic, Aquertic Argiudoll) with a pH of 6.9. A soil test indicated P and K levels were adequate. Prior to the study the plot area had been maintained at a 14 mm mowing height and fertilized with a soluble N-source, such as urea, at a rate of 49 kg N ha^{-1} per growing month to give a total of 147 to 196 kg N ha^{-1} yr^{-1}.

Measurements

Low temperature tolerance of 'Midlawn' bermudagrass, as affected by N source and timing, was evaluated during the winter of 2006-2007. Nitrogen sources included a PCU which had an analysis of 43-0-0, and urea. PCU was applied in single yearly applications at 196 kg N ha^{-1} in either April or August. Urea was applied at 49 kg N ha^{-1} in May, June, July and August. Low temperature tolerance was measured using the method described in Fry et al. (1993) with minor revisions. Briefly, the procedure was as follows: Twenty-five 5-cm dia. x 6-cm depth plugs were extracted from each treatment plot in November 2006, and January and March 2007. Plugs were immediately placed in a growth chamber and allowed to acclimate at 3° C for a period of 12 hours. Following the 12 hr acclimation period the plugs were moved to a thermo-controlled freezing chamber at -3° C (Figure 2.1). The temperature was then decreased at a rate of 3°C per hour and 5 plugs were removed at each of their respective temperatures. For the November and March sampling periods, plugs were removed at -3,-6,-9,-12, and -15° C, and for the January sampling period they were removed at -6, -9, -12, -15, and -18^{o} C. Two thermocouples were inserted into the maximum freezing temperature group in order to ensure that target temperatures were attained. Sampling temperatures were determined from the LT_{50} values for Midlawn bermudagrass described by Dunn and Nelson (1974).

After the freezing regime plugs were allowed to reacclimate at 3^{o} C for 12 hours. The plugs were then transplanted into 10-cm pots using a medium containing 3 parts peat: 2 parts sand: 2 parts vermiculite (by volume) and kept in a greenhouse at 25^{o} C for observation. The plugs were observed weekly for six weeks on two parameters: survival and percent recovery. If any regrowth was observed, the plug was given a status score of 1. If no regrowth occurred the plug was given a status score of 0. Additionally, plugs were given a percent recovery rating between 1-100% to further track recovery.

Statistical analysis

Data were analyzed with the MIXED procedure of SAS (SAS Institute Inc., Cary, NC). Differences among treatment means were separated by Fisher's protected LSD. Designated level of significance for this study was ($p \leq 0.10$).

Results and Discussion

Low Temperature Tolerance Recovery and Status

Nitrogen Source. Analysis of variance indicated a significant ($p \leq 0.05, 0.10$) treatment effect on 2 of the 3 sampling dates (Table 2.1). For both sampling dates percent recovery means were higher for PCU treatments compared to the urea treatments (Table 2.2, Figure 2.2). Percent recovery means were significantly higher for April applied PCU in comparison to urea in November 2006 and March 2007. We speculated that high NSC levels would be observed for the treatments which received a high percent recovery mean. However, we found no correlation between low temperature tolerance and NSC levels (See Chapter 1). The reason for the increased low temperature survival with the PCU compared to urea is not understood.

Previous research has shown that the individual ratios of water soluble carbohydrate within the plant may be a larger contributing factor to low temperature tolerance than the overall level of NSC (Shahba et al., 2003; Ball et al., 2002). If such differences occurred with our treatments they would not have been detected by our evaluation methods. Further research investigating individual water soluble carbohydrate levels may provide further insight into why our PCU and urea had different effects on low temperature tolerance.

Application Timing. There was no significant ($p \leq 0.10$) difference in mean percent recovery when comparing application timings for the PCU (Table 2.2). Our research found significantly higher NSC levels for August-applied treatments compared to April-applied (See Chapter 1). One might expect that the higher level of NSC in the plant would result in improved low temperature survival for treatments which received August application timings. However, no such relationship was observed. April applied timings did however provided increased low temperature tolerance when compared to urea for the November 2006 and March 2007 periods (Table 2.2, Figure 2.2).

Conclusions

In summary, PCU application timing did not have a significant effect on low-temperature survival of Midlawn bermudagrass. PCU applied in April or August resulted in similar survival. By contrast, nitrogen source did have a significant impact on low temperature tolerance. PCU fertilizers showed higher percent recovery means for the November 2006 and March 2007 sampling periods in comparison to urea. This difference was significant for both periods when comparing April applied PCU to urea. Our research did not indicate that this improved low temperature tolerance was related to NSC levels. Further research investigating individual water-soluble carbohydrates, or other factors, is needed to elucidate the mechanism of improved low temperature tolerance.

Figures and Tables

Figure 2.1- Samples in a thermocontrolled freezer preparing to undergo freeze tolerance testing.

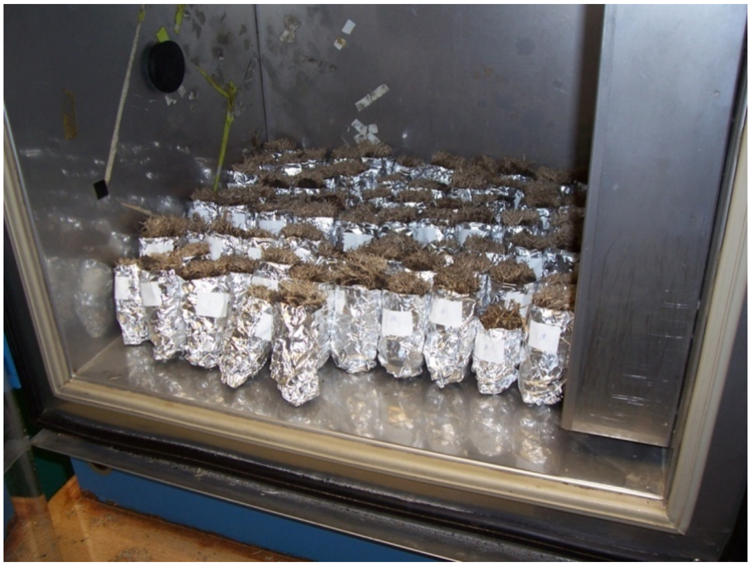

Figure 2.2- Regrowth of 'Midlawn' bermudagrass six weeks after being subjected to low temperatures; 5 replicates at each temperature. The urea plugs received 49 kg N ha^{-1} in May, June, July and August. The PCU plugs in this picture received 196 kg N ha^{-1} in April.

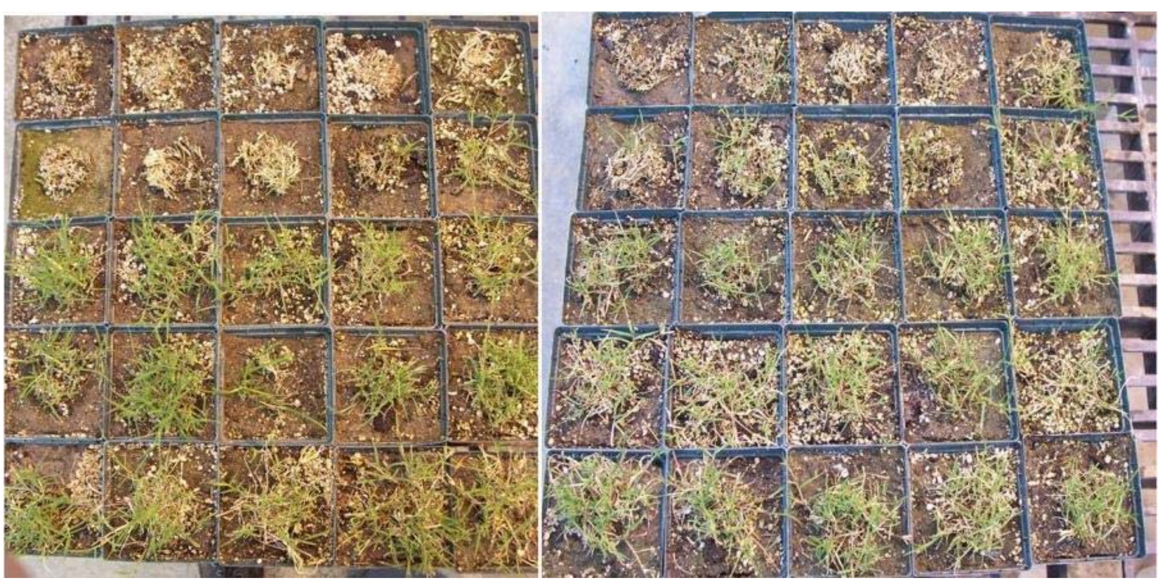

Table 2.1- ANOVA for low-temperature tolerance of 'Midlawn' bermudagrass as affected by nitrogen source and timing of application in Manhattan, KS, USA.

	Sampling Date		
	November 2006	January 2007	March 2007
Source	Significance of F		
N source/timing	0.03	NS	0.10
Temperature	<0.001	<0.001	<.0.001
Treatment x Temperature	NS	NS	NS

PCU was applied in single yearly applications at 196 kg N ha^{-1} in either April or August. Urea was applied at 49 kg N ha^{-1} in May, June, July and August.

NS= not significant.

Table 2.2- Percent recovery of 'Midlawn' bermudagrass that had been fertilized with different N sources and timings, and then subjected to low temperatures in Manhattan, KS, USA.

N source†	Timing	November 2006	January 2007	March 2007
PCU	April	88%a‡	72%	72%a
PCU	August	76%ab‡	72%	68%ab
Urea	May, June, July, August	68%b‡	68%	56%b

†PCU = polymer-coated urea. PCU was applied in single yearly applications at 196 kg N ha^{-1} in either April or August. Urea was applied at 49 kg N ha^{-1} in May, June, July and August.

‡Means followed by the same letter in a column are not significantly different at p=0.05

Means refer to recovery after exposure to low temperatures. Plugs received a rating between 1-100%. (1%=Little or no growth and 100%=Complete Growth).

Chapter 3 - Nitrogen Source and Timing Effect on Carbohydrate Status of Tall Fescue

Non-structural carbohydrates (NSC) are the energy source for turfgrass growth and recovery; therefore, NSC levels have often been used as an indicator of the physiological health and/or stress tolerance of a turfgrass (Hull, 1992). Several research studies have shown higher NSC levels in winter improve low-temperature survival of various turfgrass species (Shahba et al., 2003; Ball et al., 2002; Fry et al., 1993). Similarly, cool-season turfgrass quality during summer has been related to higher NSC content in shoots and roots (Xu and Huang, 2003; Liu and Huang, 2000). Spring regrowth after winter dormancy and turfgrass recovery from excessive traffic and other stresses are also dependent on an adequate supply of NSC (Fry and Huang, 2004).

Turfgrass cultural practices can have a significant effect on plant health by altering NSC levels. For example, lower mowing heights reduce leaf area for photosynthesis, which ultimately results in a reduction in rooting (Liu and Huang, 2002). Turfgrass fertilizer regimes can also play a role in NSC levels.

Nitrogen fertilizer is essential for high quality turfgrass, but multiple studies have documented decreased NSC levels with higher N rates (Gonzlaez et al., 1989; Watschke and Waddington, 1974; Zanoni et al., 1969; Brown and Blaser, 1965). This reduction in NSC likely occurs because nitrogen promotes vegetative growth, which has been shown to deplete NSC levels (Green and Beard, 1969; Youngner and Nudge, 1976; Fry and Huang, 2004). Thus, turfgrass stands receiving high N may be less able to tolerate and/or recover from various stresses.

Slow-release nitrogen fertilizers have the potential to provide a solution to this problem by moderating turfgrass vegetative growth. In comparison with fast-release sources, slow-release N sources may also require fewer applications, produce more uniformity, and have a lower burn hazard (Moberg et al., 1970). However, many slow-release N sources are dependent on microbial activity for N release, which makes the timing and rate of release somewhat difficult to predict. Nitrogen release from natural organic N sources and urea formaldehyde is increased when conditions favor microbial decomposition, consequently most release occurs during periods of elevated temperatures and adequate moisture (Watschke and Waddington, 1974). Polymer-coated nitrogen fertilizers have been developed that are not dependent on microbial activity for N release. Therefore, they should provide a more predictable and precise rate of N release (Christians, 2004).

Because turfgrass NSC levels are known to fluctuate seasonally (Narra et al., 2004; Miller and Dickens, 1996; Youngner et al., 1978) it is important that NSC sampling be conducted throughout the year in order to provide a clear picture of a fertilizer regime's effects on turfgrass NSC levels.

Nitrogen fertility has also been shown to have an effect on disease incidence in cool season grasses. Grasses that have been overfertilized with N develop a thin cuticle. Cell walls become thinner, allowing for easier attack by disease-causing organisms (Christians, 2004). Increasing N levels on cool-season grasses has been shown to exacerbate brown patch (*Rhizoctonia solani* Kuhn) blighting (Burpee, 1995; Fidanza and Dernoeden, 1996). The brown patch fungus causes a foliar blight and crown rot that result in patches of necrotic turf up to a few meters in diameter (Burpee and Martin, 1992). Springtime applications of soluble nitrogen sources, as opposed to slow release N sources, may have an influence on the development of brown patch during the summer months.   Evaluation of disease incidence in relationship to the N source will be useful in determining the N source and application timing combination which will maximize NSC levels while minimizing brown patch blighting during the growing season.

The objective of study 1 was to evaluate the effect of spring vs. late summer applications of PCU sources, in comparison to traditional N sources, on the NSC status, turf quality and color, and brown patch incidence of tall fescue (*Festuca arundinacea* Screb.). The objective of study 2 was to evaluate the effect of springtime applications of a soluble N source, in comparison to a PCU N source, on the NSC status, turf quality and color, and brown patch incidence of tall fescue.

Materials and Methods

Study 1 site and experimental design

This study was conducted on a 3 year old stand of tall fescue, from August 2005 to September 2007, at the Rocky Ford Turfgrass Research Center near Manhattan, Kansas, USA (39°13'53" N, 96°34'51" W). The soil at the site was a Chase silt loam (fine, smectitic, mesic, Aquertic Argiudoll) with a pH of 6.9. A soil test indicated P and K levels were adequate. Prior to the study the plot area had been maintained at a 76 mm mowing height and fertilized with a soluble N-source, such as urea, at 49 kg N ha^{-1} applied in May, September, and November to give a total of 147 N ha^{-1} yr^{-1}.

The treatments, consisting of various N sources applied in either September or September and March, were arranged in a completely randomized design with four replications. Plot size was 1.5 by 3.0 m. Nitrogen sources included two polymer-coated ureas (PCU) which varied in coating thickness (the thicker-coated product had 41% N on a w/w basis, and the thinner-coated product had 43% N), sulfur-coated urea (SCU), and urea formaldehyde (UF). Each N source was applied either in single yearly applications at 147 kg N ha^{-1} in September or two 73.5 kg N ha^{-1} applications in September and March. A control treatment consisted of urea applied at 49 kg N ha^{-1} in September, November and May. Immediately after N sources were applied, the plots were irrigated with approximately 10 mm of water.

Study 2 site and experimental design

This study was conducted on a 3 year old stand of tall fescue, from August 2005 to September 2007, at the Rocky Ford Turfgrass Research Center near Manhattan, Kansas, USA (39°13'53" N, 96°34'51" W). The soil at the site was a Chase silt loam (fine, smectitic, mesic, Aquertic

Argiudoll) with a pH of 6.9. A soil test indicated P and K levels were adequate. Prior to the study the plot area had been maintained at a 76 mm mowing height and fertilized with a soluble N-source, such as urea, at a rate of 49 kg N ha^{-1} applied in May, September and November to give a total of 147 N ha^{-1} yr^{-1}.

The treatments, consisting of various combinations of PCU and urea, were applied in September and May. The plots were arranged in a completely randomized design with four replications. Plot size was 0.75 by 1.5 meters. Each treatment received a total of 196 kg N ha^{-1} yr^{-1} in various combinations of PCU and urea. In September plots received either 98, 147, or 196 kg N ha^{-1} all from PCU. The balance of the N was then applied in May using either PCU or urea as the N source (Table 3.5). The PCU used in the spring had a slightly thicker polymer coating than that used in September (41% N versus 43% N) in order to provide a slower rate of N release during the spring and summer. Immediately after N sources were applied, the plots were irrigated with approximately 10 mm of water.

Study 1 and 2 Plot Maintenance

The plots were maintained at a mowing height of 76 mm, at a frequency of two times per week during the growing season. Irrigation was applied as needed to prevent moisture stress. Typically, plots received about 25 mm of water per week during the growing season.

Study 1 and 2 Measurements

Non-structural carbohydrate levels were evaluated using the method described by Burton (1995) with minor revisions. Briefly, two cores, 10-cm dia. x 18-cm deep, were extracted from each plot on a bimonthly basis throughout the study for study 1, and on a monthly basis during the summer months for study 2. The cores were defoliated and placed in a dark growth chamber at 24 C. Etiolated regrowth was then measured over an 8-wk regrowth period, by excising shoot growth biweekly, drying the clippings at 80^{o} C for 48 h, and recording the dry weights. Because regrowth occurred in darkness, energy for regrowth necessarily came from NSC. The soil moisture level of the cores was maintained near field capacity during the regrowth period by watering as needed based on volumetric water content measurements obtained with a time domain reflectometry (TDR) unit. In order to enhance the utilization of NSC for regrowth during the 8-wk period, each core was fertilized with 9.8 kg N ha^{-1}, using urea dissolved in water, upon being placed in the growth chamber (Adams et al., 1974).

Turfgrass color and quality were recorded on a monthly basis, during the growing season, by the same researcher throughout the study. The rating scale for color was 1-9, where 1= brown and 9= dark green. The rating scale for quality was also 1-9, where 1= brown, dead turfgrass and 9= highest quality, based on color, density, texture and uniformity (Emmons, 2000). Brown patch visual ratings were recorded on tall fescue plots during summer to evaluate disease incidence. The Horsfall-Barrat 1-12 rating scale, where 1=0% disease affected, and 12= 100% disease affected, was utilized during summer months for visual estimates of brown patch incidence (Horsfall and Cowling, 1978).

Statistical analysis

Data were analyzed with the MIXED procedure of SAS (SAS Institute Inc., Cary, NC). In cases where the F-test for treatment differences was significant, 95% confidence intervals were used for comparison of individual treatment means. The GLM procedure was used to analyze contrasts between the PCU and the traditional N sources, and between fall-applied N and spring/fall applied N. The designated level of significance for this study was ($p \leq 0.10$).

Results and Discussion (Study #1)

Non-Structural Carbohydrate Levels

Nitrogen source. Analysis of variance indicated a significant ($p \leq 0.05$) treatment effect on only 3 of 12 sampling dates (Table 3.1). However, further results from mean separation tests yielded no distinct and explainable differences among the N sources. Contrasts(comparison of group means) comparing polymer-coated N sources to more traditional N sources, were found to be significant on only one of 12 sampling dates (Table 3.1). The significant sampling period occurred in March 2006 and showed PCU sources yielded slightly higher etiolated regrowth in comparison to the traditional N sources.

Results suggest there are few benefits to be attained from utilizing a PCU N source to increase NSC levels on cool-season grasses. In situations where a slow release N source is desired UF may be utilized as a cheaper alternative to PCU with no effect on NSC status. It is also interesting to note that over the duration of the study no treatment proved better than the standard urea check. Overall, we observed very few cases where N sources had a significant effect on NSC, especially if applied at the same timing. The first objective of our study was to compare polymer-coated N sources to more traditional N sources, and our results showed little increase in etiolated regrowth with the polymer-coated sources.

For the duration of the study we observed no sampling periods with significantly lower NSC levels from plots which received the soluble urea “check” treatment as opposed to a slow-release N source. Previously conducted studies have shown soluble N sources promote vegetative growth (Fry and Huang, 2004). Vegetative growth, in turn, has been shown to deplete NSC levels in turfgrass (Green and Beard, 1969; Youngner and Nudge, 1976; Fry and Huang, 2004). Some research has suggested circumventing this problem by using N sources that release nitrogen slowly (Fry and Huang, 2004). In our study we observed no such advantage. Perhaps we would have observed higher NSC levels with slow release N sources, if we had split the total N into more than two applications, rather than applying the total amount in a single or two semi-annual applications. Such a strategy would, however, negate the labor savings to be gained from applying the entire annual N in a single application, or semi-annual applications. This labor savings has been touted as one of the primary advantages in using polymer-coated N sources.

Application Timing. Comparable to the results seen for N source effect, contrasts revealed application timing only had a significant ($p \leq 0.05$) impact on etiolated regrowth on 3 of the 12 sampling dates (Table 3.1 and Figure 3.1). The higher regrowth levels observed for November 2005 were plots which received a Sept./March split application as opposed to the single September application. This was unanticipated considering at the time of sampling the split application plots had only received 73.5 kg N ha^{-1}, whereas their counterparts had received 147 kg N ha^{-1}. The other two sampling periods with higher regrowth levels occurred in January 2007 and March 2007. Both of these instances were shortly after etiolated regrowth had reached its seasonal peak (Figure 3.1). It is possible that significant differences in January 2007 and March 2007, in contrast to the previous year, may have been partially related to temperature differences in the December to March period from one year to the next (Figure 3.2). Regardless, results indicated if a manager wishes to utilize a PCU source, a Sept./March split application timing is preferable.

The standard fertility program for cool-season grasses now includes lighter applications of N in the spring followed by heavier applications in the fall (Christians, 2004). Turfgrass experts believe that such a fertility program, utilizing a quick release source similar to our urea “check” treatment, should yield the highest NSC status. However, our results found no significant difference in NSC status when using this type of program as opposed to a slow-release N source where half the yearly N requirement is applied in spring and the other half in the fall. Using a slow-release N source with a split spring and fall application timing may provide an equivalent NSC status in turf; however the labor savings associated with making a single yearly application is somewhat negated.

Turfgrass Color and Visual Quality

Nitrogen source. Analysis of variance indicated no significant ($p \leq 0.10$) treatment effects for individual N sources (Table 3.2 and 3.3). However, contrasts were once again utilized to compare color and quality of polymer-coated N sources to more traditional N sources. Contrasts revealed significant color differences on 3 of 12 sampling dates when comparing PCU sources versus SCU/UF sources (Table 3.2). In the May 2006 and March 2007 sampling periods, plots which received PCU sources showed significantly higher color ratings in comparison to the traditional N sources. However, in the November 2006 sampling period the traditional N sources yielded significantly higher color ratings as a group compared with the PCU sources. Results suggest a manager utilizing a PCU source on a cool-season grass may see little or no improved color in comparison to using a traditional N source.

Quality contrasts revealed significant ($p \leq 0.10$) quality differences between the two N source groups on 2 of 12 sampling dates (Table 3.3). The first significant sampling date which occurred in March 2006 showed plots which received PCU N sources had significantly higher quality in comparison to the traditional sources. However, the opposite occurred in the September 2006 sampling period, with traditional sources showing significantly higher quality as a group in comparison to the PCU N sources. Results suggest there is little benefit in quality to be attained utilizing a PCU source in comparison to a traditional N source.

Application timing. There was little difference in turfgrass color or visual quality among N sources when comparing application timing among sources (Table 3.2 and 3.3). The first exception occurred in the color ratings for the January 2006 sampling period. For this period plots which received September applied N showed improved color over those with the Sept./March split application. Color means for the duration of the study were found to be insignificant when comparing individual treatments timings. However, contrasts revealed treatments with September applied applications as a group, had significantly higher mean color ratings than treatments which received Sept./March split applications (Table 3.2). Overall, when using a slow release source there appears to be a slight benefit to color from applying two applications per year as opposed to a single fall application.

Brown Patch(Rhizoctonia solani) Incidence

Nitrogen source. There was generally no difference in brown patch (*Rhizoctonia solani)* incidence among N sources when applied at the same timing. The lone exception occurred during the 23 July 2007 sampling period (Table 3.4). For this period plots which received SCU in both application timings, and PCU applied in September, showed significantly higher brown patch incidence than the other treatment sources and timings. However, the incidences only ranged from 3.5-3.7 on the Horsfall-Barratt scale which is still quite mild. Overall, brown patch pressure was low for both sampling seasons and little differences were noted among treatment source and application timings.

Conclusions for study 1

In summary, N source did not have a major impact on tall fescue NSC levels, turfgrass color, visual quality or brown patch incidence. In particular, polymer-coated N sources performed similarly to the other N sources. Timing of application was significant with Sept./March applications as a group yielding higher mean color ratings, in comparison to single September applications. For managers using a slow-release source, a more balanced approach such as splitting the yearly N requirement in half between the spring and the fall may maximize NSC status in tall fescue and improve color. This would however, negate the labor savings which may be attained from applying the total annual N in a single application.

Results and Discussion (Study #2)

Non-Structural Carbohydrate Levels

Nitrogen source. Analysis of variance indicated no significant ($p \leq 0.10$) treatment effects on any of the 6 sampling dates (Table 3.6). The first objective of our study was to evaluate the effect of springtime applications of a soluble N source, in comparison PCU, on the NSC status. Our results showed no significant increase in etiolated regrowth by using PCU in spring compared to urea.

Application timing. Analysis of variance revealed significantly ($p \leq 0.05$) higher mean etiolated regrowth for plots which received all 196 kg N ha^{-1} from PCU in a September application compared to those receiving half the annual N (98 kg ha^{-1}) in May (Table 3.6). Although this is a somewhat different result from that observed in study 1, our N rates were slightly higher in this study, and the spring applications were applied in May rather than March. Previously conducted studies have shown soluble N sources promote vegetative growth (Fry and Huang, 2004). Vegetative growth, in turn, has been shown to deplete NSC levels in turfgrass (Green and Beard, 1969; Youngner and Nudge, 1976; Fry and Huang, 2004). Some research has suggested circumventing this problem by using N sources that release nitrogen slowly (Fry and Huang, 2004). Our study indicates that timing, rather than N source, may be the more important factor. Applying all the N in September may reduce shoot growth in spring, leading to higher NSC levels. Such an N regime could only be accomplished by using slow or controlled release N source such as PCU.

Turfgrass Color and Visual Quality

Analysis of variance indicated a significant ($p \leq 0.10$) treatment effect on color for 2 of 6 sampling dates (Table 3.2). Both sampling periods occurred in the first two months of the study in June and July 2006. In the June 2006 sampling period plots which received 98 kg N ha^{-1} in spring from PCU had the best color (Table 3.7). The September only treatment (196 kg N ha^{-1} from PCU) had the poorest color, and the other treatments were intermediate. For the following sampling period in July 2006, plots which received 98 kg N ha^{-1} from urea had poorer color than all other treatments. Color differences did not persist, and no differences were observed for the rest of the study. One would have expected the urea to have an immediate impact on color in the months after application, however, this was not the case. Perhaps turf growth had begun to slow for the summer months when growing conditions in this region are not favorable for cool-season grasses. Possibly, lack of available micronutrients may have also played a role in inhibiting an immediate impact on color after fertilization with urea. Iron (Fe) is not a part of the chlorophyll, but chlorophyll will not be formed if Fe is not there in sufficient quantities (Christians, 2004). It is possible a lack of available iron may have influenced the amount of green shoot growth observed after the urea application.

Analysis of variance indicated no significant ($p \leq 0.10$) differences in quality for the duration of the study (Table 3.8). Unlike the NSC results, there appears to be no consistent effect on turfgrass color or quality whether using urea or PCU in spring, or applying all the N in September using PCU. Turfgrass managers could, therefore, save labor by applying their total N in September.

Brown Patch (Rhizoctonia solani) Incidence

There was generally no difference in brown patch incidence among N sources when applied at the same timing. The lone exception occurred during the 23 July 2007 sampling period (Table 3.9). For this period urea at 49 kg N ha^{-1} in spring showed significantly higher brown patch ratings in comparison to the other treatments. However, the incidence was only rated at 2.5 on the Horsfall –Barratt scale which is considered mild. Studies have shown increasing N levels on cool-season grasses has exacerbated brown patch blighting (Burpee, 1995; Fidanza and Dernoeden, 1996). We had hypothesized that springtime applications of soluble N sources, in comparison to slow release N, would increase brown patch during the summer months. However, it was difficult to make a decisive conclusion regarding the N source effect due to the low disease pressure we observed for both summers of the study. Future research in this area may yield more definitive results if inoculation techniques were used in order to ensure high disease pressure from *Rhizoctonia solani* during summer sampling months.

Conclusions for study 2

In summary, N source did not have a significant effect on tall fescue NSC levels, turfgrass color, visual quality or brown patch incidence. Polymer-coated N sources performed similarly to urea. Timing of application significantly increased total NSC levels when using a single application of PCU N in September compared to split applications using a combination of PCU or PCU/Urea in September and May. Results of this study suggest managers could make use of a single yearly application of N in September from a slow-release N source without sacrificing NSC in the turfgrass. However, the application rate and timing appears to be very important in comparison to the N source utilized as similar results were not recorded on tall fescue in the first study. Springtime applications of a soluble N source, in comparison to PCU showed no significant effect on development of brown patch during the summer months. However, it is important to note that disease pressure was very low for both sampling periods.

Figures and Tables

Figure 3.1- Cumulative etiolated regrowth of tall fescue (combined over all N sources) as affected by application timing over a two-year period from 2005 to 2007. Significance at p= 0.1, 0.05, and 0.01 is indicated by *, **, and *, respectively.**

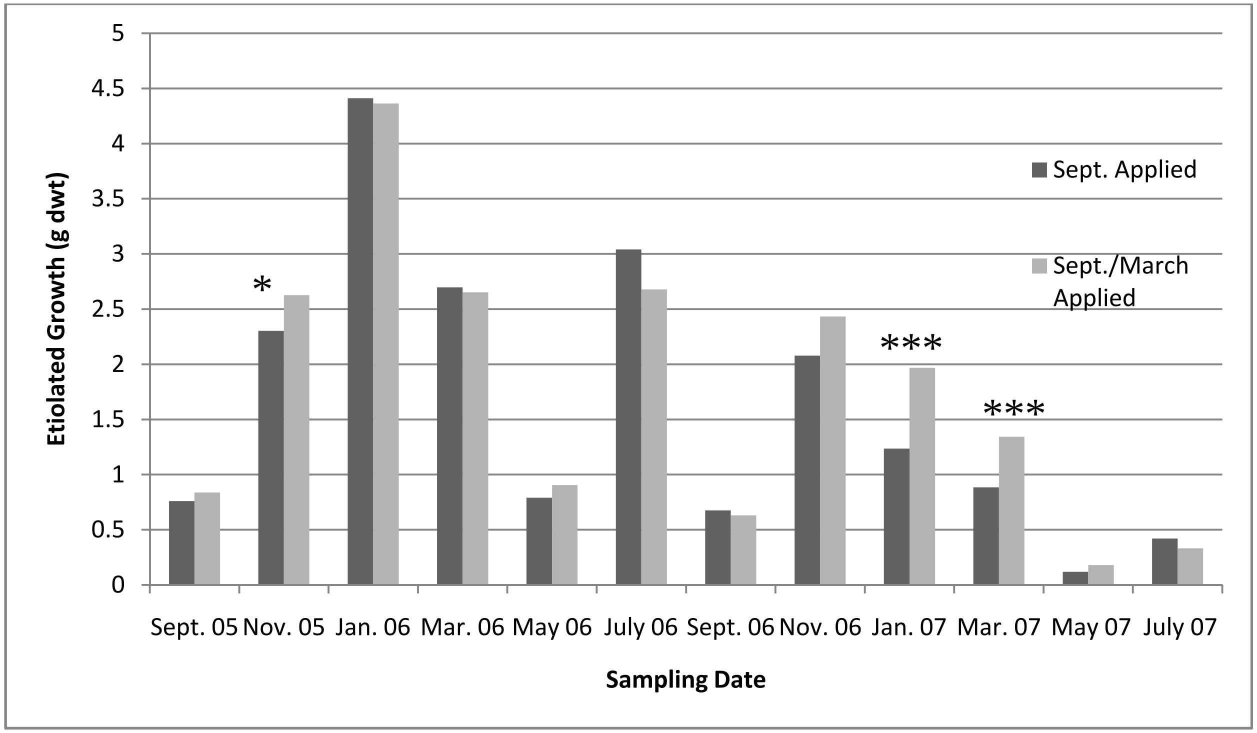

Figure 3.2- Average air temperature at the research site for the 2005-06 and 2006-07 seasons.

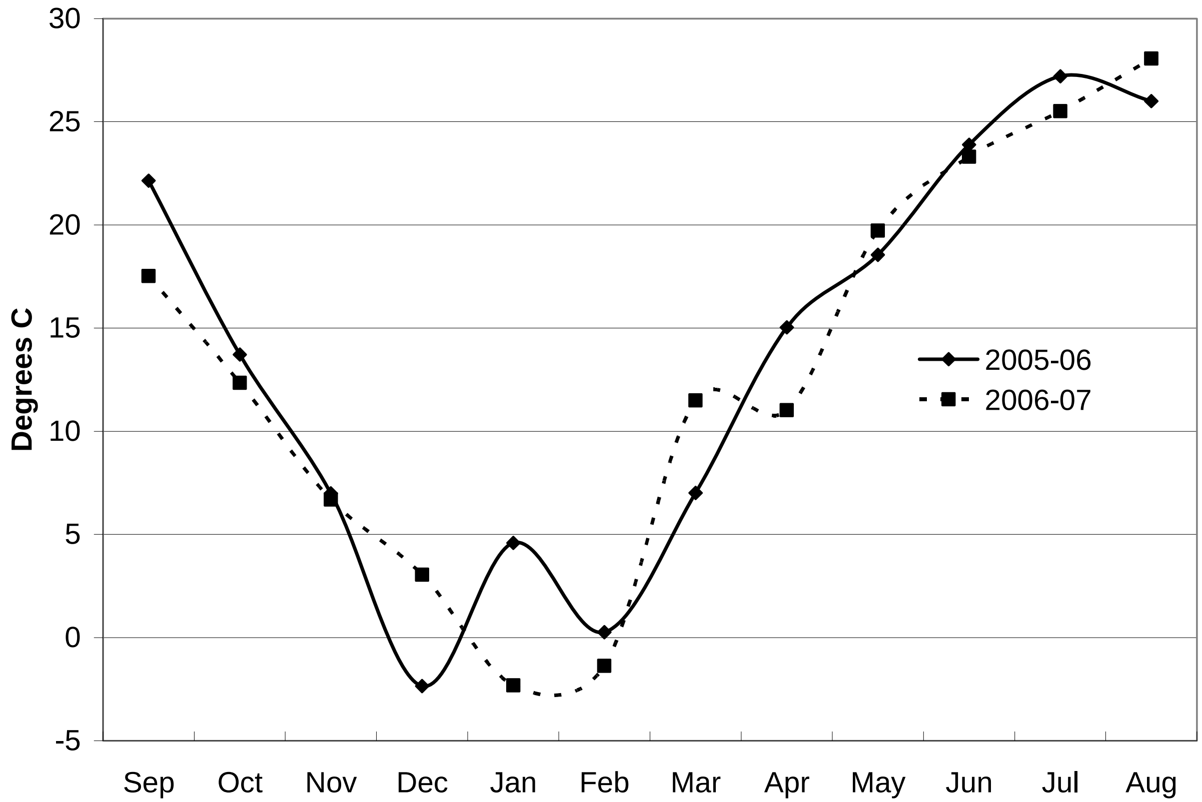

Table 3.1- Etiolated regrowth of tall fescue as affected by nitrogen source and timing of application in Manhattan, KS, USA.

		Sampling Date (mo/yr)												
		09/05	11/05	01/06	03/06	05/06	07/06	09/06	11/06	01/07	03/07	05/07	07/07	Total
N source†	Timing	g dwt												
PCU (43% N)	September	0.08	0.30	0.55	0.34	0.07 b‡	0.44	0.09	0.30	0.17	0.15 abc	0.01 b	0.04	2.54
	September/March	0.08	0.29	0.57	0.33	0.12 ab	0.38	0.06	0.31	0.25	0.19 a	0.01 b	0.04	2.65
PCU (41%N)	September	0.10	0.30	0.54	0.32	0.12 ab	0.34	0.07	0.21	0.13	0.06 c	0.01 b	0.06	2.26
	September/March	0.11	0.36	0.51	0.32	0.10 ab	0.28	0.08	0.29	0.24	0.14 abc	0.03 ab	0.04	2.50
SCU	September	0.14	0.25	0.53	0.28	0.09 ab	0.37	0.08	0.26	0.19	0.07 c	0.01 b	0.06	2.33
	September/March	0.07	0.31	0.60	0.29	0.06 b	0.39	0.08	0.23	0.21	0.10 abc	0.00 b	0.05	2.40
UF	September	0.08	0.30	0.51	0.29	0.13 a	0.38	0.09	0.33	0.21	0.14 abc	0.02 ab	0.05	2.54
	September/March	0.10	0.32	0.55	0.34	0.10 ab	0.33	0.07	0.28	0.23	0.17 ab	0.05 a	0.05	2.59
Urea	Check	0.10	0.34	0.51	0.27	0.11 ab	0.35	0.11	0.26	0.19	0.16 abc	0.02 ab	0.03	2.45
Contrast: PCU vs SCU/UF		NS	NS	NS	0.10	NS	NS	NS	NS	NS	NS	NS	NS	NS
Contrast: September applied vs. September/ March Applied		NS	0.10	NS	NS	NS	NS	NS	NS	0.01	0.01	NS	NS	NS

†PCU= polymer-coated urea; SCU= sulfur-coated urea; UF urea formaldehyde. Each N source with September application timing was applied in a single yearly application at 147 kg N ha^{-1}. N sources with September/ March timings were applied in 2 separate 73.5 kg N ha^{-1} applications. The urea check was applied at 49 kg N ha^{-1} in early September, November, and May.

‡ Means followed by the same letter in a column are not significantly different at p=0.05. Columns with no letters indicate an insignificant F-test.

NS= Non Significant

Table 3.2- Turfgrass color of tall fescue as affected by nitrogen source and timing of application in Manhattan, KS, USA.

		Rating Date (mo/yr)												
		09/05	11/05	01/06	03/06	05/06	07/06	09/06	11/06	01/07	03/07	05/07	07/07	Mean
N source†	Timing	1-9 scale‡												
PCU (43% N)	September	7.0	6.7	6.0	6.5	6.2	5.5	6.0	6.0	6.0	6.5	6.0	6.2	6.2
	September/March	6.7	6.7	5.7	6.0	6.2	6.0	6.0	6.0	6.0	6.2	6.0	6.2	6.1
PCU (41%N)	September	7.0	6.2	6.0	6.0	6.0	6.0	6.2	6.0	6.0	6.0	6.2	6.5	6.1
	September/March	6.7	6.0	5.7	6.2	6.0	6.0	6.0	6.0	6.0	6.2	6.0	6.2	6.0
SCU	September	7.0	6.5	6.0	6.2	5.7	6.0	6.0	6.5	6.0	6.2	6.2	6.5	6.2
	September/March	6.7	6.5	5.2	6.5	6.0	6.0	6.2	6.2	6.0	6.2	6.0	6.2	6.1
UF	September	6.7	6.2	5.5	6.2	6.0	6.0	6.2	6.0	6.0	5.7	6.0	6.5	6.1
	September/March	7.0	6.2	5.2	6.0	6.0	5.7	6.0	6.0	6.0	5.5	6.0	6.0	6.0
Urea	Check	6.5	5.7	5.5	6.0	6.0	5.7	6.5	6.0	6.0	6.0	6.0	5.7	6.0
Contrast: PCU vs SCU/UF		NS	NS	NS	NS	0.10	NS	NS	0.05	NS	0.10	NS	NS	NS
Contrast: September applied vs. Sept./ March Applied		NS	NS	0.05	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.01

†PCU= polymer-coated urea; SCU= sulfur-coated urea; UF urea formaldehyde. Each N source with a September application timing was applied in a single yearly application at 147 kg N ha^{-1}. N sources with September/ March timings were applied in 2 separate 73.5 kg N ha^{-1} applications. The urea check was applied at 49 kg N ha^{-1} in early September, November, and May.

‡ A 1-9 scale was used, where 1=brown and 9= dark green.

§ Means followed by the same letter in a column are not significantly different at p=0.05. Columns with no letters indicate an insignificant F-test.

NS= Non Significant

Table 3.3- Turfgrass visual quality of tall fescue as affected by nitrogen source and timing of application in Manhattan, KS, USA.

		------Rating Date (mo/yr)------												
		09/05	11/05	01/06	03/06	05/06	07/06	09/06	11/06	01/07	03/07	05/07	07/07	Mean
N source†	Timing	------ 1-9 scale‡------												
PCU (43% N)	September	6.0	6.0	6.0	6.3	6.0	6.0	5.7	5.7	6.0	6.5	6.0	6.0	6.0
	September/March	6.2	6.0	6.0	6.0	6.0	6.0	5.7	6.0	6.0	6.2	6.0	6.0	6.0
PCU (41%N)	September	6.5	6.0	6.0	6.0	5.7	6.0	6.0	6.0	6.0	6.0	6.0	5.7	6.0
	September/March	6.2	6.0	6.0	6.0	6.0	6.0	5.7	5.7	6.0	6.0	6.0	6.2	6.0
SCU	September	6.0	6.0	6.0	6.0	5.7	5.7	6.0	5.7	6.0	6.2	6.0	6.0	6.0
	September/March	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.2	6.0	6.2	6.0
UF	September	6.0	6.0	6.0	6.0	5.7	6.0	6.0	6.0	6.0	5.7	6.0	6.0	6.0
	September/March	6.2	6.2	6.0	6.0	6.0	6.0	6.0	6.0	6.0	5.7	6.2	6.0	6.0
Urea	Check	6.2	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.2	6.5	5.7	6.0
Contrast: PCU vs SCU/UF		NS	NS	NS	0.10	NS	NS	0.10	NS	NS	NS	NS	NS	NS

Contrast: September applied vs. Sept./ March Applied	NS	NS	NS	NS	0.10	NS	NS	NS	NS	NS	NS	NS	NS

†PCU= polymer-coated urea; SCU= sulfur-coated urea; UF urea formaldehyde. Each N source with September application timing was applied in a single yearly application at 147 kg N ha^{-1}. N sources with September/ March timings were applied in 2 separate 73.5 kg N ha^{-1} applications. The urea check was applied at 49 kg N ha^{-1} in early September, November, and May.

‡ A 1-9 scale was used, where 1=poorest and 9= best.

§ Means followed by the same letter in a column are not significantly different at p=0.05. Columns with no letters indicate an insignificant F-test.

NS= Non Significant

Table 3.4- Brown patch incidence on tall fescue as affected by nitrogen source and timing of application in Manhattan, KS, USA.

		---Rating Date (mo/yr)---						
		07/17/06	07/29/06	08/05/06	07/14/07	07/23/07	08/2/07	Total (Mean)
N Source†	Timing	---0-12‡---						
PCU (43%N)	September	3.7	3.5	3.2	2.5	2.5b§	2.0	2.9
	September/May	3.7	3.2	3.5	2.2	3.2ab	2.0	3.0
PCU (41%N)	September	3.7	3.5	3.5	2.2	3.5a	2.0	3.0
	September/May	3.5	3.2	3.5	1.7	2.7b	2.0	2.7
SCU	September	3.5	3.2	3.2	2.2	3.5a	2.5	3.0
	September/May	4.0	3.7	4.0	2.2	3.7a	2.0	3.2
UF	September	3.5	3.2	3.2	2.2	2.7b	2.0	2.8
	September/May	4.0	3.2	3.5	2.0	2.7b	2.0	2.9
Urea	Check	3.7	3.2	3.5	2.7	3.2ab	2.0	3.0
Contrast: September applied vs September/March applied		NS	NS	NS	NS	NS	NS	NS

†PCU= polymer-coated urea; SCU= sulfur-coated urea; UF urea formaldehyde. Each N source with September application timing was applied in a single yearly application at 147 kg N ha^{-1}. N sources with September/ March timings were applied in 2 separate 73.5 kg N ha^{-1} applications. The urea check was applied at 49 kg N ha^{-1} in early September, November, and May.

‡ Visual estimates of Rhizoctonia blight were made using the 1-12 Horsfall-Barratt rating scale. 1=0% Affected and 12= 100% Affected

§ Means followed by the same letter in a column are not significantly different at p=0.05. Columns with no letters indicate an insignificant F-test.

NS= Non Significant

Table 3.5- Treatment list for study 2.

	September†	May	
		PCU	Urea
Treatment 1	98‡	98	-
Treatment 2	98	-	98
Treatment 3	147	49	-
Treatment 4	147	-	49
Treatment 5	196	-	-

†=All PCU
‡= All units in kg N ha^{-1}

Table 3.6- Etiolated regrowth of tall fescue as affected by soluble versus controlled release N in spring, in Manhattan, KS, USA.

N Source†, rate‡, and timing		Rating Date (mo/yr)						
September	May	06/06	07/06	08/06	06/07	07/07	08/07	Mean (Study Total)
		g dwt						
PCU (98)	PCU (98)	0.20	0.36	0.24	0.10	0.06	0.04	0.71b§
PCU (98)	Urea (98)	0.14	0.45	0.23	0.04	0.06	0.04	0.62b
PCU (147)	PCU (49)	0.20	0.36	0.31	0.06	0.05	0.03	0.75ab
PCU (147)	Urea (49)	0.16	0.44	0.26	0.07	0.08	0.03	0.75ab
PCU (196)	-	0.29	0.47	0.24	0.09	0.08	0.04	0.86a

†PCU= polymer-coated urea.

‡=Amounts in parenthesis indicates rates in kg N ha^{-1}

§ Means followed by the same letter in a column are not significantly different at p=0.05. Columns with no letters indicate an insignificant F-test.

NS= Non Significant

Table 3.7- Turfgrass color of tall fescue as affected by soluble versus controlled release N in spring, in Manhattan, KS, USA.

N Source†, rate‡,and timing		Rating Date (mo/yr)						
		06/06	07/06	08/06	06/07	07/07	08/07	Total (Mean)
September	May	1-9 scale¶						
PCU (98)	PCU (98)	7.0a§	6.0a	5.7	6.0	6.0	6.2	6.15
PCU (98)	Urea (98)	6.2b	5.5b	5.7	6.2	6.0	6.0	5.93
PCU (147)	PCU (49)	6.0bc	6.0a	5.7	6.0	6.0	6.0	5.95
PCU (147)	Urea (49)	6.2b	6.0a	5.7	6.0	6.0	6.2	6.02
PCU (196)	-	5.7c	6.0a	5.7	6.2	6.0	6.0	5.93

†PCU= polymer-coated urea.

‡= Amounts in parenthesis indicates rates in kg N ha^{-1}

§Means followed by the same letter in a column are not significantly difference at p=0.05. Columns with no letters indicate an insignificant F-test.

¶ A 1-9 scale was used, where 1=brown and 9= dark green.

NS= Non Significant

Table 3.8- Turfgrass quality of tall fescue as affected by soluble versus controlled release N in spring, Manhattan, KS, USA.

N Source†, rate‡,and timing		Rating Date (mo/yr)						
		06/06	07/06	08/06	06/07	07/07	08/07	(Mean)
September	May	1-9 scale§						
PCU (98)	PCU (98)	6.2	6.0	5.7	6.2	6.0	6.2	6.07a¶
PCU (98)	Urea (98)	6.0	6.0	5.7	6.0	6.2	6.2	6.06a
PCU (147)	PCU (49)	6.0	5.7	5.5	6.0	6.2	6.0	5.96b
PCU (147)	Urea (49)	6.0	6.0	5.5	6.2	6.0	6.2	6.00b
PCU (196)	-	6.0	6.0	6.0	6.0	6.2	6.0	6.06a

†PCU= polymer-coated urea.

‡= Amounts in parenthesis indicates rates in kg N ha^{-1}

§A 1-9 scale was used, where 1=poorest and 9= best.

¶ Means followed by the same letter in a column are not significantly difference at p=0.05. Columns with no letters indicate an insignificant F-test.

NS= Non Significant

Table 3.9- Brown patch incidence on tall fescue as affected by soluble versus controlled release N in spring, in Manhattan, KS, USA.

N Source†, rate‡,and timing		Rating Date (mo/yr)						
		07/17/06	07/29/06	08/05/06	07/14/07	07/23/07	08/2/07	Mean
September	May	0-12§						
PCU (98)	PCU (98)	3.2	3.0	1.5	2.0	1.5b¶	1.2	2.1
PCU (98)	Urea (98)	3.5	3.2	1.5	2.7	1.2b	1.0	2.1
PCU (147)	PCU (49)	3.5	2.7	1.2	2.7	2.0ab	1.2	2.2
PCU (147)	Urea (49)	3.7	3.2	1.7	2.5	2.5a	1.0	2.4
PCU (196)	-	3.7	3.2	1.7	2.2	1.7b	1.5	2.3

†PCU= polymer-coated urea.

‡= Amounts in parenthesis indicates rates in kg N ha^{-1}

§ Visual estimates of Rhizoctonia blight were made using the 1-12 Horsfall-Barratt rating scale. 1=0% Affected and 12= 100% Affected

¶ Means followed by the same letter in a column are not significantly difference at p=0.05. Columns with no letters indicate an insignificant F-test.

NS= Non Significant

References

Adams, W.A., P.J. Bryan, and G.E. Walker. 1974. Effects of cutting height and nitrogen nutrition on growth pattern of turfgrasses. Proc. Int. Turgrass Res. Conf. 2:131-144.

Ball, S., Y.L.. Qian, and C. Stushnoff. 2002. Soluble carbohydrates in two buffalograss cultivars with contrasting freezing tolerance. J. Am. Soc. Hort. Sci. 127:45-49.

Beard, J. 1982. An assessment of late-season nutritional strategies on C-4 warm-season grasses. p. 81-98. *In* Sypm. on Turfgrass Fertility: Advances in Turfgrass Fertility, Columbus, OH. 20-21 Oct. 1982. Ohio Turfgrass Council.

Brown, R.H. and R.E. Blaser. 1965. Relationships between reserve carbohydrate accumualtion and growth rate in orchardgrass and tall fescue. Crop Sci. 5:577-581.

Burpee, L.L. 1995. Interactions among mowing height, nitrogen fertility, and cultivar, affect the severity of Rhizoctonia blight of tall fescue. Plant Dis. 79:721-726.

Burpee, L. and B. Martin. 1992. Biology of *Rhizoctonia* species associated with turfgrasses. Plant Dis. 76:112-117.

Burton, G.W. 1995. An efficient method for measuring sod reserves for greenhouse and field studies. Crop Sci. 35:579-580.

Carrol, J.C. 1943. Chemical changes occurring in three bermudagrass turf cultivars in relation to cold hardiness. Agron. J. 66:28-31.

Christians, N. 2004. Fundamentals of Turfgrass Management, 2nd Ed. John Wiley & Sons, Hoboken, NJ.

Dunn, J.H. and C.J. Nelson. 1974. Chemical changes occurring in three bermudagrass turf cultivars in relation to cold hardiness. Agron J. 66:28-31.

Emmons, R.D. 2000. Turfgrass Science and Management. 3rd ed. Delmar, Albany, NY.

Fidanza, M.A. and P.H. Dernoeden. 1996. Brown Patch severity in perennial ryegrass as influenced by irrigation, fungicide, and fertilizers. Crop Sci. 36:1631-1638.

Fry, J. and B. Huang. 2004. Applied Turfgrass Science and Physiology. John Wiley & Sons, Hoboken, NJ.

Fry. J.D., N.S. Lang, G.P. Clifton, and F.P. Maier. 1993. Freezing tolerance and carbohydrate content of low temperature-acclimated and non-acclimated centipedegrass. Crop Sci. 33:1051-1055.

Goatley, J.M., V. Maddox, D.J. Lang, and K.K Crouse.1994. 'Tifgreen' bermudagrass response to late-season applications of nitrogen and potassium. Agron. J. 86:7-10.

Goatley, J.M., V.L. Maddox, and K.L Hensler.1998. Late-season applications of various nitrogen sources affect color and carbohydrate content of 'Tiflawn' and arizona common bermudagrass. Hortscience. 33(4):692-695.

Gonzalez, B., J. Bocaud, J. Salette, J. Langlois, and M. Duyme. 1989. Changes in stubble carbohydrate content during regrowth of defoliated perennial ryegrass (Lolium perenne L.) on low nitrogen levels. Grass and Forage Sci. 44:411-415.

Green, D.G. and J.B. Beard. 1969. Seasonal relationships between nitrogen nutrition and soluble carbohydrates in the leaves of *Agrostris palustris* and *Poa pratensis*. Agron. J. 61:107-11.

Horsfall, J.G. and E.G. Cowling. 1978. Pathometry: The measurement of plant disease. Pages 119-136 in: Plant Disease: An Advanced Treatise. Vol. 2, How Disease Develops in Populations. J.G. Horsfall and E.B. Cowling, eds. Academic Press, New York.

Hull, R. 1992. Energy relations and carbohydrate partitioning in turfgrass. Pp 175-205, *In* D.V. Waddington, R.N. Carrow and R.C. Shearman, eds., *Turfgrass.* Madison, WI: American Society of Agrononmy.

Liu, X. and B. Huang. 2000. Carbohydrate accumulation in relation to heat stress tolerance in two creeping bentgrass cultivars. J. Am. Soc. Hort. Sci. 125:442-447.

Liu, X. and B. Huang. 2002. Mowing effects on root production, growth, and mortality of creeping bentgrass. Crop Sci. 42:1241-1250.

Miller, G.L. and R. Dickens.1996. Bermudagrass carbohydrate levels as influenced by potassium fertilization and cultivar. Crop Sci. 36:1283-1289.

Moberg, E.L., D.V. Waddington, and J.M. Duich.1970. Evaluation of slow-release nitrogen sources on Merion Kentucky Bluegrass. Soil Sci. Soc. Amer. Proc. 34:335-339.

Munshaw, G.C., E.H. Ervin, C.Shang, S.D. Askew, X. Zhang, and R.W. Lemus.2006. Influence of late-season iron, nitrogen, and seaweed extract on fall color retention and cold tolerance of four bermudagrass culitvars. Crop Sci. 46:273-283.

Narra, S., T.W. Fermanian, J.M. Swiader, T.B. Voigt, and B.E. Branham. 2004. Total nonstructural carbohydrate assessment in creeping bentgrass at different mowing heights. Crop Sci. 44:908-913.

Richardson, M.D. 2002. Turf quality and freezing tolerance of ‘Tifway’ bermudagrass as affected by late-season nitrogen and trinexapacethyl. Crop Sci. 42:1621-1626.

SAS Institute Inc. 2002-2003. Version 9.1 for Windows. SAS inst., Cary, NC.

Schmidt, R.E., M.L. Henry and D.R. Chalmers.1989. Postdormancy growth of *Cynodon dactylon* as influenced by traffic and nutrition. pp. 165-167, *The 6th International Turfgrass Research Conference.*

Schmidt, R.E. and D.R. Chalmers. 1993. Late summer to early fall application of fertilizer and biostimulants on bermudagrass. pp. 715-721, *In* R.N. Carrow, N.E. Christians, R.C. Shearmen, ed., *International Turfgrass Society Research Journal 7.* Overland Park, KS.

Shahba, M.A., Y.L. Qian, H.G. Hughes, A.J. Koski, and D. Christensen. 2003. Relationships of soluble carbohydrates and freeze tolerance in saltgrass. Crop Sci. 43:2148-2153.

Watscke, T.L. and D.V. Waddinton.1974. Effect of nitrogen source, rate, and timing on growth and carbohydrates of Merion bluegrass. Agron. Journal. 66:691-695.

White, Richard H., and Richard E. Schmidt.1990. Fall performance and post-dormancy growth of ‘Midiron’ bermudagrass in response to nitrogen, iron, and benzyladenine. J. Amer. Soc. Hort. Sci. 115(1):57-61.

Xu, Q. and B. Huang. 2003. Seasonal changes in carbohydrate accumulation for two creeping bentgrass cultivars. Crop Sci. 43:266-271.

Youngner, V.B. and F.J. Nudge. 1976. Soil temperature, air temperature, and defoliation effects on growth and nonstructural carbohydrates of Kentucky bluegrass.

Youngner, V.B., F.J. Nudge and S. Spaulding. 1978. Seasonal changes in nonstructural carbohydrate levels and innovation number of Kentucky bluegrass turf growing in three plant-climate areas. Agron. J. 70:407-411.

Zanoni, L.J., L.F. Michelson, W.G. Colby, and M. Drake. 1969. Factors Affecting Carbohydrate Reserves of Cool Season Turfgrasses. Agron. Journal. 61:195-198